SCIENCE AT A COLLIERY DISASTER

The illustration shows the rescue party at the Hamstead Colliery disaster preparing to descend the shaft. Each member of the party is equipped with an artificial respirating apparatus, so that in effect he carries his own atmosphere with him and avoids breathing the poisonous gases in the pit.

THE ROMANCE OF MODERN CHEMISTRY

A DESCRIPTION IN NON-TECHNICAL LANGUAGE
OF THE DIVERSE AND WONDERFUL WAYS
IN WHICH CHEMICAL FORCES ARE AT
WORK, AND OF THEIR MANIFOLD
APPLICATION IN MODERN LIFE

BY

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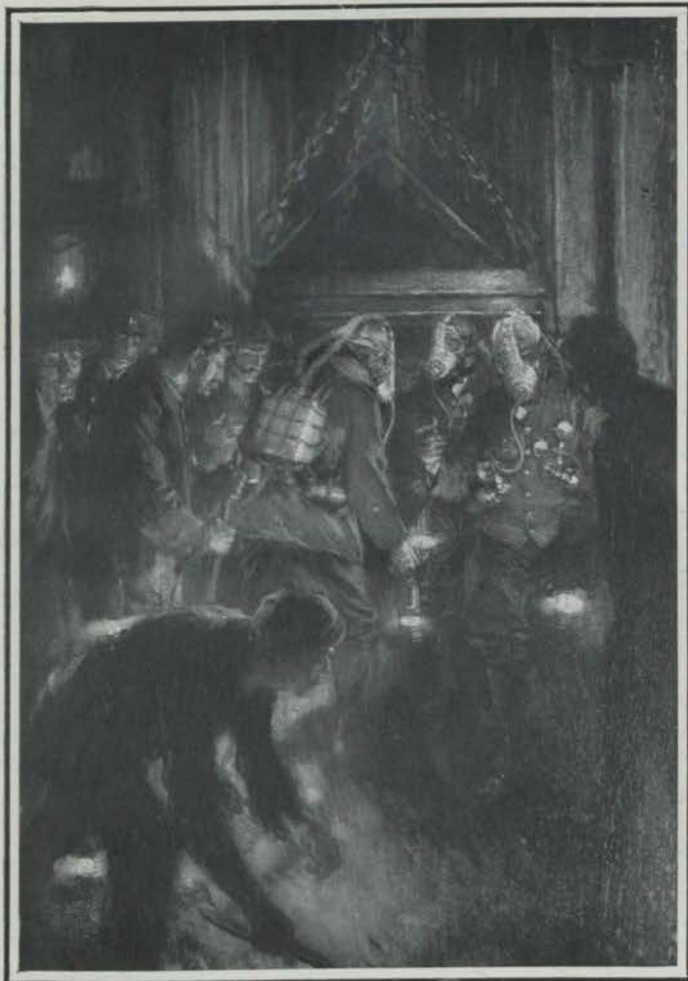SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON

WITH 29 ILLUSTRATIONS & 15 DIAGRAMS

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PREFACE

PROBABLY most people, when they think of Chemistry, suppose that its fascination and its practical bearings can be appreciated only by those who have access to some sequestered laboratory, the doors of which are closed to the uninitiated. This is a mistaken view, for in countless wonderful ways, unknown to the general reader, chemical science is supplying the ordinary needs and contributing to the conveniences of modern life.

In the present volume an attempt has been made to deal with this aspect of the subject, and the points of view adopted are different from those of the ordinary text-book. The author ventures to think that those readers who have no technical knowledge may be convinced that radium and other things which figure so largely in the newspapers are by no means the only scientific matters of thrilling interest; and perhaps even readers who are already familiar with the elements of the science may be helped to see afresh the many unsuspected and marvellous ways in which chemical forces are at work beneath our very eyes.

The chapters are so arranged that the reader who

PREFACE

takes them in order will understand what is brought before him much more easily than if he were to pick out subjects here and there. Only by such consecutive reading is it possible for him to secure the maximum of interest and instruction.

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THE ROMANCE OF MODERN CHEMISTRY

CHAPTER I

THE DAWN OF CHEMISTRY

IN this twentieth century chemistry has become a veritable storehouse of wonder, a cavern of marvel and mystery. Many generations of scientific workers have done their share in the exploration of the cavern, and in the discovery of keys to its innumerable chambers, but much that is obscure or unknown remains. To-day there are more explorers than at any previous time, more eager spirits than ever seeking to gain an entrance into those chambers which have not yet yielded up their secrets. Ever and anon some worker, more ingenious or more fortunate than his fellows, makes a notable advance, and his name is on every one's lips. But all the time, unthought of by the outside world, the rank and file of the explorers is steadily pushing forward and conquering nature's mysteries for the ultimate service of man.

In this volume we shall take a peep into some of the chambers which the workers of the past have opened up to us, as well as into some of those which are still partly unexplored. We shall see how the subtle chemical forces which are at work all around us have been revealed and harnessed for the use of man, and how order has been introduced into the apparently hopeless confusion of chemical phenomena.

It is not easy to say definitely where and when man first began to grope after the knowledge of chemistry. Of all the ancient nations the Egyptians seem to have been the most prominent in this respect; their knowledge, however, was not acquired in any systematic way, but was rather the result of chance observation. By comparison with the store which has been accumulated in the intervening centuries, the chemical knowledge of the ancients was a negligible quantity. They stood merely on the threshold of the storehouse, little dreaming of the spacious chambers into which succeeding generations were to find their way.

Suppose we consider for a moment what actually was the sort of chemical knowledge possessed by the nations of antiquity. They were acquainted with seven metals, namely, gold, silver, copper, tin, iron, lead, and quicksilver, and although some of these—gold, silver, and copper to a smaller extent—are found as such in nature, the others would have to be extracted from their ores; the ancients must therefore have been familiar with the metallurgical processes necessary for this purpose. It was not long before these seven metals became associated with the sun, moon, and the then known planets, each metal receiving the name and symbol of one heavenly body as shown below :—

Gold			The Sun			☉
Silver			The Moon			☽
Quicksilver			Mercury			☿
Copper			Venus			♀
Tin			Jupiter			♃
Iron			Mars			♂
Lead			Saturn			♄

This method of representing the metals by symbols sur-

vived till the Middle Ages, and in old prints one may see a flask or bottle within which is sketched a representation of the sun. This is to be taken as indicating that the flask or bottle contains a solution of gold.

Besides metallurgical operations the processes of soap and glass manufacture, of pottery making, and of dyeing were known and practised in ancient times. Such substances as lime, acetic acid, sugar, soda, potash, alum, and oil of turpentine were in frequent use. The manufacturing processes just mentioned are all essentially chemical, but they were carried out merely by rule of thumb, and not on any scientific plan. This is not to be wondered at, for the practical operations were in the hands of artisans alone, and it was not the correct thing for the philosophers of the ancient world to bring their wisdom to bear on arts and crafts. There was in fact a complete divorce between the practical and the theoretical, and therefore no real science; the educated people did not come into touch with the experimental facts on which alone a science could be soundly based.

The proper sphere of philosophers was considered to be speculation pure and simple, and to such purpose did they speculate on casual observations that the most grotesque theories were evolved, quite out of harmony with actual facts. An instance of the sort of thing to which this purely speculative science led is furnished by an argument of the eminent philosopher Aristotle. As a result of some of his speculations he came to the conclusion that a vessel filled with ashes would contain as much water as one of the same size which has no ashes in it. But there was absolutely no desire to see whether this was actually the case or not. These philosophers in fact stood on the threshold of Nature's storehouse,

endeavouring to predict what should be found within, but never making any attempt to effect an entrance, and see how the facts squared with their predictions.

In one respect, however, the chemical speculations of the ancient philosophers demand some attention, and that is in regard to the ultimate constituents of the visible world. There were supposed to be four primitive independent substances or elements, namely, fire, air, earth, and water, by the combination of which in different proportions the most varied products could be obtained. According to Empedocles, for example, flesh and blood consist of equal parts of all four elements, while bones are one-half fire, one-quarter earth, and one-quarter water.

The word " element" applied to these primitive independent substances has scarcely the same meaning as that which we nowadays attach to it, and indeed Aristotle regarded fire, air, earth, and water as the manifestation of different properties carried about by one and the same kind of matter. The four adjectives "warm," "cold," "dry," and "moist," describe the fundamental qualities which he supposed to be associated with this primordial matter, and to each of the four elements were assigned two of these properties. Air was represented as warm and moist, water was moist and cold, earth was cold and dry, fire was dry and warm.

All this seems very fantastic, but it was a way of looking at things that was current for a long time after Aristotle, indeed down to comparatively recent times. We may well wonder whether the views which we hold about the origin and composition of the natural world will be thought equally fantastic by our scientific descendants !

CHAPTER II

ALCHEMY AND THE PHILOSOPHER'S STONE

IN the previous chapter it was suggested that the historical development of chemistry has resembled the gradual exploration of a cavern full of wonder and of treasure. The reader must not suppose, however, that the progress of the exploration has at all times been equally rapid and equally important. On the contrary, there have been centuries during which chemists contributed very little to the real advance of their science, simply because their explorations were carried out under an entirely false guiding principle.

This remark applies to the long period in the Middle Ages during which devotion to alchemy was supreme, and although the alchemists in the course of what some one has called their "potterings" found out many new substances, and invented many useful processes, their work was singularly unproductive in the interpretation of chemical phenomena, and in the discovery of general principles. They missed the spacious chambers in the cavern because in their blind adherence to the idea that it was possible to convert the baser metals into gold, they lost their way in subterranean passages where little treasure was to be found.

We have seen that in the nations of antiquity the theoretical and practical sides of natural science were kept absolutely separate. This state of affairs, so dis-

astrous to the advance of true science, was remedied to some extent in the Middle Ages, for the alchemists were not only practical experimenters, but also, many of them at any rate, men of considerable learning and intellectual ability. Unfortunately, however, their chemical theories were based on the fantastic views of the ancient philosophers, and to these theories the alchemists stuck like limpets to the rock. They had yet to learn that the true method of advance in science is first to study the phenomena and collect the facts, and then build up a theory; the alchemists, on the other hand, preferred to start with an *a priori* theory, and then to try to make the facts fit into it.

Curiously enough, the theory of the transmutation of the metals, which dominated the chemistry, or rather alchemy, of the Middle Ages, came in the first place from Arabia. After their conquest of Egypt in the seventh century A.D. the Arabians probably absorbed and developed such scientific knowledge as was then in existence, and in any case the first man, a satisfactory record of whose chemical work has come down to us, was an Arabian, Geber by name. He had quite a remarkable amount of practical chemical knowledge for that early time; many kinds of apparatus, and many laboratory operations, such as distillation, filtration, and crystallisation, which are indispensable to every chemist, were familiar to him.

Valuable as Geber's practical work was, his theories about the nature of the metals were very wide of the mark. He considered that the metals were all composed of sulphur and mercury; these two substances, or two principles which were embodied in them, were regarded as the "parents" of all the metals. One metal was

supposed to differ from another only in the proportion of mercury and sulphur which it contained; thus gold was particularly rich in mercury, whereas the common metals had a large proportion of sulphur. On this view it ought to be possible to change one metal into another by merely altering the relative proportion of the two constituents, and the problem of transmuting lead or copper into gold would then be reduced to the discovery of some agent which would withdraw sulphur from the baser metal and add mercury to it.

That this way of looking at things should be accepted at all is perhaps not so very strange when we consider what the thinkers of a thousand years ago had inherited from Aristotle and other ancient philosophers. We have seen that Aristotle regarded fire, air, earth, and water as different properties carried by one original kind of matter, and it is not a very big step from this view to the belief that by simply modifying its properties one kind of matter could be converted into another kind. Since water was regarded as moist and cold, while air was moist and warm, it was thought possible by heat alone to convert the second chief property of water into the second chief property of air; that is, it was believed that water could be transformed into air.

So we see that the views of Geber and the alchemists who followed him in the Middle Ages were more or less a natural development of the speculations of the ancient philosophers. What is difficult to understand is how the belief in the transmutation of metals continued to dominate the study of chemistry so long as it did, for it was not until the beginning of the eighteenth century that chemists became generally sceptical about the possibility of converting base metal into gold. For the

space of eight centuries or thereabout the efforts of the great majority of those people who studied chemistry were directed to the discovery of the Philosopher's Stone—the Great Elixir which should have the power of changing lead or any other common metal into the noble gold.

If we are to trust the records that have come down to us, the philosopher's stone was not only sought for, but found,—by a few favoured individuals. An eminent physician and chemist, van Helmont by name, who lived in the seventeenth century, states that with a small specimen of the philosopher's stone, received from an unknown source, he had transformed a considerable quantity of mercury into pure gold. A little later a physician in the household of the Prince of Orange published a detailed description of the way in which, with the help of a certain preparation, he had effected the transmutation of lead into gold.

What are we to make of these stories? For no single chemist nowadays believes that anybody ever succeeded in producing so much as one grain of gold from any of the baser metals. The two men whose statements about the production of gold have just been quoted were eminently respectable, and there seems to be no ground whatever for supposing that they wished to deceive their contemporaries or posterity. The only conclusion to which we can come is that they were themselves deceived, that they were the victims of illusion. That seems to be the most charitable explanation.

We may, however, ask the question whether there was anything at all to account for the transmutation of metals being regarded as an incontrovertible fact for so long a period. No doubt the ancient tendency to place more
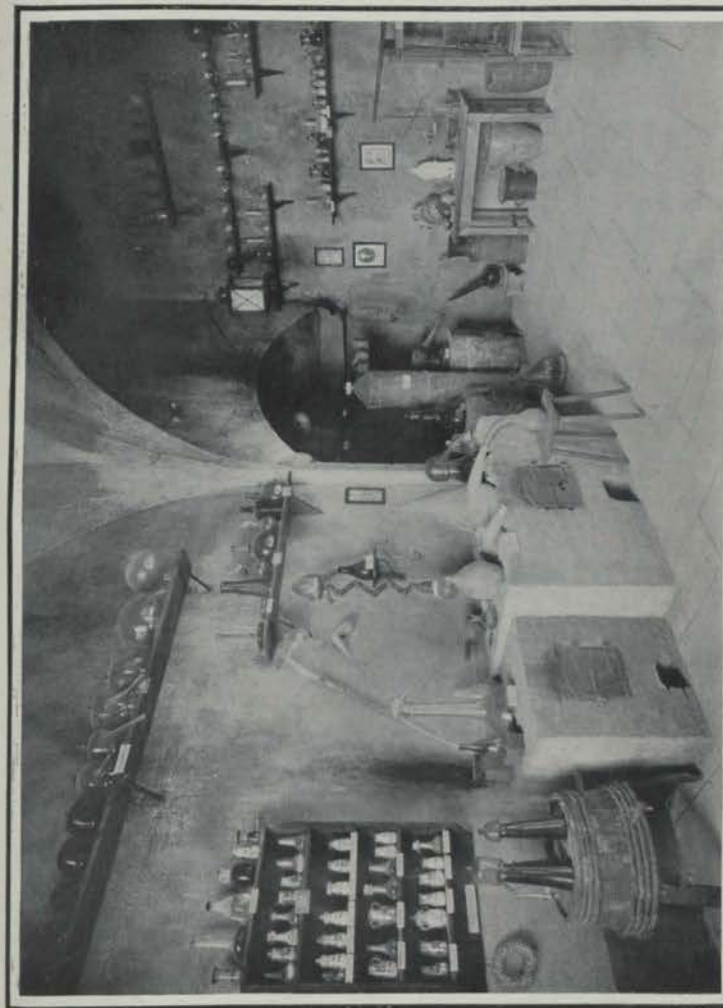
AN ALCHEMIST'S LABORATORY

By permission of the Deutsches Museum, Munich

This is a photograph of the reconstructed alchemist's laboratory in the new German museum at Munich. The most prominent features are the furnaces and the fantastically shaped retorts for carrying on distillation.

trust in an abstract theory than in any experimental facts had something to do with the persistence of the belief, but in addition certain chemical phenomena were known, which to a superficial observer would seem to show that one metal could be converted into another. For example, there is the experiment, which any one may repeat, of putting a piece of iron, such as a steel knife-blade, into a solution of blue vitriol or sulphate of copper. However short a time the iron is left in the blue vitriol solution, it comes out exactly like copper, with the same characteristic reddish colour. This is a very simple straightforward experiment, and to the alchemist it admitted of no other explanation than that the iron had been converted into copper. We know now that no such change takes place : some copper comes out of the solution and is deposited on the surface of the iron, while by way of holding the balance even, an equivalent amount of the iron passes into solution.

Other circumstances also favoured the postponement of the day when the truth about the transmutation of metals was to be recognised. For one thing, the alchemists received valuable support from princes and rulers who were in financial difficulties. It was thought distinctly worth while to have a man about court who might be able to produce gold out of practically nothing, and alchemists were therefore encouraged to continue their search for the philosopher's stone, often at considerable expense to their patrons. This money aspect of the business, as the reader will easily understand, led naturally to all sorts of quacks and charlatans setting up as alchemists, and imposing on the credulity or stupidity of princes who were in want of money.

Again, the air of secrecy which pervaded the alche-

mists' doings and writings helped to smother the truth. Naturally, a man who thought he had discovered the philosopher's stone and could turn lead into gold, was very careful not to let his secret get abroad, for if every one knew the trick, the gold would have no more value than the lead out of which it was made. Hence the writings of the alchemists are full of the most unintelligible nonsense that was ever put on paper. Many of them profess to describe their method of preparing the philosopher's stone, but the description consists of nothing but foolish jargon.

Perhaps the best way to bring home to the reader the extraordinary character of the alchemistic writings is to quote the following translation from a book on alchemy that appeared in 1608. The philosopher's stone is supposed to be describing itself: "I am the old dragon that is present everywhere on the face of the earth; I am father and mother; youthful and ancient; weak and yet more strong; life and death; visible and invisible; hard and soft; descending to the earth and ascending to the heavens; most high and most low; light and heavy; in me, the order of nature is oftentimes inverted, in colour, number, weights and measure. . . . I am the carbuncle of the sun, a most noble clarified earth, by which thou mayest turn copper, iron, tin and lead into most pure gold."

The philosopher's stone was supposed to possess the most marvellous power, Roger Bacon, one of our own countrymen, declaring that it was able to transform a million times its weight of base metal into gold. Besides this it was supposed to have the power of prolonging life, and was therefore regarded as an "elixir vitæ." Many other beliefs held at that time were, however,

equally absurd. Thus, for example, it was thought that just as an exhausted soil becomes fertile again after a time of rest, so a gold mine which was exhausted would, if left to itself for a long period, again yield abundance of the precious metal!

As time went on many chemists, while still adhering to their belief in the transmutation of metals, began to work on other and more useful lines. One school, headed by Paracelsus, devoted themselves to studying the bearing of chemistry on medicine, and made a number of valuable discoveries in this direction. Paracelsus taught that "the object of chemistry is not to make gold, but to prepare medicines," and although this by itself is rather a limited field, it had the effect of gradually drawing men away from the pursuit of alchemy. The way was thus prepared for the rejection of the alchemistic doctrines, which had so long rested like a blight on real chemical science. A healthy desire arose to investigate chemical phenomena for the sake of knowledge alone, and it was under these conditions that Nature began to reveal her secrets more rapidly. Especially when the explorers discovered the great value of the balance and learned what it had to teach them about the commonplace phenomena of burning, they got back again to the right lines of exploration. From that day to this there has been on the whole steady progress, and it is now our task to look at some of the secret marvels of Nature which have been revealed in these last one hundred and fifty years.

CHAPTER III

NATURE'S BUILDING MATERIAL

A COMMON way of classifying natural objects is suggested by the familiar questions—" Is it animal ? " " Is it vegetable ? " " Is it mineral ? " Now, although from the chemical point of view we are chiefly concerned with so-called " dead " matter, there are many things belonging to the animal and vegetable kingdoms which we must take into consideration. A certain object may be assigned to one of these two kingdoms, not because it is at present alive, but simply because at one time or another in its history it has been a part of a living thing, a plant or an animal. A bone, for example, would be considered to belong to the animal kingdom, although in itself it is as dead as a door-nail, apart from the living and throbbing body of which it was a member. A tree that refuses to become green under the touch of spring would still be regarded as " vegetable," although, so far as growth is concerned, it might as well be a block of granite.

What makes all the difference between the mineral kingdom on the one hand, and the animal and vegetable kingdoms on the other hand, is the mysterious thing called " life," not the mere materials of which the various objects are built up. It is no doubt true that the materials associated with plants and animals, and thus involved in the processes of life, are frequently of

a special kind, and this is indicated by describing them as of " organic " origin, in contrast to the " inorganic " substances which are more especially characteristic of the mineral kingdom. It used to be thought up to about one hundred years ago that organic substances could be produced only under the influence of life, but this has been found to be a mistaken view. The chemist can produce organic substances in the laboratory, starting with inorganic materials, and the organic substances so produced are the same in all respects as those formed in the living organism. But however much the chemist may pride himself on his achievements in building up organic substances, there is one thing he has not been able to do, and that is to produce an organism, even of the most elementary kind. Life, which makes all the difference between the organic substances and the organism, is apparently beyond the resources of human manufacture. Its origin must be traced to a higher source.

A little thought will suffice to remind us of the diverse material used in building up our world, both organic and inorganic. Besides the coal and the minerals which we extract from below the crust, and the many things which we grow on the surface of this little island, we have at our disposal nowadays the products of the ends of the earth in all their variety. But a little simplification may be introduced into this extraordinary diversity when we bear in mind that the chemist has been able to split up most of the complex substances with which we are familiar. He has shown that by various agencies, such as, for example, the action of heat, a complex substance may be broken up into simpler substances, these latter into still simpler ones, and so

on. At last we arrive in this way at an irreducible minimum of substances which obstinately refuse to break up into anything simpler, and which cannot be converted into each other.

These elements, as the chemist calls them, are, so to speak, the bricks out of which all known substances are built up. They number about seventy, and each kind of brick possesses characteristics which distinguish it from all the other kinds. That being so, it is not difficult to understand how the combination of the elements leads to all the infinite variety of nature. For the reader will see at once that if he was provided with seventy kinds of bricks, each kind with its own characteristic shade of colour, and if he was required to put together a structure containing at least two kinds of bricks, and up to any number of bricks of each kind, there would be a countless host of products.

Now what are these seventy fundamental substances? Many of them are familiar to the reader, by name at least; for example, lead, sulphur, gold, copper, phosphorus, oxygen, mercury, tin, hydrogen, silver, and carbon. But quite half, probably, of the elements are unknown, even by name, to the ordinary individual, whilst to the chemist himself they are frequently not much more than names. And this is not to be wondered at; for the importance of some of the elements, judged by the part they play in the building up of the world and in the service of man, is extremely small. Thus glucinum, gallium, scandium, and many others would not be much missed were they to disappear altogether from the family of the elements.

Any one who wants to understand something of the fascinating science of chemistry must be quite clear

about the part played by the elements and about the relations in which they stand to the infinite variety of naturally occurring substances. Amongst the elements themselves there is great diversity. Some are gaseous substances, like oxygen, hydrogen, nitrogen, chlorine, and helium ; two are liquids under ordinary conditions, namely, mercury and bromine ; while the great majority, chiefly metals, are solid substances. But this division of the elements into gaseous, liquid, and solid substances is somewhat arbitrary, and is valid only for the particular conditions which prevail on our earth. On those heavenly bodies which are much hotter than our planet, many of the elements with which we are familiar as solids exist in the gaseous condition. In the extraordinary heat which prevails on the sun even iron is a vapour.

It must be borne in mind that the elements are found in nature mostly in some form of mutual combination. Only a few of them occur in the uncombined state, or "native" as it is called. The noble metals and some other elements, such as copper, sulphur, oxygen, and nitrogen, belong to the latter class, but the minerals composing the great bulk of the earth's crust are combinations of the other elements with oxygen and sulphur. The fact that some elements never occur in the native condition becomes intelligible when we make ourselves acquainted with the properties of these elements. Take the case of phosphorus. The chemist has been able, by certain subtle processes, to extract this element from the ashes of bones, but it has such an aversion to the state of single blessedness, that unless precautions are taken to keep it out of contact with air, it reverts to the combined state and unites with the oxygen of the atmosphere. It is therefore easily understood why phosphorus is never

found native, and a similar explanation is forthcoming in the case of other elements.

It may occur to the reader to ask—Is it quite certain that the so-called elements represent the ultimate units of which the natural world is built up ? Is it not possible that some substances which are at present regarded as elements may turn out to be combinations of other elements ? This is perfectly possible, but not very probable. It is certainly true that water, soda, and potash, which up to one hundred or one hundred and twenty years ago were regarded as elements, were then found to be really compound substances, and it is conceivable that a similar thing might happen again. But it is less likely nowadays, for a substance which has to run the gauntlet of the chemist's modern methods of attack can scarcely pass unscathed unless it is really of an elementary character.

On the question how far the present accepted list of elements is to be regarded as final, the discovery of radium has thrown an interesting and somewhat startling light. For it appears that radium, although an element in the commonly accepted meaning of the word, is undergoing continuous transformation into other elements, the gas, helium, being one of the products of change. The idea that one element could be transformed into another was cherished by the alchemists, as we have seen, but the whole course of chemical progress in the last century was against the acceptance of that idea. And just as chemists were getting settled in their minds about that important question, radium came along and introduced an air of uncertainty again into the whole business. If it should turn out that one element can actually be converted into another, as radium appears to be changed into helium, there will be some support given to the hypothesis that the

elements are simply modifications of one original parent substance. This plausible suggestion was made long ago, and has been revived at occasional intervals, but the evidence of experiment has so far been against its acceptance.

In the earlier part of this chapter the elements have been frequently referred to as existing in a state of combination, in the form of compound substances. Now a compound of two elements is something quite different from a mere mixture. The two elements which combine do so in a very thorough and intimate fashion, with the result that each, as it were, loses its own individuality, and an entirely new individual, with other characteristics, is produced. The two differently coloured bricks, which we may suppose to represent the two elements, are not merely laid side by side so that we could lift the one away from the other without any trouble, but they are fused and coalesced in some mysterious manner into one new brick, different in shape and colour from each of the two original ones. The only statement we can make with certainty about the new brick is that its weight is equal to the sum of the weights of the two component bricks.

It is very interesting to observe that in some cases we can start with two elements and make either a mixture or a compound of them. Two such elements are iron and sulphur. If the iron is taken in the form of fine filings, which are grey in colour, and if these are intimately mixed by grinding with sulphur, which is yellow, a powder is obtained which is intermediate in colour between grey and yellow. And in this mechanical mixture each component retains its own characteristics just as if the other were not there. The particles of iron can be drawn out of the mixture with a magnet; the

particles of sulphur can be dissolved out by using a suitable liquid. The reader will therefore see that it is a comparatively easy matter to separate the components of a mechanical mixture.

Suppose now that some of the iron-sulphur mixture is put in a tube and that the tube is heated by a flame at one end. Something of importance obviously takes place, for the contents of the tube above the flame begin to glow vigorously and are raised to a white heat. Even if the tube is no longer heated externally, the flame being removed, the glowing continues until the zone of incandescence has passed right through from one end of the iron-sulphur mixture to the other. This extraordinary display of energy is evidence that the iron and sulphur are combining chemically, and if the product is examined when it has cooled, it will be found that a new substance with entirely different properties has indeed been produced. There are no iron particles now to be attracted by the magnet, and no liquid can be found which will extract the sulphur and leave the iron behind. The iron and sulphur particles are no longer lying side by side ; they have united and coalesced to form a compound —sulphide of iron—the properties of which are quite different from those of iron and sulphur. Countless other illustrations might be cited of the fundamental difference between a mere mixture of two elements and a chemical compound of the two. A familiar case is gunpowder. This is a mechanical mixture of sulphur, carbon, and nitre, and it is only when the gunpowder is fired that the real chemical process begins. This process results in the production of a number of new substances—gases—absolutely different from the original constituents of the gunpowder.

Apart from the thorough-going change of properties which accompanies the combination of two elements, chemists have discovered some very remarkable facts bearing on the proportions by weight in which combination takes place. Elements are exceedingly particular as to how far they give themselves away, and nothing will persuade them to go more than a certain distance in meeting the advances of other elements. When iron and sulphur combine, they do so in the proportion of seven parts of iron to four parts of sulphur. If a mixture of eight ounces of iron with four ounces of sulphur were heated, nothing would induce that extra ounce of iron to give up its independence and enter the compound. And similarly if we took a mixture of seven ounces of iron with five ounces of sulphur, the extra ounce of sulphur would absolutely refuse to be anything else than sulphur. So that elements combine in perfectly definite proportions. However or wherever a compound is produced, in the laboratory of the chemist or in the laboratory of Nature, it invariably consists of the same elements united in exactly the same proportions.

There are cases, indeed, in which two elements unite to form more than one compound. Thus there are two oxides of copper, one containing eight parts by weight of copper to two parts by weight of oxygen, and another containing eight parts of copper to one of oxygen. Observe that the amount of oxygen uniting with eight parts of copper must be either one or two ; no compound can be formed containing between one and two parts of oxygen to eight parts of copper. And this is merely an example of what is always found to be the case. When one element combines with another element to form more than one compound, the amounts of the second element

which combine with a definite weight of the first element are as one to two, or two to three—some simple ratio of that sort.

These remarkable facts about the proportions in which the elements combine were discovered soon after the balance had become part of the regular equipment of a laboratory, and chemists began to cast about for an explanation. The result was that they came to regard matter as made up of separate particles of extremely small size called molecules, which were incapable of further division except by chemical means. A fragment of iron, if magnified sufficiently, would thus resemble a heap of cannon balls, each cannon ball representing a molecule. It must be remembered, of course, that this is only a theory, a picture, for nobody has ever divided matter so finely that further division was impossible; a single separate molecule has never been picked out; indeed, it must be much smaller than anything that has ever been seen, even under the most powerful microscope.

Although the molecule of a substance is the smallest particle of that substance which can exist by itself, it is possible to break it up by chemical means. The chemist's experiments have led him to believe that a molecule consists of so-called atoms, sometimes all of one kind, sometimes of different kinds. When the atoms in a molecule are all of the same kind, it is an element which we are considering; when the atoms are of different kinds, it is a compound. To separate the atoms which are present together in any one molecule, we bring another kind of molecule, with different atoms, alongside. In a great many cases the atoms will promptly change partners, and new molecules—that is, new substances—are produced. Suppose, for example, we bring together a molecule AB,

containing one atom A and one atom B, and another molecule CD, containing one atom C and one atom D, then a chemical reaction will take place resulting in the formation of two new molecules AC and BD, or possibly AD and BC.

This way of picturing the constitution of matter enables us to explain the definite proportions in which elements are found to combine. Take the case of copper and oxygen, already mentioned. Chemists have come to the conclusion that the atom of copper is four times as heavy as the atom of oxygen. Now the simplest way in which combination could take place would be by one atom of copper joining with one atom of oxygen, to form one particle or molecule, as it is called, of copper oxide. Each molecule, therefore, of copper oxide would contain four parts by weight of copper to one part of oxygen, or, what is the same thing, eight parts by weight of copper to two parts of oxygen. And what has been said of each separate molecule may be said also of the mass of copper oxide, which is simply the sum total of the myriad separate molecules. The proportion of copper to oxygen in the mass of copper oxide would be the same as in each individual molecule.

Remembering that the atoms are indivisible, we can easily see that the next simplest ways in which copper could combine with oxygen would be by two atoms of copper joining with one atom of oxygen, or by one atom of copper joining with two atoms of oxygen. The atom of copper being four times as heavy as the atom of oxygen, the first of these two compounds would contain eight parts by weight of copper to one part of oxygen, while the second would contain eight parts by weight of copper to four parts of oxygen. As mentioned above, one of these

compounds, the first, has actually been discovered, and it is probable that the second also exists.

With the atomic theory of the constitution of matter, therefore, we can explain the very notable simplicity and constancy which characterise the manner of combination of the elements.

CHAPTER IV

INVISIBLE SUBSTANCES, AND HOW WE KNOW OF THEIR EXISTENCE

" SEEING is believing" is a familiar proverb, but we must recognise that the saying does not contain all the truth about the relation of seeing to believing, and that we believe in many things which we cannot see. Even in the realm of matter, apart altogether from the realm of mind, there are some things the existence of which is not directly obvious by the evidence of our senses. The chemist, whose business it is to deal with all sorts and conditions of matter, knows many substances—"gases," he calls them—of which he could not say—"There! See, smell, touch, taste." A gas may be without smell or taste, it may be as intangible as a spirit, and as for seeing it, why, it may be off and away while the observer still thinks he is looking at it. And yet it is possible to satisfy ourselves by some more or less indirect observations that these invisible, odourless, intangible, and tasteless substances do really exist. The chemist, at least, believes in the existence of gases such as oxygen, hydrogen, nitrogen, and carbon dioxide as firmly as he believes in the existence of iron, sulphur, turpentine, or water.

It must be observed that the difficulty which is met with in the case of the four gases just mentioned does not occur with all gaseous substances. Some betray their

presence by their smell ; coal gas, for example, is invisible, but fortunately our noses soon warn us when it is out of bounds. Other gases, again, are coloured, and we have thus direct evidence of their presence.

But there are several indirect ways in which we may convince ourselves that air, oxygen, nitrogen, hydrogen, carbon dioxide, and similar elusive substances have a material existence. Air is indeed invisible, but from the effects which it produces when in motion we may be pretty sure as to its material nature. In every case where mechanical work is done, we shall find on consideration that the origin of it lies in the motion of some material body ; and the wind, which in its destructive mood can lay low a whole forest, can be regularly harnessed to work by the sails of our ships and the arms of our windmills. Since work is done by the wind, there must be a material body moving, and the material body, in this case, is the air.

A very good reason for regarding air as a material substance is based on the fact, to which every reader will assent, that two different material bodies cannot occupy a given space at the same time. If we are foolish enough to run against a stone wall we learn by experience that one material body resents the attempt of another material body to take its place ; it offers resistance. Now that is exactly how the air and other gases behave. If a tumbler is inverted in a basin of water, the water does not rise and completely fill the tumbler. There is something inside which takes up room and so offers resistance to the water occupying the same space. Reasoning from our general experience of material bodies, we may conclude that the invisible something inside the tumbler is certainly of a material nature.

Once again—all solid and liquid substances with which we are familiar are characterised as light or heavy—in other words, they have weight. In this respect also air and other gases conform to what is commonly characteristic of all material bodies. It is true that, bulk for bulk, gases weigh much less than water, or wood, or stone, but the difference is only one of degree. One simple way of showing that air has weight is to put a little water in a glass flask, and let it boil vigorously until the flask is full of steam. It is then corked tightly and removed at once from the source of heat. When the flask and its contents have become quite cold, they are put on one side of a sensitive balance, sufficient weights being put on the other side to keep it level. The cork is then removed for a moment, and it will be observed that the side of the balance on which the flask was placed goes down at once, showing that the mere opening of the flask causes it to become heavier. What has happened is that the steam which filled the flask when it was hot became condensed to water when the flask had cooled, thereby leaving room for air to enter as soon as the cork was removed. It is the entrance of this invisible something from the surrounding atmosphere which makes the flask heavier. Gases, then, have weight, and are on this ground also to be reckoned as material substances.

As has been said already, gases are very light compared with other substances ; they are matter in a very attenuated form. A pint of water is nearly 800 times as heavy as a pint of air, and with the gas hydrogen the contrast is still more marked. For air is fourteen and a half times as heavy as hydrogen, so that a pint of water weighs 11,500 times as much as a pint of hydrogen. It may truly be said that a pint of hydrogen is as light as

the proverbial feather, for its weight is only between one five-hundredth and one six-hundredth of an ounce. Hydrogen is, in fact, the lightest substance known.

The fact that hydrogen is so much lighter than air is of great importance in the manipulation of balloons. In order that a balloon may itself rise in the air and carry as well a load in its car, it must be filled with something which is considerably lighter than air. For this purpose hydrogen is the ideal substance, but coal gas, which contains a good deal of hydrogen, is often employed. Bulk for bulk, coal gas is about half as heavy as air.

We have been comparing air with hydrogen, but it is important to bear in mind that whereas hydrogen is an element, air is a mixture chiefly of the two elements, oxygen and nitrogen, in the proportion of one volume of the former to four volumes of the latter. Air is not a chemical compound of oxygen and nitrogen, and from what has been said already about the essential difference between a mechanical mixture and a chemical compound of two elements, it will be understood that the properties of air are a sort of cross between the properties of oxygen and those of nitrogen. Both these gases are without colour or smell, but in their chemical behaviour they are widely different. Oxygen is a very active element, eager to enter into chemical combination with all sorts of bodies, and its power of supporting life is simply one phase of its activity. Nitrogen, on the other hand, is a neutral, sluggish, and inert gas, without any ambitions in the direction of chemical union. This being so, it is not surprising that air acts like diluted oxygen, the nitrogen, as it were, chilling the enthusiasms of the more active gas. Many things burn in air—that is, they combine chemically with the oxygen which it contains—but the combustion is

much more vigorous when pure, undiluted oxygen is supplied. The process of respiration is very similar to the process of combustion, and it will be remembered that in cases of serious illness, and as a last resort, pure oxygen is sometimes supplied to the patient instead of air, in order to support for a little longer the flickering flame of life. A little chip of wood serves very well to show the difference between pure nitrogen, pure oxygen, and the air which is a mixture of both. If the chip is set alight and is then blown out, it continues to glow in the air for some considerable time. When the still glowing chip is thrust into a jar of pure oxygen it at once bursts into flame, whereas if it were thrust into a jar of pure nitrogen it would be immediately and completely extinguished. So we learn that of the two chief constituents of atmospheric air one supports combustion, the other does not.

Besides oxygen and nitrogen, there are a number of other gases in the atmosphere, but only in very small amounts. The chief of these are argon, a gas resembling nitrogen, to the extent of 9 volumes in 1000 of air, water vapour in varying amount, and carbon dioxide to the extent of 3 or 4 volumes in 10,000. The last-mentioned gas is being constantly produced by the combustion of all sorts of fuel, and in the respiration of animals. Whereas the air which we take into our lungs contains, as has just been said, ·03 or ·04 per cent. of carbon dioxide, expired air contains as much as 3 to 5 per cent. of carbon dioxide and correspondingly less oxygen. Strange to say, this constant enormous production of carbon dioxide does not lead to any increase in the average amount of that gas in the atmosphere, for it is as constantly being removed by the instrumentality of

the vegetable world. The green leaves of plants, aided by sunlight, have the power of decomposing carbon dioxide, liberating the oxygen, and using the carbon for their own consumption. In regard, therefore, to the production and consumption of carbon dioxide, the animal and vegetable kingdoms are complementary to each other.

To the ordinary person it may appear rather a difficult matter to detect the presence of these odourless, invisible gases, but the chemist has discovered ready methods of recognising and distinguishing them. The properties of each gas have been carefully studied, and in almost all cases substances have been found which will behave in some characteristic manner when a particular gas is present, and remain unaffected when that gas is absent. One of these useful substances, employed to test for the presence of carbon dioxide, is lime water. When slaked lime is shaken with water, a little of it dissolves, the water becomes slightly alkaline, and the clear part free from sediment is known as lime water. Now when a mixture of gases containing carbon dioxide is shaken with lime water, or is bubbled through the lime water, the latter becomes quite cloudy, owing to the formation of chalk. No other gas behaves towards lime water in this peculiar manner, so that we are able to obtain visible proof of the presence of a gas which is itself quite invisible.

It is sometimes very necessary to be able to detect the presence of carbon dioxide; for although the gas is not actively poisonous, yet it does not support life, and its presence in large quantity is very harmful. In all processes of fermentation, as, for example, in the brewing of beer, large quantities of carbon dioxide are produced. Further, this gas, being considerably heavier than air, has a habit of accumulating at the bottom of vessels and

forming what may be regarded as invisible pools. Hence it has occasionally happened that a brewery worker, descending into one of the large vats for the purpose of cleaning it, has collapsed fatally—practically drowned in the carbon dioxide which had collected at the bottom of the vat. When a descent has to be made either into a brewer's vat, or into an old well, where a similar accumulation of carbon dioxide may occur, a lighted candle ought first to be lowered to the bottom. Should the candle continue to burn as brightly as in the open air, no one need hesitate to follow it. If the candle, however, goes out, or even gets dim only, it is evidence that there is a dangerously large quantity of carbon dioxide present.

The element carbon combines with oxygen in more than one proportion, giving rise not only to carbon dioxide, but also to carbon monoxide. This latter substance is a colourless and odourless gas, which burns with a blue flame and is intensely poisonous. Any one who watches a clear coal fire on a winter evening will notice little tongues of blue flame; these are due to carbon monoxide, which readily combines with more oxygen to form carbon dioxide. Carbon monoxide has a curious effect on the blood—an effect which is directly associated with its poisonous properties. It has the power of forming a compound with the haemoglobin, the colouring matter of the blood, and this involves a slight change of tint. By shaking up the suspected gas with a little blood, and then comparing the latter with some of the original blood, either by mere inspection or by means of a spectroscope, one may detect quite small quantities of carbon monoxide.

Some very interesting cases are on record in which mice have been used to indicate the presence of carbon monoxide in an atmosphere. Small animals, such as mice, are

affected by this poisonous gas more rapidly than human beings, and the behaviour of mice therefore serves to give warning of its presence in dangerous proportions. After the Snaefell Mine disaster in 1897, for instance, the rescue party, headed by Professor Le Neve Foster, descended ladder after ladder in the shaft only after a mouse had been previously let down to the next lower level. A lighted candle also was attached to the cage containing the mouse. "By the aid of this testing apparatus," says Professor Foster in his Report, "it was easily ascertained without any risk that the air was not bad as far as the 115 fathoms level, and that it became poisonous and deadly at the 130. The mice showed precisely the same symptoms as human beings; for, if not completely dead on arriving at the surface, they had lost all power in their legs, whilst pinkness in the snout recalled the pink lips of the dead bodies of the unfortunate miners."

Until recently it was the regular custom to carry a couple of white mice on every submarine boat, the object being the detection of any carbon monoxide which might be produced by imperfect combustion of the gasolene. It appears, however, that mice are not sufficiently sensitive to small quantities of the gas, and the practice of carrying them on submarines is now quite rare.

The question may have occurred to the reader— how does it come about that gases, while obeying the fundamental laws of matter in many respects, are yet so utterly different from the more compact forms of matter with which we are acquainted—namely, liquids and solids? It is not only that gases are frequently invisible, but they are peculiar also in their ability to occupy fully any space that is offered to them. If a quantity of gas which fills a ten-gallon gasometer is

transferred to one holding twenty gallons, the gas will occupy every corner of the latter. There is, of course, less of it at any particular point, and its total weight remains the same, but its distribution is carried to the utmost limits of the containing vessel, however large that may be. A moment's thought will show how different this is from the case of a liquid such as water. Ten gallons of water remain ten gallons whether the containing cistern holds ten, twenty, or a hundred gallons. Gases, then, are distinguished from liquids by their remarkable expansibility and compressibility. The space or volume which a given quantity of gas occupies depends altogether on the pressure to which it is subjected, and the very simple law has been discovered that the volume of a gas diminishes in the same proportion as the pressure increases; that is, when the pressure is doubled, the volume is halved; when the pressure is trebled, the volume is one-third of what it was originally, and so on.

The volume of a gas is further very sensitive to changes of temperature, and it has been found that a gas which occupies ten gallons at 32° Fahrenheit will occupy between thirteen and fourteen gallons at 212° Fahrenheit, provided the pressure has remained the same. This behaviour, again, is quite different from that exhibited by liquids. Everybody knows that a pint of water does not become noticeably more bulky when it is raised to boiling. As a matter of fact, it does expand, but the expansion is too slight to be detected by the eye.

These striking differences between gases and liquids were, of course, obvious to our scientific forefathers, and some generations ago they adopted the explanation which

still holds the field. We first assume the atomic nature of matter; that is, we suppose that if we had a microscope powerful enough, we should find that an apparently continuous and homogeneous piece of matter is really discontinuous, consisting ultimately of tiny, separate, and distinct specks or molecules, just as what looks like a single homogeneous black mound in the distance may turn out on closer inspection to be a heap of separate cannon balls. Then we suppose further (and this seems very unlikely at first) that in the case of a liquid or a gas the ultimate particles are in a state of continual motion. The particles or molecules of a gas are to be pictured as rushing hither and thither at a very high speed, constantly colliding with one another and with the walls of the containing vessel. The pressure which the gas exerts on the walls of the containing vessel—a pressure which we may easily measure—is due simply to the impacts delivered by the myriads of moving molecules. Each molecule, as it comes up to the wall of the containing vessel, delivers its blow, and rebounds with undiminished speed, to continue its zig-zag course among the other molecules. If part of the wall of the containing vessel is removed, then the molecules immediately rush ahead and occupy whatever space is offered to the gas.

Although the picture just outlined of the conditions which prevail in a gas may seem somewhat improbable to the reader, it has been found capable of giving an excellent interpretation of the varied behaviour of gases. But that is another story, and would lead us too far.

The molecules of a gas are very small compared with the spaces between them. When it is remembered that the molecules in a volume of gas about the size of a

pin head are thirty million times as numerous as the human beings on the face of the globe, it will be seen that a gas molecule is quite the smallest thing we can think of. Not less surprising than the size of the molecules is the rate at which they move. If it came to a race between an express train and a molecule of oxygen, the train would be hopelessly out of it; for the oxygen molecule slips along at the rate of about twenty miles a minute.

Now why should liquids be so different from gases, so much more easily visible, so much more tangible, so much less changeable in their volume? The key to the difficulty lies in the recognition that in a' liquid the molecules are much closer together than in a gas. Just as one heavenly body attracts another, so a molecule is subject to the attractive force of the surrounding molecules, and it is only because the molecules of a gas are *relatively* so far away from each other that the attraction may be neglected in this case. In a liquid, however, where the molecules, although still endowed with the power of rapid motion, exert a powerful attraction on each other, it becomes very difficult for an individual molecule to escape through the surface of the liquid. There is, as it were, a social force exerted which seeks to prevent the individual molecule deserting the community. Those molecules which attempt to escape through the surface with a rush and so evaporate have to run the gauntlet of the crowded molecules around, and most of them are prevented. Thus it comes that a liquid is not at liberty to expand to any extent like a gas; a liquid has a definite volume, whereas a gas, like the Vicar of Bray, adapts itself to suit the circumstances in quite a remarkable manner.

CHAPTER V

ELEMENTS WITH A DOUBLE IDENTITY

IN the study of chemistry one constantly encounters puzzling phenomena, the interpretation of which involves much patient labour on the part of the investigator. One of these puzzling things is the fact that some substances which are undoubtedly elements have a way of appearing in different forms according to the circumstances under which they are produced. We know that an actor plays sometimes one part, sometimes another; but although his get-up differs from time to time, it is always the same man underneath. So an element may be found masquerading in the garb of strange, unwonted properties, which are apt to deceive the onlooker, and it is one of the triumphs of chemical science that by its penetrating methods it has been able to identify a given kind of matter however it may be masked.

To begin with, it is found that some substances are like the chameleon, which can change the colour of its skin, or like the mountain hare, whose fur is brown in summer and white in winter. Such substances exist in two forms of different colour. It is not only in regard to colour, however, that the two modifications differ; their other properties are quite distinct also. A good illustration of this is furnished by phosphorus, which was referred to in a previous chapter as one of the elements which occur in nature always in a state of combination, and

never free. Phosphorus, however, can be extracted from bone ash by certain processes, and when prepared in this way it is a yellowish-white, waxy solid which can be cut with a knife. It has to be kept under water, for if exposed to the air it combines with the oxygen and is gradually converted into a compound of phosphorus and oxygen.

Phosphorus is very easily melted, and if the water under which it is kept is raised to a temperature a little above blood heat, the phosphorus becomes a liquid. It takes fire with the greatest readiness, and if, instead of being melted under water, a piece of phosphorus is heated in the air, it will ignite at a temperature very little above its melting-point.

In the dark a lump of phosphorus exhibits a curious glow or phosphorescence, which is directly connected with the action of the oxygen in the air upon it. From what has been said it will be understood that phosphorus is not dissolved by water, but there is one liquid which dissolves large quantities of the element, namely, carbon disulphide. On this property a pretty experiment can be based, for if a little of the solution of phosphorus in carbon disulphide is poured on blotting-paper, the finely-divided phosphorus which is left after the evaporation of the carbon disulphide takes fire spontaneously.

Ordinary phosphorus is further extremely poisonous, and many cases have occurred in which children have been poisoned by sucking the ends of matches, in the preparation of which phosphorus is used.

Let the reader now draw a mental picture of this yellowish-white, waxy solid, easily melted and readily set on fire, very poisonous and giving a characteristic phosphorescence in the dark, and put side by side with

it the picture of another substance with the following different characteristics :—a red powder which cannot be melted, which can be heated in the open air to a temperature of 450° Fahrenheit without taking fire, which does not phosphoresce in the dark, is not poisonous, and not soluble in carbon disulphide.

Nobody looking casually at these two substances would dream of regarding them as anything else than quite separate and distinct. And yet the fact is they are both the same element—phosphorus. The chemist has learned how to convert the ordinary yellow phosphorus into the red, and how the reverse change of the red into the yellow may be effected. Besides, the compounds which are prepared from the red variety are exactly the same as those obtained from the yellow form, so that there is no doubt that phosphorus is an element with a double identity.

How is it that a given element is able to assume different characteristics? How is it that such totally distinct properties can be associated with one and the same kind of matter? There are two possible causes for this curious phenomenon, and if we build on the foundation already laid in a previous chapter, we may be able to make the explanation clear.

It was said there that the smallest particles of a substance which can exist by themselves are called molecules, each of these containing one or more atoms. In the case of an element the atoms which go to make up the molecule are certainly all of one kind, but a further question arises about the number. And the first possible cause of the phenomenon that an element exists in two absolutely different forms, like red and yellow phosphorus, is simply this, that the molecules in the two cases contain

a different number of atoms. Since we are dealing with one and the same element, the atoms in the two cases must be the same in kind, but there may be more of them in the one case than in the other.

There is, however, another possible explanation. We must remember that not only are atoms grouped to form molecules, but molecules are massed together to form the substance as it presents itself to our eyes. If the hordes of molecules are arranged in regular fashion, then we get a crystalline substance; if they are arranged anyhow, we get an amorphous substance—that is, one without form. So with phosphorus, the molecules may be marshalled differently in the two varieties.

Of the two explanations which may thus be given for the existence of phosphorus in two distinct forms, the latter is the more probable. Red or amorphous phosphorus differs from yellow phosphorus, not in having a different number of atoms in the molecule, but in that the molecules are arranged differently in the two cases.

A most interesting and more familiar example of an element occurring in different forms is furnished by carbon. There are no less than three modifications of this element, two of which at least are as the poles asunder in respect of outward appearance and commercial value. It is indeed difficult to realise that dull, amorphous carbon, in the forms of charcoal or lampblack, is the same element as the brilliant, flashing diamond. Yet so it is; while, in addition to these two modifications of carbon, there is a third, quite distinct from both, and variously known as graphite, black-lead, or plumbago. Graphite is a little more distinguished-looking than charcoal, but is mean and commonplace in comparison with the diamond. The three forms of carbon, however, differ not

only in outward appearance, but in the value we set on them and in the uses to which they are put.

The diamond is very highly prized as a gem, and fetches in the market far more than its weight in gold. All real diamonds which the reader has ever seen have been obtained from natural sources; and diamond mining is a regular form of enterprise.

Many attempts have been made in recent times to manufacture diamonds, reminding one of the efforts of alchemists to convert lead into gold. Reflection, however, shows that these modern attempts are considerably less ambitious. Their aim is, not to change one element into another, but to convert one form of a given element into another form. The forms of carbon other than the diamond are easily obtainable, and the endeavour to change some of this plentiful material into a more valuable article is very natural.

More than that, the attempt to manufacture diamonds has been actually successful from the scientific and laboratory point of view, although not from a commercial standpoint. Moissan, the French chemist, working on the idea that diamonds are carbon which has been crystallised under great pressure, dissolved amorphous carbon in a crucible containing molten iron, heated the crucible in the electric furnace, and cooled it suddenly by plunging into molten lead. The temperature of molten lead is very much lower than that of molten iron, so that the outside portions of the latter in the crucible solidified immediately. As the iron inside this crust gradually solidified, enormous pressure was produced; for iron, like water, expands when it passes from the liquid to the solid state. The carbon, therefore, which was dissolved in the iron crystallised out under great pressure.

Fragments of diamond were obtained in this way, too small, however, to be of any value as gems.

Although it is so difficult a matter to obtain even very small diamonds from charcoal or graphite, the reverse change can be quite simply effected. If a diamond is strongly heated it becomes more bulky and is converted into something that resembles coke or graphite; that is, it loses all the special crystalline character to which the diamond owes its brilliancy.

The reader must bear in mind the distinction between artificial and imitation diamonds. Such artificial diamonds as were made by Moissan were the real article, and were found to consist of carbon. Imitation diamonds, on the other hand, contain no carbon; they consist of a soft, heavy flint-glass, known by the curious name of "paste." One interesting way of distinguishing real from imitation diamonds is to bring them close to a little radium salt in a dark room; under this stimulus the real diamond phosphoresces, but the imitation article makes no response.

The diamond is not only ornamental; it has many practical uses as well. One of the most remarkable things about it is its extraordinary hardness, in virtue of which it can scratch even a piece of hardened steel. With a fragment of a diamond fitted in a stem it is possible to write on glass as with a pen on paper, and with the natural edge of a small diamond crystal one can make a cut in a glass plate, so that the latter can be broken off like a piece of wood which has been nearly sawn through. The hardness of the diamond accounts also for its great usefulness in rock-boring tools; with a diamond drill, that is, a steel cylinder round the edge of which is fixed a series of diamonds, the hardest rocks can be gradually

pierced. In polishing a diamond the only material which is of any use is diamond dust ; even emery is too soft to touch it. The phrase " diamond cut diamond " has its explanation in what has just been said.

Graphite, or black-lead, as it is commonly called, is easily distinguished from the diamond ; it is a greyish black substance, crystalline certainly, but soft and soapy to the touch. People gave the name of " black-lead " to this form of carbon because they were under the mistaken impression that it contained lead. The power of graphite to give a mark on paper, a property which has found application in the manufacture of pencils, is exhibited also by metallic lead, hence the really erroneous name of " black-lead."

There are many other ways in which graphite is usefully applied besides the manufacture of pencils. It is scarcely affected at all by exposure to great heat, and is accordingly made up along with clay into crucibles for use at high temperatures. Then it is used to coat iron-work—grates, for example—in order to protect it from rusting, and at the same time to give it a shiny appearance. Another curious use to which graphite is put is the lubricating of machinery working at a high temperature, at which ordinary oil would be unsuitable.

Whereas diamond and graphite occur naturally, the various forms of amorphous carbon are generally obtained as the products of human operations. Thus wood charcoal is got by the partial combustion of wood, lampblack is the product of the imperfect combustion of oil, while animal charcoal is obtained by heating bones very strongly. Wood charcoal, lampblack, and animal charcoal or boneblack all consist of amorphous carbon, and are applied in many useful and interesting ways.

One of the main characteristics of wood charcoal is its power of absorbing gases in large quantities, a property which renders it of value in the purification of bad air. By passage through charcoal filters sewer gases and other noxious emanations may be rendered harmless. Boneblack, again, has a remarkable power of removing colouring matter from liquids, such as red wine or indigo solution ; it is accordingly employed very extensively in decolourising sugar during the process of refining. Lampblack, on the other hand, is applied for quite different purposes. It is useful as an artist's pigment in both oils and water colours, and forms the chief ingredient of Indian ink and printing ink.

The uses to which carbon in its various forms may be put are, in fact, legion, and in the face of these it is necessary to re-emphasise the fact that diamond, black-lead, and charcoal are all modifications of this one element. The fundamental experiments on which this statement is based were carried out more than a century ago. Before this, people were in great doubt about the exact nature of the diamond, but it was then shown that, starting with a given weight of either diamond, graphite, or charcoal, one obtained in all three cases the same weight of the gas carbon dioxide, and nothing else besides. This experiment proved incontestably that diamond, graphite, and charcoal are merely different forms of one and the same element.

The explanation which was given for the existence of two modifications of phosphorus is valid also in the case of carbon. Diamond, graphite, and charcoal differ, not in the number of atoms contained in the molecule, but in the arrangement of the molecules to form the substance as it appears to our eyes.

There is, however, one notable illustration of an element existing in two forms which differ in respect of the number of atoms in the molecule. That is the common element oxygen. The molecule of this gas contains two atoms, but under certain circumstances it is possible to induce three atoms of oxygen to club together in a molecule, and then we have ozone. Long before anybody knew about this curious substance, a peculiar smell had been noticed whenever an electrical machine was at work, and people adopted what seemed the simplest explanation and regarded it as the "smell of electricity." We now know that an electrical discharge, either as a spark from an induction coil, or in the shape of lightning, converts some of the oxygen in the air into another substance, ozone, which is responsible for this peculiar smell.

To speak of ozone as "another substance" is both right and wrong. It is right because, in regard to the properties which it possesses, ozone is quite distinct from oxygen. In some respects it behaves like intensified oxygen, oxidising things which that gas cannot touch. An illustration of this is the extraordinary effect which it has on mercury. The merest trace of ozone introduced into a vessel containing the metal seems to scare it out of its usual behaviour; the bright, lustrous surface becomes dull and unresponsive; instead of moving about freely, it sticks to the glass as if it were greased.

In a second sense it is wrong to speak of ozone as "another substance" than oxygen, for they are simply two forms of the same element—"allotropic" forms, as the chemist calls them. The existence of phosphorus and carbon in more than one modification was attributed to a different arrangement of the molecules, but such an explanation could not possibly be correct in the case of

gases like oxygen and ozone. For, as has been pointed out already, the molecules of a gas are rushing hither and thither at a high speed, and any definite arrangement of these particles is quite out of the question.

The few cases discussed in this chapter of elements existing in more than one form are simply illustrations of what has been observed all over the field of chemistry. It is very frequently found that two compound substances with the same chemical composition are quite distinct in their outward appearance and general behaviour. In some instances the difference is merely one of crystalline form, and is to be attributed to a different arrangement of the molecules. In other compounds, however, the origin of the distinction is far more subtle, and is found in a different arrangement of the atoms within the molecule. The story of the way in which chemists have discovered the internal structure and anatomy of the molecule is very fascinating, but it is long and intricate, and would detain us from excursions into interesting fields which are close at hand.

One other curious phenomenon, however, deserves notice here. When a compound exists in two crystalline modifications, it is very commonly observed that one of the forms has but little persistence, and changes into the other on the slightest provocation. Some years ago the writer came across an interesting case of this kind. He obtained a substance which crystallised in the form of shiny leaflets, but these were no sooner produced than they began to change, entirely of their own accord, into little needle-shaped crystals. The first form of the substance, in fact, never existed for more than a few minutes.

A host of similar interesting cases might be quoted,

but enough perhaps has been said to convince the reader that the study of the various forms in which an element or compound can exist reveals Nature in very curious moods, and brings the chemist into touch with some of the most interesting problems of matter.

CHAPTER VI

METALS, COMMON AND UNCOMMON

NO one can fail to notice that metals and alloys play a very important part in the economy of modern life. It has not always been so in the history of the world, for, "as every schoolboy knows," there was a time when tools and weapons were made exclusively of stone. That primitive stage in man's conquest of nature was followed by the Bronze Age and the Iron Age, and ultimately, when Greece and Rome were at the height of their glory, as many as seven metals were known and utilised. At the present time the number of known metals is very much greater, and innumerable alloys, made by mixing two or more metals, find application in our technical and social life. We see them everywhere, from powerful engines and gigantic bridges down to needles and pins; we carry them about with us, on our boots, in our pockets, on our fingers, in our hair, and sometimes even in our mouths.

The majority of the seventy known elements are metals, and among these there are all sorts and conditions. Only one is a liquid—mercury or quicksilver—and its curious combination of the properties of a metal and those of a liquid render it useful for many special purposes. In the same way, however, as liquid water may be converted into steam by heating and into ice by cooling, so the liquid metal may be boiled, producing mercury vapour, or it may be

solidified by the application of cold. Indeed, during winter in extremely cold countries like Siberia the mercury in the bulbs of the thermometers may be frozen; this happens when the temperature falls 40° below zero Fahrenheit.

Metals exhibit great variety of density, and it must not be supposed that a metal is necessarily a heavy substance. It is true that mercury is nearly fourteen times as heavy as water, and that gold is about nineteen times as heavy, yet there are metals—sodium, for instance—which are lighter than water; if a piece of this metal is thrown on water it swims about on the surface. The reader may remember aluminium as a comparatively light metal, the weight of which, bulk for bulk, is only one-seventh of that of gold.

Only a few of the metals are found in the uncombined or "native" condition. These are the so-called "noble" metals—gold, platinum, &c.—which are distinguished by the fact that they do not tarnish, and are not readily attacked by acids. Other metals occur in the form of ores, and have to be extracted from these by laborious processes. However it has come about, the majority of the metals have combined with oxygen or sulphur, and their ores consist therefore mainly of oxides or sulphides, mixed naturally with a smaller or greater amount of earthy matter. The operations or metallurgical processes necessary for winning metals from their ores are modified by the idiosyncrasies of the particular metal which is sought, but the essential chemical reaction involved is generally the removal of oxygen from the ore by the agency of carbon. If the ore does not already consist of the oxide, the latter is obtained by roasting the sulphide in a current of air, by which process the sulphur in the sulphide is replaced by oxygen.

The oxide is mixed with coke, which contains a high proportion of carbon and the mixture is heated in a furnace, a "flux," such as lime, being added to remove the earthy matter from the ore in a fluid form. At the high temperature of the furnace the carbon in the coke deprives the metal of its oxygen and carries it off in the form of carbon monoxide or carbon dioxide. The metal is thus obtained in the free state, and is generally run out of the furnace in a molten condition, while the earthy material that was in the ore is separated along with the flux as slag.

Perhaps the commonest example of such a metallurgical operation is iron-smelting, a process which may be seen at work in many parts of Great Britain. In the case of iron it is desirable to inform ourselves a little more about what is done with the crude metal obtained from the blast furnace, and it is well that we should understand the chemical differences between the various kinds of iron which are of technical importance, namely, cast-iron, wrought-iron, and steel. The different properties which characterise these varieties of the metal show in a very interesting manner how the behaviour of a pure substance is modified by the presence of small quantities of foreign matter.

In a description, given in an earlier chapter, of the attempts which have been made to manufacture diamonds, it was said that molten iron dissolves carbon. Since now in the process of iron-smelting the fused metal has been in contact with coke in the furnace, it is not surprising that the crude metal which is taken out of the furnace contains an appreciable amount of carbon, as much as 3 to 5 per cent.; it is run into moulds, and is then known as cast or pig-iron. Careful examination has shown that

of the total carbon present in cast-iron some has combined with the metal to form a compound known as a carbide, while the rest has crystallised out during cooling in the form of graphite.

If the carbon is removed from cast-iron as completely as possible we get wrought-iron, which contains only about one-tenth of 1 per cent. of carbon, and differs very notably in its properties from cast-iron. In the first place, wrought-iron can be welded—that is, if two pieces of this material are made red-hot they soften, and in this state may be hammered together. This cannot be done with cast-iron, which is a hard, brittle, crystalline substance.

Again, cast-iron is much more easily melted than wrought-iron. The latter is very nearly pure metal, whereas the former contains an appreciable quantity of foreign material. Now it 'is a well-known fact that if a small quantity of a foreign body is added to a pure substance, the melting-point of the mixture is lower than that of the pure substance. Salt water, for example, contains much more dissolved matter than fresh water, and is more difficult to freeze; or, to put it the other way round, ice melts at a lower temperature in salt water than it does in fresh; in fact, a strong solution of common salt in water will not freeze even at 0° Fahrenheit. The fact that cast-iron melts more easily or has a lower freezing-point than wrought-iron is therefore an illustration of a very general principle. The reader will observe that the freezing and melting-points are to be regarded as the same temperature, and this is always so if we are dealing with a pure substance. The difference is merely this, that if we are thinking of the solid being converted into liquid, the

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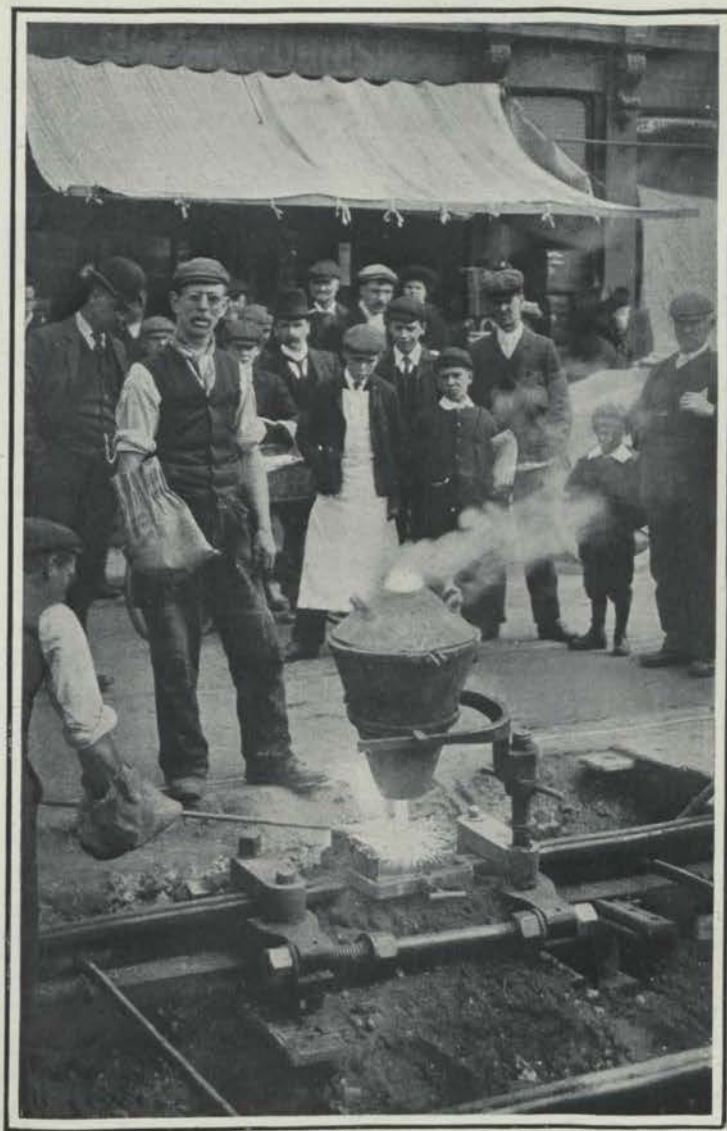
MOLTEN IRON WITHOUT A FURNACE

The crucible is charged with a mixture of metallic aluminium and iron oxide, known as "thermit," and the mixture is ignited. Chemical action sets in, which results in the formation of metallic iron and aluminium oxide, and the heat generated is so intense that the iron is melted. As shown in the illustration, the molten iron may be used for welding tram rails. The heat of the chemical action is so great that the eyes of the operators have to be protected by darkened glasses.

temperature at which this takes place is called the melting-point; if, on the other hand, we are thinking of the change of liquid into solid, the temperature at which this change occurs is called the freezing-point. The two temperatures are the same if the substance is pure.

The third variety of iron, namely, steel, is intermediate between cast and wrought-iron in regard to the amount of carbon which it contains. The remarkable thing about steel is that when it is heated and then suddenly cooled by plunging into cold water it becomes exceedingly hard, so much so that it has the power of scratching glass. Curiously enough, if this hard steel is again heated and then allowed to cool *slowly*, it is found to be nearly as soft as ordinary iron. By regulating the temperature to which the hardened steel is exposed the second time, any required degree of hardness may be attained. Articles made of steel, such as razors, scissors, and watch-springs, are therefore first hardened, and then "tempered" by heating them to a point between 430° and 550° Fahrenheit, the temperature varying according to the purpose for which the article is to be used. A razor, for example, is heated only to 430°, a temperature at which the metal acquires superficially a pale yellow colour, due to the formation of a film of oxide. Watch-springs or sword-blades, on the other hand, which should be softer and more elastic, are tempered by heating to 550°, and the colour of the surface film passes through various shades—yellow, brown, purple, and blue—as the temperature rises. The degree of heat attained in tempering may in fact be judged from the colour of the surface. Thus hardened steel which has been heated to 430°, and then

allowed to cool slowly, is said to be "tempered to the yellow," and is hard enough to take a fine cutting edge. It must be remembered that steel which has been hardened without being tempered is of no use for ordinary purposes; it is too brittle.

It is many centuries now since man first began to discover the valuable properties of iron, and the passage of time has only led to a gradually widened range of application, and to improved methods of production. One can name metals, however, which for a long time after their discovery were regarded as curiosities, and have only recently and more or less suddenly been in large demand as their useful properties have been realised. Aluminium is a notable example of this. Fifty or sixty years ago it cost twenty shillings an ounce; now it can be purchased for less than a shilling a pound. The very high price of the metal was due, not to scarcity of material from which aluminium could be produced, but to the fact that there was little or no demand for it, and no satisfactory method of extracting it from its ores.

As a matter of fact, aluminium is one of the most common constituents of the earth's crust, occurring in the combined state as mica, felspar, clay, and slate. It is in many respects a remarkable metal. It is exceedingly light, and yet, unlike most other metals of this class, is not easily tarnished even in the presence of moisture. On account of its lightness it is extensively used in military fittings, while its resistance to the action of animal and vegetable juices renders it serviceable in the manufacture of cooking utensils.

Although aluminium in the mass is not easily oxidised in air, probably because it gets coated with a thin film of

oxide which acts as a protective layer, the powdered metal burns vigorously, like magnesium, when it is heated, and in this way a very high temperature is produced. If the oxygen which is necessary for the combustion of the aluminium is mixed with the metal at the start, instead of coming from the air as the burning proceeds, an even higher temperature can be reached. But how, the reader may ask, can we mix a gas with a solid? In the literal sense, certainly, this cannot be done, for to burn half an ounce of aluminium powder as much as fifteen pints of oxygen gas would be required. But the oxygen may be mixed with the aluminium in a compact or condensed condition in the form of some compound, out of which the aluminium has no difficulty in extracting it.

Iron oxide is such a compound, so if a mixture of powdered aluminium and iron oxide, known as "thermit," is ignited at one point an action sets in which spreads through the whole mass, giving out intense heat, and resulting in the formation of aluminium oxide and molten metallic iron. The aluminium, in fact, feeds on the oxygen of which it has deprived the iron. The heat produced in this competition for the oxygen is so intense that if some thermit mixture is placed on an iron plate half an inch thick, and ignited, a hole is melted in the plate.

The heat stored up in thermit may, however, be turned to more practical account in the following interesting manner :—If the ends of two steel rails are pressed together and some of the intensely hot fluid iron produced in the thermit reaction is run out of a crucible on to the junction, the crevices are filled, the heat is such that the ends of the rails are softened, and may be welded by the applied pressure so that a sound joint is made. In a

similar way thermit may be employed for repairing iron shafts and pipes.

In aluminium we have an example of a metal the price of which has fallen in a remarkable manner, not because fresh sources of the metal have been discovered, but because the increased demand has led to cheaper and more efficient methods of production. There are other metals, however, which are costly, not because there is any difficulty about their extraction, but because the natural supply is limited.

Platinum is a case in point. Endowed with unique and valuable properties, it is comparatively rare, and possibly the reader has never seen a specimen ; it costs nearly twice as much as gold. Platinum is a silvery metal, twenty-one times as heavy as water, bulk for bulk, and does not rust or tarnish. Like gold, it is a "noble" metal, and is not dissolved by any single acid which we know, not even by *aqua fortis* (nitric acid). A mixture of nitric and hydrochloric acids, however, will dissolve both platinum and gold, and it was the power of this mixture to attack the latter metal which led the alchemists to speak of it as "*aqua regia.*"

Platinum is in a special sense the chemist's metal. Its very high melting-point — 3200° Fahrenheit — and its chemical inertness make it valuable to him, and platinum-crucibles are to be reckoned among the indispensables of a properly-equipped chemical laboratory.

There is another characteristic of platinum which to the casual reader may seem most insignificant, but which, as it turns out, is of the greatest importance in a certain manufacture. This is the fact that with rising temperature platinum expands at nearly the same rate as glass. Why should that be of any consequence? the

reader may ask, and what has platinum got to do with glass? Well, it is generally recognised that bodies expand when heated—they become more bulky as the temperature rises. As a rule, the expansion differs with different substances, but it so happens that platinum expands to the same extent as glass for a given rise of temperature.

We may realise the significance of this fact when we remember that it is sometimes necessary to pass a metal wire through the walls of a glass vessel. This has to be done, for example, in the electric glow lamp, the illuminating power of which is due to a carbon filament raised to a white heat by the passage of an electric current. As the carbon would soon burn away if it were surrounded by air, the little glass globe which protects the filament must be freed from air and then sealed up. The wires, therefore, which carry the current must pass through the walls of the globe, and the question at once arises, what metal should be used for these wires?

Copper, the metal which is so commonly used for electric wiring, would be quite unsuitable, because it does not expand and contract with change of temperature at the same rate as glass. If we passed a copper wire through a piece of glass while the latter is hot and soft, and melted the glass all round the wire, then on cooling, owing to the unequal contraction of the metal and the glass, a condition of strain would be produced, leading finally to the fracture of the glass.

A metal is required which expands and contracts at the same rate as glass, and the one metal with this characteristic is platinum. Hence it comes that an electric glow lamp has two little pieces of platinum

connecting the ends of the filament inside with the terminals outside.

Thus it is that what may seem at first to be nothing more than a dry laboratory fact, without any practical bearing, may turn out to be of the greatest importance for the requirements of everyday life.

Such a case of the discovery of a new use for a metal, and a consequent fresh demand for it, might be paralleled by what has happened recently in connection with tantalum. This is a rare metal, and up to within a year or two ago very little attention had been paid to it, as a glance at any chemical text-book will show. It has been discovered, however, that tantalum has certain properties of commercial value, and people are now on the look-out for fresh sources of this somewhat scarce material.

The illuminating power of the electric glow lamp depends, as has been said already, on a carbon filament being raised to incandescence by an electric current. Now these carbon filaments are very fragile creations, and one might at first be inclined to wonder why fine metallic wires are not used instead; for it is well known that a metallic wire is similarly heated by the passage of a current. The explanation is simple; in order to get a respectable light from an incandescent metal wire, we should have to raise it to a temperature at which it would melt. This would happen even with platinum, for the temperature of the carbon filament in an electric glow lamp is several hundred degrees higher than the melting-point of that metal.

It is just here that the valuable properties of tantalum come in. Briefly stated, they are these: tantalum can be drawn into very fine wire, about one-thousandth of

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SEALING PLATINUM WIRES INTO AN ELECTRIC GLOW LAMP

Platinum expands on heating and contracts on cooling at the same rate as glass. Hence if the wires are sealed into the fused glass at a high temperature, the joint is still tight after cooling, and the glass is not strained as it would be if the rates of contraction were different.

an inch in diameter, and its melting-point is exceedingly high, so high that the fine wire may be raised to a white heat by an electric current without melting.

The tantalum lamp, then, which is now on the market, is exactly analogous to the electric glow lamp, except that the filament is made of tantalum instead of carbon. As regards efficiency, the tantalum lamp compares favourably with the ordinary glow lamp, and it is said to have a longer life. So the time may come, if sufficient tantalum can be procured, when the carbon filament will have become merely a curiosity.

Tungsten and osmium are other out-of-the-way metals which have recently found an important application in the manufacture of electric lamps, so that tantalum is not the only competitor in the field against the carbon filament.

The application of electricity to all sorts of objects has led to extended demands for other metals than those just quoted. Copper, for instance, which offers very slight resistance to the passage of a current, is much in demand for electric wiring; enormous quantities of the metal are now devoted to this purpose. Copper enters also into the composition of many alloys—brass, bronze, and the like; but the subject of alloys is a big one, and must be reserved for another chapter.

CHAPTER VII

WHERE TWO METALS ARE BETTER THAN ONE

IN the foregoing chapter we have had illustrations of the differences exhibited by metals in regard to specific gravity and fusibility, but there are, of course, many other properties—hardness, malleability, ductility, and the like—which have to be taken into account when we are considering the suitability of a given metal for a certain purpose. Frequently it happens that the metal is suitable for the purpose in all respects save one, in which case it may be possible to correct the deficiency by adding another metal, provided at the same time that this second constituent does not detract from the valuable properties of the first. The effect of the presence of carbon in iron might be considered as an illustration of this principle, but carbon is not a metal, and the amount present is not great, so that wrought-iron, cast-iron, and steel are rather in a class by themselves.

We may make good the deficiencies of a metal by the addition of another in more than one way. It is not always necessary actually to mix the metals; we may put one on the top of the other, as in tinplate or galvanised iron. In regard to strength, durability, and cheapness, iron is an excellent material, but the weak feature about it is its liability to corrode when exposed to a moist atmosphere : it rusts.

Articles made of iron which have to be exposed to air

and moisture must therefore be protected. In the case of large structures, such as bridges, locomotives, and steamers, this is done by painting them, but with smaller and more easily-handled articles the same end is attained by coating them with a layer of another metal which is not easily corroded by the action of moist air. Tin and zinc are metals which fulfil these conditions, and they are further comparatively fusible, so that a sheet of iron may be easily coated with either by simply dipping it into a bath of the fused metal. Iron coated in this way with a layer of tin is known as tinplate ; similarly treated with zinc, it is known as galvanised iron.

So that things are not always what they seem. Even the common pin is a fraud in this sense, for if we could open it out we should find brass wire in the inside, quite different from the white metal on the outside. Brass, as the reader probably knows, is a yellow alloy containing a lot of copper, and the easiest way of showing that pins contain this metal is to dissolve one in nitric acid. The pin is gradually consumed by the acid, it ultimately disappears, and a blue liquid remains, similar to what is obtained by treating a piece of pure copper in the same way. So we may conclude that there is copper in the pin. The white outside is a coating of tin ; this, however, is not put on, as in tinplate, by dipping in a bath of the fused metal, but by another interesting method.

The reader may recollect that among the things that lent support to the alchemists' belief in the transmutation of metals was the observation that a piece of iron immersed in a solution containing copper acquires the appearance of copper. This little trick can be performed with other metals also, and is applied in the manufacture of pins. The brass wires which form the substance of the

pins are put in a solution containing tin, and the result is that a coating of this metal is deposited on the brass.

Such a method of depositing one metal on another is very closely related to the process of electro-plating. When an electric current is passed between two metal rods or electrodes immersed in a salt solution, the salt is decomposed and the metallic constituent is deposited on one of the electrodes. Suppose now that the solution contains a salt of silver, and that we replace the rod on which the metallic constituent is deposited by a spoon made of some alloy, then on passing the current the usual thing happens, and we get a fine, coherent deposit of silver on the spoon; the latter is electro-plated.

In this way articles made of common metals or alloys may be plated with gold, silver, copper, or nickel. For example, we can protect steel articles, such as bicycle fittings, from atmospheric corrosion by plating them with nickel. Articles, on the other hand, which are to be used for the table or for ornament may be similarly coated with silver. Spoons and forks, for instance, are generally made of Britannia metal, an alloy containing mostly tin and antimony, or of German-silver, an alloy of copper, zinc, and nickel; when these articles are coated with silver they are less easily attacked by acid liquids, and at the same time their appearance is improved.

Plating, after all, is a device for hiding the shortcomings of one metal by covering it with another. There is, however, a second way of making good the deficiencies of a metal, and that is by mixing it thoroughly with another of different character. In what way the properties of one metal are modified by thus alloying it with a second may be best understood from a few examples.

The ubiquitous penny piece is commonly known as "a

copper." This metal in the pure condition, however, would be too soft for the wear and tear which a coin has to undergo, and consequently 5 per cent. of foreign metal (mostly tin) is added to the pure copper in order to harden it. The curious thing is that tin itself is quite a soft metal, and yet the addition of 5 per cent. of it to pure copper produces an alloy which is much harder than copper itself.

Similarly, pure gold and silver are too soft to be used either for coins or ornaments, and for this purpose they must be hardened by the addition of another metal, generally copper. The colour of an English silver coin does not betray the presence of copper, but if a threepenny bit were dissolved in nitric acid we should get the blue solution which is characteristic of copper. Since pure silver dissolved in nitric acid gives a colourless solution, we may conclude that our silver coins contain copper; as a matter of fact, they have $7\frac{1}{2}$ per cent. of that metal.

An English gold coin is also alloyed with copper to the extent of 1 part for every 11 parts of gold. Such an alloy is described as 22 carat gold, because out of 24 parts of the alloy, 22 parts are pure gold. For ornaments other alloys are made containing less of the precious metal, and described as 18, 12, or 9 carat gold, these figures indicating that 24 parts of the alloy contain 18, 12, or 9 parts of pure gold respectively.

Another property which is altered by adding a second metal is the fusibility, and an alloy as a rule melts at a much lower temperature than one would expect from the melting-points of the constituent metals. The influence of a foreign body on the melting-point of a pure substance has already been referred to in connection with cast

and wrought-iron, but with alloys the effects are much more striking.

Common solder is a case in point. Soldering consists in joining two metals by an alloy which is more easily melted than either, and which at the same time will coalesce with each metal. Tin and lead, a mixture of which forms ordinary plumber's solder, melt at 440° and 617° Fahrenheit respectively, while the solder itself melts at 374°.

The reader may already have remarked the frequency with which tin is used either to plate or alloy with other metals, and it is in fact very seldom employed by itself. Even the so-called "tin" foil in which chocolates are wrapped contains lead, and the utensils which we call "tins" are generally iron plated with tin.

In the case of solder, as we have seen, the alloy melts at a temperature lower than the melting-point of either constituent. But of the lowering of melting-point produced by mixing far more striking examples are obtained when we take four metals to make an alloy. Lead, tin, bismuth, and cadmium melt at 617°, 440°, 514°, and 608° respectively, and yet by mixing these metals in certain proportions we can prepare an alloy which melts in hot water and is known as "fusible metal."

These easily-melted alloys are put to some curious uses; for example, in connection with fire-alarms. A quantity of fusible metal is arranged in a receptacle in such a way that when a certain temperature has been exceeded the alloy melts, and releases a spring or allows a lever to fall. By this device an electric circuit is closed and a bell is rung.

Then, again, fusible alloys play a useful part in the sprinklers which are fitted up in factories and workshops.

These consist of water-pipes led round the upper part of a room, and at intervals on the pipes there are valves secured by fusible alloy. If a fire should break out in any room fitted with such a sprinkler, the heat will melt the fusible alloy at one or more of the valves, the water will burst out, and there is a fair chance that the fire will be extinguished before it has attained very large proportions.

With such examples before us of the way in which the hardness and fusibility of a metal are altered by the addition of another, we are led up to the question—Are these alterations due to the formation of a new substance, a compound of the metals, or are they accounted for by the mere mixture of the constituents?

The difference between a mechanical mixture of two elements and the compound formed by their chemical combination has already been discussed. We must next try to decide whether the features which we generally notice in chemical action are to be observed when we make two metals into an alloy. Now it must be admitted that it is rather difficult to settle the question whether an alloy is a mixture or a compound. In some respects, it is true that the mixing of two metals resembles what takes place when two elements combine. Thus we have seen that when iron and sulphur act on each other an enormous amount of heat is liberated, and such liberation of heat very frequently accompanies chemical action. Well, a similar thing occurs when we add sodium to mercury to make an alloy (or an "amalgam," as it is called when mercury is one constituent); each addition of sodium is accompanied by a flash of light. So also when a piece of aluminium is added to fused gold, an extraordinary evolution of heat is observed,

and the molten mass is raised to incandescence. Such an occurrence may be taken as evidence that chemical combination has taken place.

Again, the colour of some alloys is markedly different from that of the constituents. Silver and zinc are both white metals, and yet they form a beautiful pink alloy. Gold and aluminium also furnish us with an illustration, for when they are mixed in certain proportions a brilliant purple alloy is obtained, quite distinct in colour from both constituents.

In spite of these examples, however, it must be said that we do not observe in the formation of alloys generally such a thorough-going change of properties as commonly results from chemical combination. The question, therefore, of mechanical mixture v. chemical compound is not so easily decided.

Modern investigators have tackled the problem by studying the freezing-points of alloys in their relation to the freezing-points of the constituent metals, and in the course of these investigations many interesting results have been brought to light. It is almost the invariable rule that when a little of a metal B is added to a metal A, the fused alloy begins to solidify at a lower temperature than pure A; it is said to have a lower freezing-point. As we go on adding more and more of the metal B, the alloys produced have lower and lower freezing-points. The same series of phenomena is observed when we add increasing quantities of the metal A to the pure metal B.

Suppose we try to picture these results graphically, that is, with the help of a curve. In doing this we represent the composition of the alloy by distances measured along a horizontal line, while the tempera-

tures at which the alloys freeze are represented by lengths measured vertically. This is a very common method of summarising the results of scientific investigation and of showing the way in which one quantity depends on or varies with another. An example of such a use of curves is furnished by the card which comes off an aneroid barometer at the end of a week. On this card vertical distances represent the height of
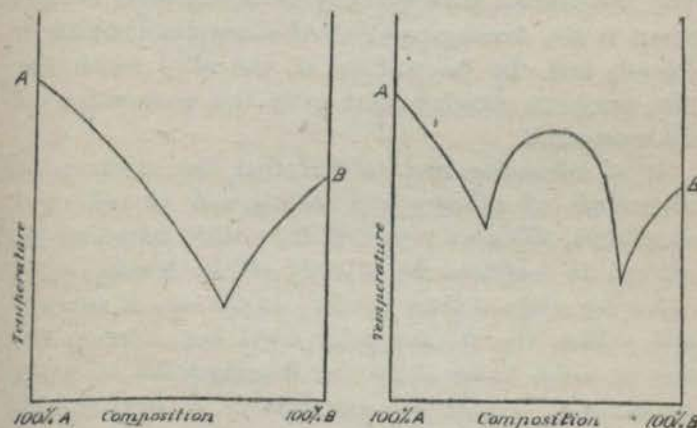
FIG. 1a.   FIG. 1b.

the barometer, and horizontal distances represent intervals of time. The curve traced on the card shows the way in which the height of the barometer has varied during the past week.

If, now, we similarly represent the way in which the freezing-point of an alloy varies with its composition, we should obtain, in many cases at least, a curve in two branches, as shown in Fig. 1a. Careful investigation has shown that these are the cases in which chemical combination has not taken place. The solid

which separates out when the fused alloy begins to solidify is either pure A or pure B, never a compound of the two metals.

In the cases where the two metals do form a compound, the curve showing the variation of freezing-point with composition is of a different character; there is then an intermediate branch of the freezing-point curve, shaped more or less like a camel's hump (see Fig. 1b). The temperature corresponding to the summit of the hump is the freezing-point of the compound which is formed, and the composition of the alloy which has this maximum freezing-point gives the composition of the compound.

It is interesting now to find that the existence of compounds of mercury and sodium, and of gold and aluminium, which we suspected from their behaviour on mixing, is confirmed by a study of the freezing-point curves for alloys of these metals. In the case of mercury and sodium the freezing-point curve has a hump the top of which is far above the freezing-point of either constituent, so that the existence of a compound is here proved very definitely.

The freezing-point curve for alloys of gold and aluminium has actually two separate humps, showing that these metals combine to form two compounds with different proportions of the constituents. One of the humps corresponds to the formation of the beautiful purple alloy already referred to, and it is very remarkable that this compound, containing 20 per cent. of aluminium, should melt at the same temperature as pure gold.

Another method of investigating the nature of alloys which has recently been employed with success is the

study of their structure with the aid of the microscope. If a section of an alloy is polished, treated with a little acid or other corrosive liquid, so as to bring out the details on the surface, and put under the microscope, one can observe an outline of crystalline structure which cannot be detected by the unaided eye. Those who have experience in this sort of investigation can actually distinguish the various kinds of crystals which have separated while the alloy was passing from the fused to the solid condition.

CHAPTER VIII

ACIDS AND ALKALIS

OF the various classes into which chemical compounds may be divided, acids form one of the largest and most important. They get their name from the sour taste which is supposed to characterise them, but this characteristic is by no means universal. From the chemist's point of view, all acids are similar in that they contain the element hydrogen, this hydrogen being replaceable by a metal. In many cases we can actually follow the replacement of the hydrogen in an acid by a metal; as, for example, when a few pieces of magnesium ribbon, iron wire, or granulated zinc are put in hydrochloric acid—"spirits of salt," as the druggist may call it. The acid and the metal attack each other, the latter disappears gradually and turns out the hydrogen, which comes bubbling off as a gas. What takes place might be expressed as follows:—metal acid→a salt+ hydrogen, the salt left in solution being magnesium chloride, iron chloride, or zinc chloride, according as magnesium, iron, or zinc was the metal taken. The corrosive acid is, in a sense, destroyed by the metal, and the plumber's description of zinc chloride as "killed spirits of salt" is therefore quite to the point.

The behaviour of acids in attacking or corroding metals is very general, and even domestic illustrations are available. Vinegar is a household article, but it is well to

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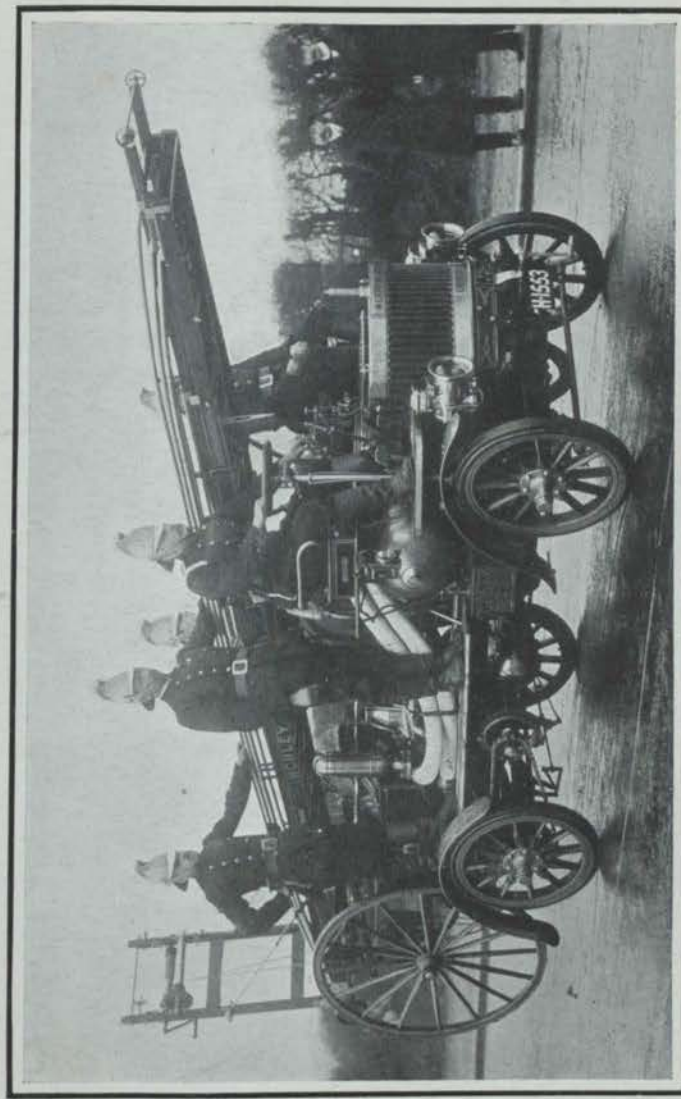
Merryweather & Sons, Ltd.

A CHEMICAL FIRE-ENGINE

In such an engine the pressure required to throw water on a burning building is obtained by mixing a carbonate and an acid, and so generating carbon dioxide. A tank for holding the carbonate solution is seen in the illustration, underneath the driver's seat. The usefulness of such an engine is restricted to the early stages of an outbreak.

sharp-pointed instrument, then on exposure to the vapour of hydrofluoric acid the glass is eaten away at the places where the wax has been removed. In this way the design traced upon the wax is reproduced on the glass, the surface, however, being deadened where the acid vapour has acted. If it is desired to etch without deadening the surface, the glass is immersed in a *solution* of hydrofluoric acid; this treatment leaves the glass polished and clear even where it has been etched.

The process of etching on glass is invaluable to the maker of scientific instruments, for it is frequently desirable to have figures marked on glass apparatus itself rather than on any scale attached to the apparatus. An "ink" is actually sold containing the ingredients necessary to produce hydrofluoric acid, and mere writing with this on a piece of glass apparatus is sufficient to leave an impression.

The constituent of glass attacked by hydrofluoric acid is silica. This is the oxide of the element silicon, and forms a very large proportion of the rocks in the earth's crust. Sand, for example, is impure silica, and the behaviour of hydrofluoric acid towards silica is well illustrated by allowing it to act on powdered sand in a leaden vessel. The sand gradually disappears, because the silicon in it forms a gaseous compound with the fluorine contained in the hydrofluoric acid. It is difficult to realise that the essential constituent of sand may be converted into a vapour, but that is what is effected by the action of the hydrofluoric acid.

Bearing in mind this corrosive action of hydrofluoric acid on glass, we see that it would be inadvisable to keep a solution of the acid in any glass vessel; as a matter of fact, it is usually sold in gutta-percha bottles.

The more powerful acids have a destructive and corrosive action not only on metals, but on many other substances also, notably on organic materials. The most outstanding in this respect is sulphuric acid or oil of vitriol, an innocent enough looking liquid, which, however, is extraordinarily destructive of animal and vegetable tissue, and requires very careful handling. If a drop of it gets on the skin and is not at once washed off, a very painful wound is produced. Occasional newspaper reports show that there are people who regard vitriol throwing as a proper way of settling old scores, but from what has been said it will be understood that it is a diabolical proceeding, and is very rightly scheduled as a crime. The destructive action of sulphuric acid on vegetable tissue is seen when a drop falls on wood. The latter turns black and has a charred appearance, just as if it had been burned.

Sulphuric acid is characterised by an extraordinary fondness for water. If cold sulphuric acid is added to cold water in a glass vessel, the warmth of their meeting is quite remarkable, and the vessel becomes too hot to hold. Further, if a dish containing a little sulphuric acid is left exposed to the air, the bulk of the liquid gradually increases, and if left long enough the dish would overflow, the reason being that the sulphuric acid absorbs from the air as much moisture as possible, and so becomes diluted. The affinity of sulphuric acid for water is much utilised by chemists in order to render gases absolutely free from moisture. A current of hydrogen which is being evolved by the action of a metal on hydrochloric acid comes off fully charged with water vapour, but if it is made to bubble through sulphuric acid, the water molecules are seized by the acid and the hydrogen is obtained dry. So

thorough is the scrutiny that scarce a single water molecule escapes.

One property characteristic of acids generally is their power to make carbonates effervesce. Here again domestic resources will be sufficient to supply us with an illustration, for most houses can furnish vinegar and washing-soda. As has been said already, vinegar contains a certain proportion of acetic acid, and washing-soda is nothing else than carbonate of soda. When, therefore, we pour a little vinegar on washing-soda we bring together an acid and a carbonate, and the result is the usual one, namely, effervescence due to the liberation of carbon dioxide.

This production of gas which occurs when an acid and a carbonate are brought together is applied very ingeniously in the chemical fire-engine. The essential parts of this engine are a large closed tank, charged with a solution of bicarbonate of soda, and, inside the tank, a leaden jar containing sulphuric acid. At the proper moment, the acid is tipped into the soda solution, and the carbon dioxide which is generated exerts a pressure sufficient to force water a considerable distance or height. The advantage of this fire-engine is obviously that the chemical forces may be brought into play instantaneously; there is no necessity to wait until the steam is up.

The action between an acid and a carbonate may be used in another way in the direct extinction of small fires. It is well known that combustion is not possible in an atmosphere of carbon dioxide, hence if we can surround a piece of burning wood, for example, with such an atmosphere, we may smother the fire. This is the object of the fire grenades which are to be seen hanging in factories and public buildings. They contain the substances necessary for the production of carbon dioxide, and these

are brought together by throwing down and breaking the glass vessel in which they are contained.

The reader is doubtless aware that much of our building material consists of limestone, the chief constituent of which is carbonate of lime. Bath stone and dolomite, for example, are affected by acids in exactly the same way as ordinary carbonates, and inasmuch as the air in our large towns contains some acid constituents, derived mostly from the sulphur in coal, calcareous or chalky stones like these are liable to disintegration. The Houses of Parliament and York Minster furnish examples of the way in which a calcareous building stone decays under the influence, amongst other factors, of the acid constituents of the atmosphere.

Bearing in mind another general characteristic of acids, we have a very simple clue to a conjuring trick which seems marvellous to the uninitiated. It is found that certain vegetable products assume one definite colour in the presence of acids, and another colour in the presence of alkalis, which, as we shall see presently, are the exact opposites of acids in many respects. A solution of litmus, for example, is turned red by acids, and blue by alkalis, while a solution of phenol phthalein is colourless in the presence of acids, and intensely red in the presence of alkalis. These substances are called indicators, and are of the greatest use in chemical work, because they enable the chemist so to neutralise any solution that it is neither acid nor alkaline. In the conjuring trick a series of glasses are rinsed out alternately with acid and alkali, and then water containing some phenol phthalein is poured from the first glass into the second, from the second into the third, and so on. What the spectator sees and marvels at is a

colourless liquid becoming suddenly red on being poured into an apparently empty glass, and the same red liquid becoming colourless again when poured into another also apparently empty glass.

As a class, alkalis are the opposite of acids, not only in regard to the indicators just mentioned, but in many other respects. The addition of an alkali to an acid destroys or neutralises the characteristic properties of the latter, and if the right quantity is added the solution then contains nothing but a salt—a kind of neutral substance which does not exhibit the behaviour either of an acid or of an alkali. The process of neutralisation may be represented in the following way: acid+alkali→a salt+water; from which it will be seen that the same sort of body is produced in this way as is formed by the action of an acid on a metal.

In certain circumstances an alkali may obviously be used as an antidote to an acid; if, for instance, a drop of an acid is allowed to fall on clothing, the production of a stain, and ultimately a hole, may be prevented by the immediate application of an alkali, for the salt which is thus formed is quite harmless so far as any action on the cloth is concerned, and may be washed out with water. Again, if any acid has been swallowed, an alkaline substance is the thing to take. In both cases, however, the right alkaline substance must be chosen, otherwise the cure may be worse than the disease; for certain alkalis have a very powerful action on animal and vegetable tissues, destroying such things as skin and paper. Two alkalis of this description are caustic soda and caustic potash, which, although extensively used in the manufacture of hard and soft soap respectively, are perhaps not so familiar to most people as
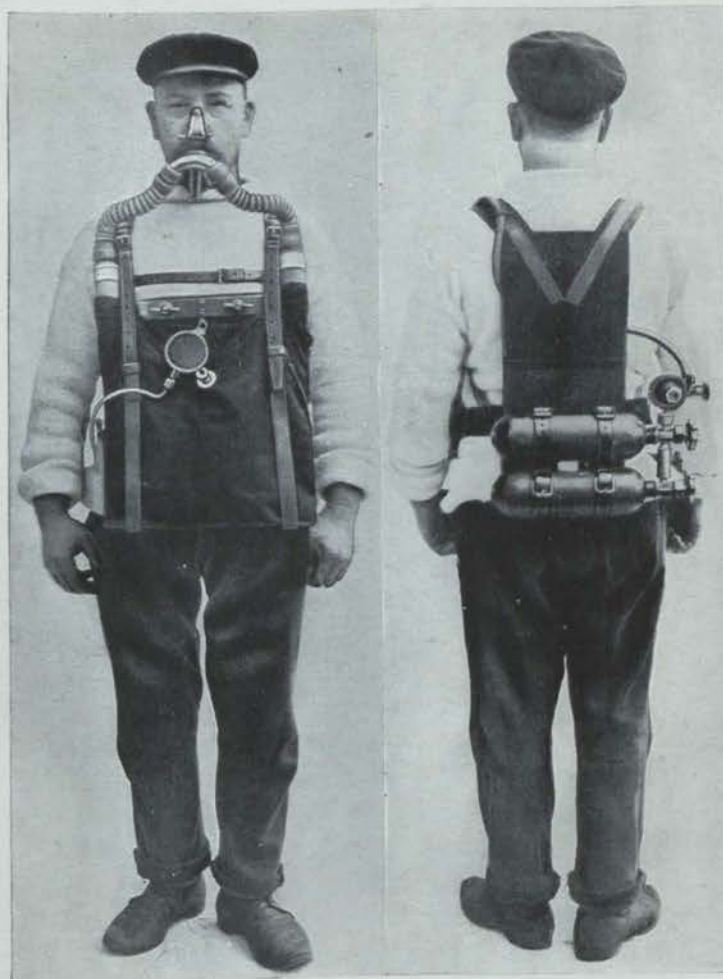
By permission of   Siebe, Gorman & Co.

HOW A MAN MAY BREATHE SAFELY IN A POISONOUS ATMOSPHERE

The mouth is connected with a breathing bag (carried on the chest) into which oxygen is delivered from steel bottles shown on the back of the right-hand figure. The bag contains also caustic soda to absorb the carbon dioxide exhaled from the lungs.

the so-called "mild" alkalis, carbonate of soda and carbonate of potash.

What has been said about an alkali acting as an antidote to an acid will enable the reader to understand that air containing carbon dioxide may be purified by passing over caustic soda. For carbon dioxide is an acid gas, and as such is readily absorbed by an alkali. Hence it is possible to devise an arrangement whereby a person may breathe in a closed space without suffering from accumulated carbon dioxide. It is only necessary that oxygen should be supplied to replace what is absorbed in the lungs, and that the exhaled air should be freed from carbon dioxide by contact with alkali before it is again inhaled. Both these conditions are fulfilled in the so-called oxygen respirating apparatus. This consists of a bag of air carried on the breast and connected by various tubes with (1) the mouth and nostrils, (2) a compartment filled with alkali, and (3) cylinders containing compressed oxygen and carried on the back. Any one provided with a portable apparatus of this description is independent of the surrounding atmosphere, and may therefore venture into places, entrance into which would ordinarily mean certain death. An equipment of this kind was used with success in the rescue work at Courrières, where, as the reader may remember, a very serious mine disaster occurred not very long ago.

But we must return to the question of the well-known alkalis. Solutions of these substances are soapy to the touch, and are extremely useful for cleaning purposes. One thing, however, which should not be cleaned with alkali is the modern aluminium ware used for cooking. Of the few metals which are dissolved by alkalis, aluminium is one.

Potash furnishes an interesting illustration of a useful substance coming from unlikely sources, of which two may be mentioned. Wood contains a certain proportion of potash, absorbed from the soil by way of food, and in countries which are well timbered potash is extracted from wood ashes, in which there may be as much as 10 per cent. of the alkali. Its very name is derived from the fact that the wood *ashes* are dissolved in water and the solution is evaporated down in iron *pots*.

Another and still more strange source from which potash is derived is the fatty matter in the fleece of sheep. This "suint," as it is called, contains quite an appreciable amount of the potassium salt of an organic acid, and when this is extracted, evaporated, and strongly heated, potash is left behind.

Besides the mild and caustic alkalis which have just been described, there is what is known as the "volatile alkali"—ammonia. Although this substance is a gas composed of nitrogen and hydrogen, it is an alkali just as much as caustic potash or washing-soda. It neutralises acids and exerts the same effects as other alkalis on litmus or phenol phthalein.

One of the most remarkable properties of ammonia gas is its extreme solubility in water. If a flask quite full of the gas is uncorked with the mouth under water, the latter will rush in and occupy the whole of the flask just as if there had been nothing there at all. Measurements have been made of the solubility, and it has been found that one cubic inch of water will absorb at the ordinary temperature as much as 700 cubic inches of ammonia gas. The solution so obtained may therefore be regarded as a convenient and compact form of ammonia, and it is this which is supplied to us when we ask for ammonia at

the shops. The liquid we buy contains a large proportion of water, but it would clearly be impracticable to buy and sell ammonia in the pure gaseous state.

This convenient way of handling a substance in solution instead of in the pure, undiluted state is employed also in the case of some of the acids. Oil of vitriol, to be sure, is almost pure sulphuric acid, but "aqua fortis" is only a solution of nitric acid, and "spirits of salt," as a rule, does not contain more than one-third of its weight of hydrogen chloride, which is itself a gas.

Ammonia, as an alkali, has the power of neutralising acids, and an interesting experiment which shows that the process of neutralisation leads to the formation of an entirely new substance, a salt, is the following:—A glass cylinder is filled with ammonia gas, and closed with a glass plate; a similar cylinder is filled with hydrogen chloride, and the two are placed mouth to mouth with the glass plate between. If the glass plate is slipped out, the colourless alkaline gas in the one cylinder and the colourless acid gas in the other immediately rush upon each other, and a white, powdery substance, sal ammoniac, is produced. Here we have the interesting case of two gases uniting to form a solid, entirely different in character from the original reacting substances.

Lime is another alkaline body, of which enormous quantities are required in the arts and manufactures, and yet the majority of people know very little about its valuable properties. Lime is the oxide of the metal calcium, and is obtained by strongly heating carbonate of lime, which nature supplies in profuse measure and in such various forms as marble, limestone, and chalk. We may note that from the point of view of ultimate chemical

composition chalk is as good as marble; it is only the poor brother in the family.

By dropping a little acid on marble, limestone, or chalk, we can satisfy ourselves that they give an effervescence of carbon dioxide. As a matter of fact, carbonate of lime is just a neutral salt formed by the union of the alkaline lime and the acidic carbon dioxide. This salt, however, differs from other common salts, because when it is heated it gives off its acidic component, the carbon dioxide, while the lime remains behind. This chemical change is carried out on the large scale when limestone is strongly heated in lime-kilns; the process is termed "lime-burning." The reader must not suppose that lime burns in the sense that a piece of coal does; the term refers only to the strong heating to which the limestone is subjected. The product of lime-burning is called "quick" lime, but for a great many purposes, such as the preparation of building mortar, this must be converted into "slaked" lime by the action of water.

The slaking of lime is a beautiful example of the changes brought about by a simple chemical action; for if a little water is sprinkled on one of the hard lumps of quicklime obtained from a lime-kiln, some remarkable effects are observed. For a minute or two nothing is apparent, but presently steam rises from the lime, and if the observer touches the mass with his hand he will realise that much heat is being generated. The chemical forces at work are such that the hard lump of lime splits up and crumbles down to a soft powder, which is absolutely dry in spite of the added water. The secret of this striking phenomenon is that a new chemical compound has been formed; the water
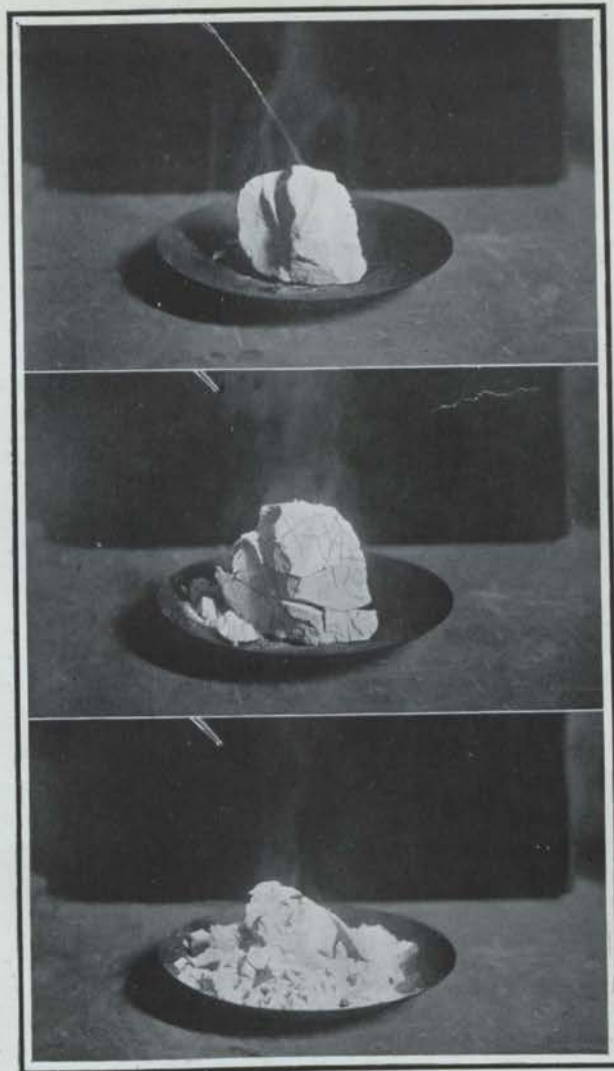
A SIMPLE CHEMICAL CHANGE

Cold water is poured on a hard lump of quicklime, which may begin to emit steam even before all the water has been added (see top illustration). The second illustration shows a further stage, at which quantities of steam are evolved and the lump is swelling and cracking in every direction. Finally it collapses into a heap of dry soft material—slaked lime.

has united with the quicklime to produce slaked lime : hence its disappearance.

The slaking of lime is accompanied by a considerable increase in bulk, and this fact has been occasionally applied in the blasting of coal in fiery mines, where the use of ordinary explosives is dangerous. A so-called "cartridge" of quicklime is pressed into a cavity drilled in the coal, and water is then forced in by a pump. The result is that the lime slakes, and the force of the expansion which accompanies the slaking process is such as to split the surrounding masses of coal—an excellent example this of the chemical energy latent even in the most commonplace materials. We do not usually associate anything very striking with such matter-of-fact substances as lime and water, and yet in their own quiet way they can together do the work for which the aid of a high explosive is generally requisitioned.

Lime is very extensively employed in the preparation of building mortar. For this purpose sand and slaked lime are used, and they are made up together with water until the mixture has a pasty consistency. The setting of mortar which occurs a few days after it has been made and applied is simply a process of drying by exposure to the atmosphere. But even after the mortar has set it undergoes a further change—it gradually hardens. This process of hardening is a chemical one, and is due to the slow absorption of carbon dioxide from the atmosphere.

It can easily be shown that lime has the power of absorbing carbon dioxide, for if lime water, which is simply a clear solution of slaked lime, is exposed to the air for some time, a white film of chalk collects on

the surface. So also the lime in mortar gradually absorbs carbon dioxide, becoming converted into the hard carbonate of lime. It will, of course, take a very long time for the hardening to be complete, but the examination of ancient mortar from Greek and Roman ruins has shown that in these cases the carbon dioxide absorbed from the atmosphere has been sufficient to convert all slaked lime into the carbonate. In fact, by pouring a little acid on a piece of old mortar any one can see that it contains a carbonate. Every stone or brick wall, therefore, in which mortar has been used must be pictured as the scene of a slow, imperceptible chemical change—a change which will probably go on as long as the wall lasts.

CHAPTER IX

NATURAL WATERS, AND WHAT THEY MAY CONTAIN

IT was a commonly-accepted idea among the ancients that fire, air, earth, and water were the four elements, the simplest forms which matter could assume. This conclusion was not reached as the result of experiments, of unsuccessful attempts to get at something more simple ; for the ancient philosophers never made any chemical experiments at all. So far as they concerned themselves with the science, they were what we might call "study-table chemists," and they thought it a much finer thing to make theories than to make experiments. To indulge in the latter practice was regarded as an occupation quite below the level of a philosopher. Now all this has changed, and in the last two centuries men have used the experimental method with infinite skill and patience to wring from Nature many of her most valuable secrets. Amongst other things, it has been discovered that water is not an element, as the ancients thought, but is capable of being broken down into yet simpler and more elementary substances, hydrogen and oxygen. So far, then, the ancients were wrong, but at the same time they were correct in regarding water as one of the first-rank substances in Nature, not only because it is so

abundant, but because it is so absolutely essential to life of all kinds.

From the chemist's point of view, water is an exceptionally interesting substance. For, in the first place, it furnishes an excellent example of the thorough-going alteration which matter may undergo when it takes part in chemical processes. Think of it. Hydrogen and oxygen, the elements which combine chemically to form water, are gaseous, invisible substances which we may mix without any obvious change taking place. In the mixture neither gas interferes with the other, and each retains its own characteristics and properties. But bring a lighted taper or match near the mouth of the vessel which contains the gases, and what is the result? The gases, which have up to this point been in peaceful contact, are stimulated to mortal combat, a loud explosion occurs, and the gases are destroyed, leaving behind only the sweat of battle in the shape of a few drops of water. One has seen a conjurer converting handkerchiefs into rabbits, and a pack of cards into thin air, but his feats are tricks after all, and the more genuine cause of wonder is to be found in the marvellous things which Nature has to show. Among these marvels are such changes as that by which hydrogen and oxygen are converted into water, a substance with absolutely new properties and characteristics.

Water, however, is interesting in other ways. Has the reader ever observed that ice floats in water? He may have seen it, but not perceived it. Probably the fact has just been accepted as a matter of course, without any inkling of its importance. But the truth is that water is somewhat eccentric in this respect. Generally speaking, when any substance is exposed to lower and
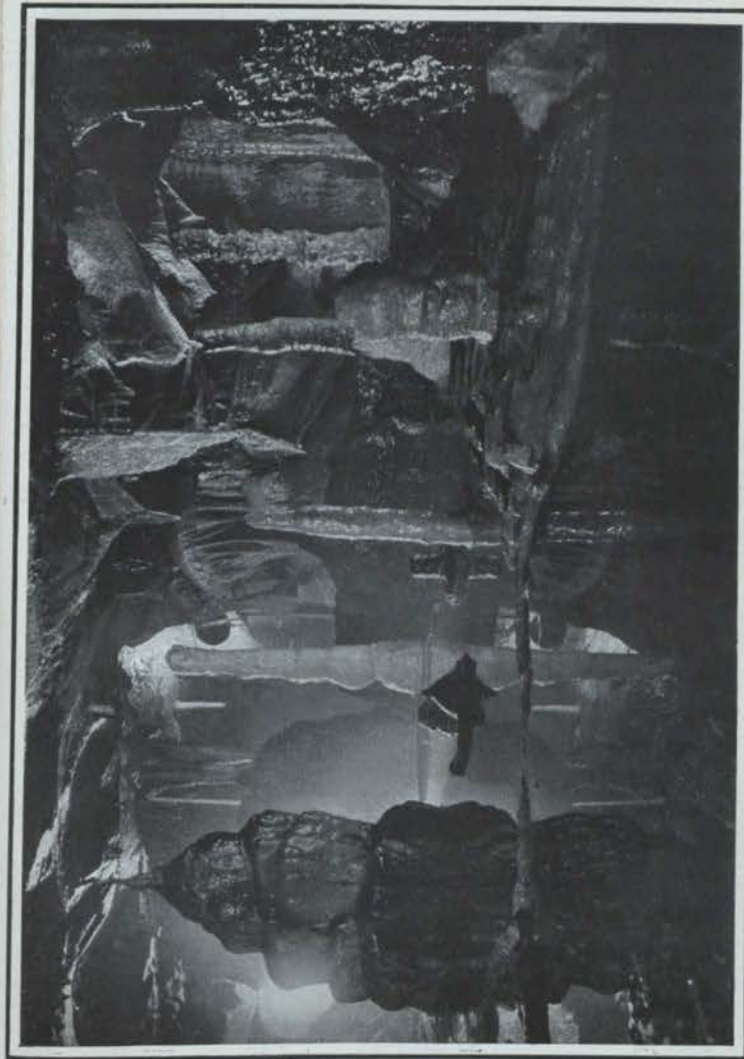
A WONDERFUL RESULT OF PROLONGED CHEMICAL ACTION

This striking array of stalactites and stalagmites is found in one of the caves at Cheddar, in Somerset. These icicle or pillar growths consist of chalk (carbonate of lime) extracted by percolating water from the limestone rocks above the cave.

Photo Frith

lower temperatures, and thereby passes from the condition of a gas to that of a liquid, and from the condition of a liquid to that of a solid, it shrinks and becomes more dense—that is, a given bulk of the substance weighs more and more. Water, however, is peculiar. As the temperature falls, it changes from steam to liquid water, and from liquid water to ice, but there is not throughout these changes a continuous increase of density. Water does indeed become more and more dense down to a certain point, 39° Fahrenheit, but here it reverses its behaviour; it expands and becomes lighter as it gets colder. So it comes about that ice is lighter than the water from which it freezes, and accordingly floats on the surface of the water. A little thought will show how significant this fact is in the economy of Nature, for the preservation of life in our lakes and seas during a severe winter is possible only because the surface ice protects the water underneath from freezing.

The same fact, however beneficial in its consequences in the realm of Nature, is liable to put us moderns sometimes to considerable inconvenience. We fit our houses with water-pipes, and it is only when the grip of winter has been unusually severe and our pipes are burst, that we learn that Nature will have her way in spite of our devices. Since ice occupies more space than the same weight of water, the pipes are burst when the water freezes, although it is not till the thaw comes that the damage is revealed to us.

Now the waters with which Nature supplies us, not always very regularly, according to our way of thinking, are never pure from the chemist's point of view. Many of them are fresh and quite suitable for drinking purposes, but even they contain substances which make them a little

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different from pure water. Thus it is well known that practically all natural waters contain in solution an appreciable amount of solid matter. A large part of this solid matter may be deposited when the water is boiled, and a glance inside the kitchen kettle will, in many cases at least, suffice to show that this is the case. The so-called "furring" of a kettle is simply due to the solid matter depositing when the water boils. The same thing happens in engine boilers, and the incrustation or scale that forms on the plates of the boiler is a cause of serious trouble. For it is very difficult to remove the scale without damaging the boiler, and so long as it is allowed to remain extra heat must be supplied to the boiler if the output of steam is to be maintained. The extra heat is required because the scale is a bad conductor of heat; it has been found that a boiler incrustation one quarter of an inch in thickness involves a consumption of fuel 50 per cent. greater than would be required if the boiler plates were clean.

Different natural waters contain quite different amounts of dissolved solid matter. Some, such as sea water, contain a great deal; others, such as rain water, contain very little. A good idea of the relative average amounts

Fig. 2.—Showing the relative amounts of solid matter dissolved in various waters.

of solid matter contained in fresh waters from various sources will be obtained by a glance at the accompanying diagram. The heights of the columns are proportional to the amounts of solid matter in the various waters. Deep-well waters contain on the average about half an ounce of solid matter for every thousand ounces of water, and the proportion of solid matter in the other fresh waters may be roughly gauged from the diagram. If the amount of solid in sea water were to be represented in the same way, a column eighty times as high as the highest in the diagram would have to be introduced. This obviously must be left to the imagination of the reader.

To the ordinary individual, waters are familiar as "hard" or "soft," and this classification gives a rough idea of the amount of solid dissolved in the water. Hard waters contain a large amount of solid; soft waters, which require but little soap to make a lather, are those which are comparatively free from dissolved solid.

The question next arises, what are the solids that we find in the various natural waters, and where do they come from? If sea water is left out of account for the present, it may be said that the main substances occurring in natural waters are sulphate and carbonate of lime (and magnesia, to a less extent). The proportion of these substances held in solution by a water depends on its history.

As a matter of fact, carbonate of lime (chalk) is not soluble in pure water, but only in water charged with carbon dioxide. If now the reader recollects that there is opportunity for rain to become charged with carbon dioxide from the atmosphere, he will understand that the water which falls on the surface of the earth and percolates through the soil and the rocks will have the power of

dissolving from these the carbonate of lime which they contain, as well as more soluble substances. When this water comes to the surface again in a well or spring it is found to be hard. But the simple process of boiling may render it comparatively soft, since in this operation the carbon dioxide with which the water is charged is boiled out, and the carbonate of lime, being no longer soluble, is deposited. That the " furring " in the aforementioned kitchen kettle is caused by a carbonate is shown by the effervescence which occurs on the addition of a little hydrochloric acid—"spirits of salt," as it is commonly called.

Apart from actual boiling, mere exposure of such a hard water to the air will deprive it of its carbon dioxide by evaporation, and in so far as the carbon dioxide is removed, in so far is a deposit of carbonate of lime produced. This is the way in which these curious excrescences known as stalactites and stalagmites are formed. Water which has percolated through some depth of soil and rock, and become hard in the process, may arrive at the roof of some underground cavern. The drops which there form are subject to evaporation, and part of the carbon dioxide with which they are charged is removed. This leads to the deposition of chalk, and a tiny contribution is made to the growth of the stalactite. A further quantity of carbon dioxide evaporates as the drops fall on the floor of the cavern, a further deposit of chalk is formed, and a tiny contribution is made to the growth of the stalagmite column.

Another very interesting natural phenomenon closely related to the formation of stalactites and stalagmites is the action of what are known as " petrifying springs." If a wicker basket, for example, is exposed to the action
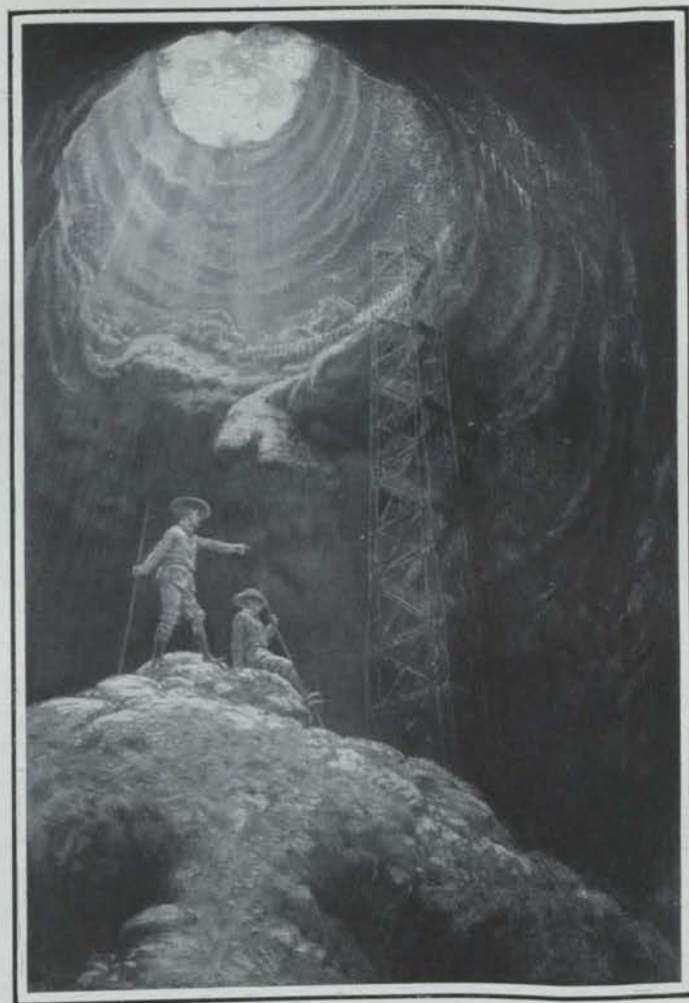
WHERE STALACTITES ABOUND

The entrance to the recently explored stalactite caverns at Padirac, in France.

of such a spring, it is gradually impregnated and coated with a stony-like substance. The explanation is that the water of a petrifying spring is hard, and contains a considerable quantity of carbonate of lime in solution. When the water comes to the surface it deposits carbonate of lime, because it loses by evaporation some of the carbon dioxide in virtue of which it has the power of dissolving that substance. This deposition of calcareous matter may take place on any objects, such as leaves or twigs, exposed to the play of the water, but it is thought by some people that certain bog-mosses or water-plants are specially effective in causing decomposition of the carbonic acid, and thereby inducing the deposition of a crust of carbonate of lime on their stems and branches.

Most of the water which has percolated through the soil and the rocks, and thereby collected a certain amount of solid matter, finds its way into streams and rivers and ultimately into lakes and seas. It will be obvious that the amount of solid matter in the sea and in lakes which have no outlet must be gradually increasing, since the supply of water is roughly balanced by continual evaporation from the surface. The rate of increase of the solids in sea water is very small because of the enormous quantity of water, but in the case of an inland lake in a hot climate, where there are heavy rains alternating with periods of rapid evaporation, the amount of dissolved solid is very high and increases fairly rapidly.

The Dead Sea is a case in point. Its waters are exceedingly brackish, and contain no less than about a quarter of their weight of solid matter, mostly sodium chloride (common salt) washed out from the neighbouring hills. The presence of so much solid makes the

water of the Dead Sea considerably heavier, bulk for bulk, than fresh water; it is so dense that eggs will float in it, and it will not allow the human body to sink. Ordinary sea water also is somewhat denser than fresh water, and its superior buoyancy is possibly known already to the reader by personal experience.

Much of the water which is distributed over the surface of the globe is quite unsuitable for the use of man. All brackish waters come under this category; and many an unfortunate sailor who has been cast adrift at sea has realised the bitter truth that there was " water everywhere, but not a drop to drink." Even from sea water, however, it is possible to obtain pure water by the process of distillation. The water is boiled in a suitable vessel, and the steam is led away through a cooled pipe, at the end of which the condensed water may be collected in a pure state. The solids dissolved in the sea water are not volatile, and are accordingly left behind in the boiler. At the present day much of the fresh water required on board our great ocean liners is obtained by subjecting sea water to distillation.

When one thinks of it, Nature herself is constantly making use of this process. The evaporation that continually takes place from the surface of the ocean is really a slow distillation; the water vapour condenses into clouds, and falls, some of it at least, as rain on the surface of the land. Rain is natural distilled water.

For many domestic and industrial purposes it is necessary to purify even ordinary fresh water, especially when it is hard. This process of "softening" water may be effected in several ways. It has already been stated that mere boiling will diminish the hardness of a water, but even water that has been boiled will not

at once give a lather with soap. Instead of giving an immediate lather, a curd is formed—evidence that the sulphate of lime still remaining in the water is being removed or precipitated by the soap. Only after this removal is complete will the soap form a lather.

The lime in a hard water may be removed also by the addition of sodium carbonate—washing-soda, as it is commonly called—or of lime water. If the water is to be obtained free from the deposit of chalk which both these substances produce, it must be allowed to stand in tanks, and then run off after the precipitate has settled to the bottom.

Occasionally the impurities in a water are of an organic nature, and these may be such as to render the water unsafe for drinking purposes. This organic matter may come from decomposing vegetable substances, or it may be of animal origin, and come from sewage or surface drainage. Sometimes our senses of taste and smell will warn us of this, but in the last resort we must depend on a chemical and bacteriological examination of the water. Such an examination will reveal, in the case of a polluted water, an unduly high amount of nitrogenous compounds, and possibly also large numbers of disease germs. To make the water safe, it must either be filtered through sand or unglazed porcelain, or it must be sterilised by boiling. All germs seem to find exposure to boiling water a somewhat trying experience, and few survive the ordeal. This will be clear from a special example which has been put on record.

A particular water of bad quality was found to contain 460,000 germs per cubic centimetre. Exposure to a temperature of 194° Fahrenheit for ten minutes reduced the number to twenty-six, and even these hardy individuals

had to give up when the water was boiled for ten minutes. As the palatable quality of a water depends on the quantity of dissolved gases, such as oxygen and carbon dioxide, the device of boiling it renders it somewhat insipid. If this is considered a disadvantage, it can be made more palatable by aeration, that is, by shaking it for a little with air.

Besides the various kinds of fresh water and the brackish water of our seas and inland lakes, Nature supplies us here and there with waters of a peculiar kind, distinguished not so much by the quantity of matter which they contain as by the fact that this matter is of an unusual kind. There are the so-called "mineral waters," which, in many cases at least, come from considerable depths below the surface, and are frequently hot on that account. Some of the well-known mineral waters are alkaline and contain carbonate of soda, notably those which are charged with extra large quantities of carbon dioxide, such as Apollinaris and Seltzer waters. Carbon dioxide has been forced into these waters under high pressure far below ground, and when they come to the surface and under the lower pressure which prevails there they cannot contain themselves, as it were, and so are marked by their characteristic effervescence.

Here and there one finds iron or chalybeate springs. Carbonate of iron, like carbonate of lime, is not soluble in pure water, but is taken up by water charged with carbon dioxide. Thus it is possible to obtain a water which holds in solution a considerable quantity of otherwise insoluble iron. When such a water comes to the surface, it loses some of the carbon dioxide with which it is charged, and the channel down which the water runs
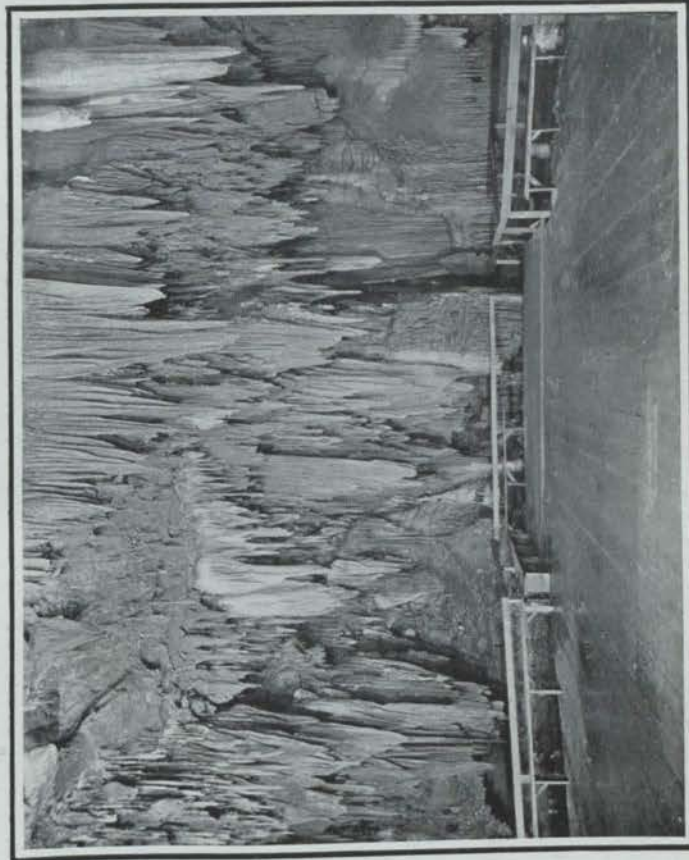
Photo A WONDERFUL CEILING *Copyright, 1880, by C. H. James*

An underground cavern (Luray in the United States), called the Ballroom, the roof of which has been fashioned by the continual drip of water charged with carbon dioxide and carrying chalk in solution.

away is tinged a yellowish or reddish colour, owing to the action of the oxygen in the air on the carbonate of iron deposited from the spring water.

Saline springs containing sulphate of magnesia and sulphate of soda are frequently found. The waters of these springs are bitter and act as purgatives. It is interesting to note that sulphate of magnesia is commonly known as Epsom salts, on account of the fact that it was found in a spring at Epsom by a London physician of the seventeenth century. There are springs of this class in other parts of England, but the best known spas at which bitter waters are available are Sedlitz, Friedrichshall, and Kissingen.

Other mineral waters which are peculiar are those which contain sulphur in some form or other; the springs at Harrogate and Strathpeffer are the best known of the kind in this country. Owing to the sulphuretted hydrogen and the sulphide of soda which these waters contain, they have an unpleasant taste and smell, but they are much valued for their medicinal properties. Those happy individuals, however, who have hitherto escaped the ills to which flesh is heir, will have no desire to cultivate a closer acquaintance with sulphur springs.

CHAPTER X

CHEMICAL CHANGES WHICH PRODUCE LIGHT AND HEAT

TO the popular mind a chemical laboratory is suggestive of explosions—reactions which result in the very evident production of light and heat, and sound into the bargain. But it is not necessary to visit a chemical laboratory in order to observe chemical changes which produce light and heat, for we are all chemists to some extent, at our own firesides. When we strike a match or light a fire we make a chemical experiment, but the "Red Flower" is so familiar to us that we miss the meaning and the marvel of it.

The making of fire is one of the oldest chemical achievements of the human race, and in our modern world the part played by combustion is of enormous importance. A little thought will show it is on those chemical changes which produce light and heat that we depend for a great many of our modern social conveniences. Where does the power come from which drives our motor cars? Why, from the combustion of petrol. Further, when a man stands on the footplate of a "Flying Scotchman," or in the engine-room of the *Mauretania*, he begins to understand what wonders in the way of locomotion we owe to the combustion of coal.

"Ah, yes!" some reader may say; "but we are going in for electricity nowadays, are we not? We are lighting

our streets with electric light instead of gas, and our railways are being electrified." That is all quite true, but even then we have not got rid of combustion as the source of nearly all our energy. Except where water-power is available, the introduction of electricity means simply that the combustion has been centralised. Instead of burning gas at each street lamp, we burn coal or gas at some central furnace, and use up the energy of combustion in driving a dynamo; instead of having a fire on each locomotive we have again a central furnace at the power-station. Hence the production of energy, whatever its form, still depends almost exclusively on the time-honoured process of combustion.

Now, although the various things which are burned for the purpose of producing light and heat are outwardly very different—gas, coal, paraffin oil, candles, wood, methylated spirits, petroleum, peat, &c.—the process of combustion is essentially the same in each case. The substances just mentioned are alike in containing carbon and hydrogen, either in the form of the elements themselves, or in the form of compounds, and the process of combustion is simply the chemical combination of these two elements with the oxygen of the atmosphere. Hence, if we understand what happens in the combustion of a candle, for example, we should be able to give an intelligent explanation of what takes place in a paraffin oil lamp or in a coal fire.

When the carbon and hydrogen in a candle combine with the oxygen of the atmosphere, the products are our old friends carbon dioxide and water. Carbon dioxide is an invisible gas, as the reader will remember, and the water formed in the flame is given off as an invisible vapour. The candle, therefore, gradually disappears as

it burns, leaving little or no trace behind. To the superficial observer the fact that the candle disappears and leaves nothing tangible in exchange might seem to throw doubt on the law of conservation of matter, according to which matter cannot be destroyed. But it will be admitted that the law would still be fulfilled if the disappearance of so much matter in one form were compensated by the production of an equivalent amount in another form; and the reader who has followed the argument of the foregoing chapters will recognise that some forms of matter are invisible.

The fact is, the invisible products of the combustion of a candle—that is, the carbon dioxide and the water vapour—weigh more than the candle. This is only natural, for just as it takes two to make a quarrel, so there are two parties to a combustion, namely, the combustible substance, in this case the candle, and the supporter of combustion, the oxygen from the air. As the combustion consists in a *combination* of the carbon and hydrogen of the candle with the oxygen of the air, the products are necessarily heavier than either the candle or the oxygen separately. The chemist can easily show that this is so by absorbing and weighing the carbon dioxide and water, but it will be sufficient for our purpose to show that each of these substances is present in the gases arising from a candle flame.

In order to show that carbon dioxide is one product of a candle flame, we may fix a small piece of candle on a wire, light the candle, and lower it into a glass jar, into which we have previously poured a little lime water. When the candle has been allowed to burn in the jar for ten or fifteen seconds, it is taken out, the jar is closed by a cork, and the contents are shaken. It will then be

seen that the lime water has become turbid, showing that the air left in the jar after the burning of the candle contained carbon dioxide.

The production of water in the flame of a burning candle may be very readily demonstrated with domestic apparatus. A tumbler of cold water, the colder the better, is carefully wiped on the outside, so that it is perfectly dry, and is then held a little above the candle flame. The outside of the tumbler at once becomes cloudy owing to the condensation of tiny drops of water.

The extent to which carbonaceous fuel is converted into carbon dioxide and water depends on the supply of the air which supports the combustion. If for any reason the supply of air is cut off, combustion ceases. Hence it comes that a candle cannot continue to burn in a closed space for more than a very short time. Not only does it exhaust the oxygen, but by its own combustion it produces substances which are unfavourable to a continuance of the process. In an atmosphere of carbon dioxide and water vapour no combustion is possible. On the other hand, the more air or oxygen we supply to the burning fuel, the more complete is the combustion.

The oldest method of supplying more air to burning fuel, and thereby securing more complete combustion, is the familiar one of making a draught. The difference between an oil-lamp flame with the chimney off, and the same flame with the chimney on, is due to the draught which the chimney makes; this draught means an inrush of air at the bottom of the chimney and a better supply of oxygen to the flame of the burning oil.

Perhaps the reader has tried sometimes to fan the flickering flame of a newly-lit fire by holding a newspaper in front of the upper part of the grate. The result of

this is that the chimney draught sucks the air right through the fuel, which is thereby fed more perfectly with the oxygen it so badly needs. If the newspaper were not there, the bulk of the air which is drawn up the chimney would come in through the upper part of the grate front, without passing through the fuel. The village blacksmith, too, when he makes his bellows roar, is in quest of more rapid combustion, and consequently more intense heat.

Imperfect combustion is responsible for the smoke that hangs like a pall over so many of our large cities. We in England insist on having the cheery but unscientific open fireplace, with the result that the fuel is imperfectly burned, and our chimneys pour a constant stream of smoke into the atmosphere. Smoke is charged not only with finely-divided carbon and soot, but also with oily and tarry vapour, whereas if there were perfect combustion nothing but invisible gases would leave the chimney. Just imagine what that would mean! Apart from the saving in fuel, we should never require the services of the chimney sweep, and we should be spared many of the grimy fogs which come, especially in London, to clog our breathing organs and to depress our spirits.

Why should it be so uneconomical and unscientific to burn coal in such open fireplaces as are common in England? The key to the answer lies in the fact that when coal is heated it first gives off a quantity of inflammable gas, and it is really this gas which burns when we put coal on a fire. But unfortunately in our open fires the fresh coal is put *on the top*, so that the gas which comes out of the coal as it gets warmed up is in a part of the fire where the supply of oxygen is limited. Not only has a considerable portion of the oxygen been used

A BIG BLAZE AT BAKU

At Baku in the south of Russia there are enormous natural stores of petroleum and when they are tapped the petroleum gushes up with extraordinary force. Occasionally one of these oil fountains catches fire and the result, as shown in the illustration, is a column of fire 200–300 feet high, surmounted by a huge cloud of smoke.

up in the combustion of the glowing fuel at the bottom of the grate, but the carbon dioxide which is produced there, and which ascends through the freshly-added fuel, makes it impossible to get perfect combustion of the latter. Hence it comes that quite a respectable fraction of our best household coal simply goes up the chimney unburnt, to become subsequently a nuisance to ourselves and our neighbours.

The abolition of smoke is a consummation devoutly to be hoped for, and considerable advance has already been made in that direction. Improvement has been effected chiefly in the diminution of smoke emitted from factory chimneys. For this we are indebted, partly at least, to the introduction of mechanical stokers, which feed coal into factory furnaces so that the fresh fuel is put where it has an excellent supply of oxygen. The mechanical stoker subsequently moves the coal on to other and hotter parts of the furnace, and it has the further advantage that it obviates the necessity of opening the furnace doors—an operation which involves the admission of a draught of cold air.

Appliances have been devised for securing more perfect combustion in house fires by introducing the coal from below, but none of these have come into general use. The adoption of such a plan would involve the reconstruction of all our fireplaces.

Another method of getting rid of the smoke nuisance is to subject the coal to destructive heating in a gas-works, and to use the gas so obtained for heating purposes instead of coal. This is the plan that will probably be adopted in the long run. A gas stove is, however, much less fascinating than a coal fire; sentiment clings round the old fireside, and the institution will die hard.

PRODUCTION OF LIGHT AND HEAT

When gas (or a candle) burns in the air, the supply of oxygen is not sufficient for complete combustion of the carbon and the hydrogen, except in the outermost envelope of the flame, and the fact that we get any light at all from an ordinary gas or candle flame is due to a host of unburnt particles of carbon in the interior. These particles are raised to a white heat by the flame, and so make it luminous. That the ordinary gas or candle flame contains particles of carbon may be very easily shown by holding a cold surface just into the top of the flame, when a deposit of soot (that is, carbon in a finely divided form) is obtained.

FIG. 3.—A Bunsen Burner.

When the supply of air to a gas flame is increased by mixing the gas with air just before it reaches the actual place where it is burned, then the combustion is more complete, the flame is hotter and no longer luminous. The particles of carbon which ordinarily make the flame luminous are now all converted into carbon dioxide, even in the interior of the flame, by the extra oxygen supplied. This is the principle of the well-known Bunsen burner, which finds application now, not only in the laboratory but in our houses, on incandescent burners and gas stoves.

A simple Bunsen burner is shown in the accompanying diagram. The current of gas which rushes out at the central nozzle sucks in air through the surrounding holes at the bottom of the burner, while the mixture of air and gas ascends, and is burned at the top of the tube.
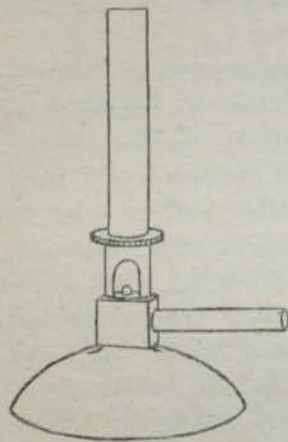
PRODUCTION OF LIGHT AND HEAT

The flame is very hot, gives out almost no light, and if a cold surface is put into the flame, no soot is deposited. This kind of flame is therefore especially suitable for heating and cooking purposes, for blackening of the utensils is avoided. The part played by the air in such a burner can be very simply demonstrated. If the burner is lighted and the observer puts his fingers over the air inlet holes at the bottom of the tube, the flame, instead of giving practically no light, becomes luminous at once.

If the reader will take the trouble, this little experiment may be carried out with an ordinary incandescent burner. The air inlet holes are easily discovered, and if the burner is lit on some occasion when the mantle has been removed, the effect of letting in or shutting off the extra supply of air is very evident.

It has been already stated that an ordinary gas or candle flame is luminous because it contains particles of unburnt carbon which are raised to incandescence, and so emit light. If this is so, then we may expect that if we take a non-luminous flame like that of a Bunsen burner, and introduce into it some solid substance which can stand a very high temperature without melting, this flame will become a source of light. This is exactly the principle which has been applied in our modern incandescent burners. As has just been pointed out, the flame of an incandescent burner, apart from the mantle, is quite without luminosity, and the mantle is simply an infusible substance which is raised to incandescence by the heat of the flame.

A similar device used to be much in vogue for the exhibition of lantern slides—in the so-called lime-light. By allowing a very hot flame to play on a little lump of

lime, the latter is raised to a white heat, and emits a very powerful light.

In an electric glow lamp the light proceeds from a carbon filament raised to incandescence, but in this case the source of heat is an electric current, not a flame of burning gas. The electric glow lamp furnishes at the same time an interesting illustration of what has been said about there being two parties to a combustion. The filament in the lamp is made of carbon; there it is, glowing brightly, and yet apparently it suffers no wastage; it appears to burn, but it is not consumed. Why is this? Because the other party to a combustion, the oxygen, is absent on this occasion. The lamp has been rendered vacuous during the process of manufacture—that is, the air which it contained was removed—and so no combustion is possible. The tender little filament is protected by its glass cage from the hordes of oxygen molecules that would be only too ready to fall upon it if they had the chance.

It must not be supposed that the term combustion is to be applied exclusively to those cases where a carbonaceous fuel is burned. Many other substances combine readily with the oxygen of the air, and the chemical change involved in this combination produces light and heat.

Everybody who has seen an underground cavern illuminated by the burning of magnesium ribbon knows what an intense light is emitted in this process; and the process is essentially the same as the burning of a piece of charcoal. When charcoal is burned, oxide of carbon (carbon dioxide) is produced; when magnesium is burned, oxide of magnesium (magnesia) is produced.

The burning of magnesium illustrates very excellently

one or two points which have been mentioned already. In the first place, it shows what fundamental changes those substances undergo which take part in a chemical action; we start with a piece of metallic ribbon and the invisible air, and there is left behind a soft, white, powdery mass of magnesia. In the second place, the intense light observed when magnesium burns is due to the presence of little particles of infusible magnesia, which are rendered incandescent by the great heat of the chemical action.

Again, it is easy to show that just as the carbon dioxide and water produced by the combustion of a candle are heavier than the candle, so the white powder produced by burning a piece of magnesium ribbon weighs more than the ribbon. The discovery that the products of combustion are heavier than the combustible substance was really a very important one in the history of chemistry; for up to about 120 years ago it was generally supposed that a combustible substance contained something called phlogiston, which came out of the substance when it was burned. It was the famous French chemist Lavoisier who finally overthrew this theory, and emphasised the fact that instead of losing anything when it was burned, a combustible substance actually became heavier.

The meaning of the term "combustion" has been extended in the foregoing paragraphs so that the burning of coal and the burning of magnesium are brought under the same category. We may now extend the term still further to cover many chemical processes, which, although they do not very obviously produce light and heat, yet depend essentially on the same chemical phenomenon, namely, the combination of some substance with the oxygen of the atmosphere. These are cases of slow com-

bustion, and may be referred to generally as oxidation processes.

One of these processes, which, without producing any light, produces a good deal of heat, is the respiration of animals. What goes on in our bodies, through the agency of the lungs and the blood, is neither more nor less than a combustion, in the course of which the carbon compounds in the body, the fat, &c., are burned to carbon dioxide and water.

It is very easy to show that air expired from the lungs is heavily charged with carbon dioxide. Ordinary fresh air contains so little of this gas that a pint bottle full produces no milkiness when shaken up with a little lime water. But if the air which we breathe or blow out from our lungs is made to bubble through a little lime water, a very marked turbidity appears. Exact measurements have shown that whereas fresh air contains 3 to 4 parts by volume of carbon dioxide in 10,000, the air which issues from the lungs is charged to the extent of 400 to 450 parts carbon dioxide in 10,000. A little carbon dioxide is also given off through the skin, and it is computed that the total carbon dioxide evolved by the lungs and skin is about three-quarters of a cubic foot per hour. An ordinary gas burner produces about one and a half cubic feet of carbon dioxide in the same time, so that as far as the contamination of the air in a room is concerned, a gas burner is equal to two men.

Another change which comes under the same category as respiration, and which we might describe as a slow combustion, is the rusting of iron. Rusting is the combination of the metal with the oxygen of the air, and is thus exactly parallel to the burning of magnesium ribbon, except that it takes so much longer. The total heat evolved

in the process of rusting is not any less than it would be if the oxidation took place rapidly; it is only spread over such a long time that the evolution of heat at any particular moment is not noticeable.

Rusting is an example of spontaneous oxidation. It is not necessary to strike a match to start the process; rusting is only too ready, as we often know to our cost, to start on its own account. It is, indeed, essential that carbon dioxide and moisture should be present before rusting can take place, but these substances are both present to some extent in ordinary air, and the only way to keep iron from rusting is either to paint it, or to plate it with some other metal which is less ready to hold traffic with the air. Metals which are commonly used for this purpose are zinc, tin, and nickel. Galvanised iron and tinplate, which are manufactured in such large quantities, are simply iron which has been coated with zinc and tin respectively in order to protect it from corrosion. Every cyclist knows that so long as the nickel-plating of his handle-bars is intact there is very little tendency to tarnish, but that wherever the protective layer of nickel has been removed rust is not long in putting in an appearance.

CHAPTER XI

HOW FIRE IS MADE

IN the forgoing chapter it has been said that the making of fire is one of the oldest achievements of the human race. So old is it that there is no trustworthy evidence of any tribe which was ignorant of fire and its uses. There is nothing impossible in the supposition that there may have been such a tribe, but we have no proof. It should be remembered that man must have been familiar with fire on the large scale, even before he knew how to produce it himself; for we may presume that lightning and volcanic eruptions have always been features of life on the earth. Apart, however, from these exceptional manifestations, the primeval man must one day have discovered how to produce fire with the ordinary means at his disposal. The reader can imagine the amazement and delight, perhaps the alarm, of the first human being who succeeded in making fire for himself, and of those who afterwards made an independent discovery of the same thing. How it was actually done we can only conjecture, but we shall probably get fairly near the true answer if we can discover the methods of making fire which have been practised among primitive tribes even in comparatively recent times.

The ancients solved the problem of the original discovery of fire in a manner that has the merit of simplicity, even if it does not commend itself to the scientific mind of this

twentieth century. They supposed that fire had been stolen from heaven by Prometheus, who carried it off in a hollow tube; while, according to another account, he obtained it by holding a rod close to the sun. "A fairy story," some reader will say; and certainly one feels that the ancients, having looked at the difficulty, simply told a pretty tale and passed by on the other side.

All the chemical methods of producing fire, those, namely, which are now employed, are comparatively new, and up till about a century ago, only what we might call mechanical methods were available. Friction, for example, as everybody knows, produces heat, and one of the oldest ways of producing fire consisted in rubbing one stick against another until the wood inflamed. In some primitive tribes a stick was pushed backwards and forwards in a groove in a piece of wood; sometimes the one stick was used as a drill, and was rapidly rotated in a hole cut out of a fixed block. Evidence of the extraordinary dexterity with which these fire-sticks can be manipulated by savages is found in Captain Cook's description of the production of fire among some Australian tribes. He writes: "To produce fire they take two pieces of dry, soft wood, one a stick about 8 to 9 inches long, the other flat; the stick they shape into an obtuse point at one end, and pressing it upon the other, turn it nimbly by holding it between both their hands, as we do a chocolate mill, often shifting their hands up and then moving them down upon it, to increase the pressure as much as possible. By this method they get fire in less than two minutes, and from the smallest spark they increase it with great speed and dexterity." How we should grumble nowadays if we had to work hard for two minutes before getting a light! The chances are that the savage would beat the civilised man

at this game, and we moderns would probably require much more than two minutes to produce fire with these primitive appliances.

Another elementary way of making fire is to strike flint and steel together, allowing the sparks which are thrown off to fall among some easily-ignited material such as tinder. This latter substance consists of the element carbon in a finely-divided condition, and is obtained by charring fragments of linen. The tinder, although it is not actually inflamed by a spark, glows with sufficient heat to ignite sulphur-tipped wooden splints—"spunks," as they used to be called.

The flint and steel method of obtaining fire for domestic and other purposes was known to the Greeks and Romans, and was the one commonly in use in most countries up to the end of the eighteenth century. Even the inhabitants of such an out-of-the-way place as Tierra del Fuego have for centuries been accustomed to get fire in this way, only instead of steel they used pyrites— a mineral compound of iron and sulphur. It appears, in fact, that this mineral got its name from the use which was originally made of it in this way. Both flint and pyrites received the name of "fire-stone" (Greek πυριτης).

Another curious device which may be employed in making fire depends on the fact that if air is suddenly compressed, heat is produced. A simple instrument based on this principle and known as a "fire-syringe" or a "pneumatic tinder-box" is to be found in any list of scientific apparatus. It consists of a glass tube fitted at both ends with brass caps, through one of which moves a rod with piston attached. If a piece of tinder is put in the bottom end of the tube, and the

air in the tube is compressed by rapidly pushing down the piston, the tinder ignites. A similar apparatus, with a tube, however, of hard wood or ivory, has actually been found in use in Burmah.

Among the mechanical methods of producing fire we must not forget to reckon the lens or burning-glass, by which the rays of the sun may be focussed at a point. Combustible material which will not ignite when merely exposed to the sun will at once take fire if brought to the point at which the heat is thus concentrated. The burning-lens was known to the Greeks, and is commonly used by the Chinese. Some readers may remember the story according to which Archimedes, during the siege of Syracuse, set the Roman fleet on fire with the aid of burning-glasses. It is rather a "tall" story, not confirmed by the historians, but it serves at least to show that the use of the lens in the production of fire was familiar to the ancient world.

All the foregoing methods of obtaining fire are physical or mechanical methods, and it was not till 1805 that an attempt was made to employ a chemical method for the purpose. In that year a certain Frenchman showed that splints of wood coated with sulphur and tipped with a mixture of chlorate of potash and sugar would ignite when brought into contact with sulphuric acid—oil of vitriol, as it is commonly called. The chemical action which takes place spontaneously between the acid, the chlorate of potash, and the sugar is accompanied by the evolution of so much heat that ignition takes place, the sulphur first and then the wood bursting into flame.

The first really practical lucifer matches were made in England about 1827. They consisted of wooden splints or sticks of cardboard coated with sulphur, and

tipped with a mixture of sulphide of antimony, chlorate of potash, and gum. They were ignited by being drawn between two folds of glass paper tightly pressed together, and a piece of this paper was supplied with each box. These matches required much pressure for ignition, and as they were liable to throw off sparks, they required careful handling. A shilling per box of eighty-four was the price, and it is instructive to compare this figure with the cost nowadays, when we can get as many as four hundred for a penny.

The great modern development of the match industry began with the introduction of phosphorus. This element was discovered and its properties were known long before, but its application in the manufacture of matches began in the thirties of last century.

Phosphorus in the ordinary condition is a wax-like substance which melts at 111° Fahrenheit, and takes fire very readily just above its melting-point. It is, in fact, this property of very ready ignition which makes phosphorus valuable in the manufacture of matches. The slightest friction will cause it to catch fire, and hence if a splint of wood tipped with some mixture containing phosphorus is rubbed against a rough surface—for example, sand-paper—it will ignite immediately. The ignition is much facilitated by mixing the phosphorus with an oxidising agent, that is, a substance which contributes to the combustion of the phosphorus by supplying it with oxygen. Saltpetre, chlorate of potash, and red lead, which all contain a high percentage of oxygen, are the substances chiefly used for this purpose. In addition to these two essential constituents of a match-tipping mixture, namely, the phosphorus and the oxidising agent, there are also binding ingredients, generally glue,

colouring matters, such as ultramarine or vermilion, and gritty material, such as powdered glass or fine sand, the object of which is to increase the susceptibility of the mixture to friction.

In order that the splint might be sure to catch when the match was struck, it was at one time customary to dip it in sulphur before tipping with the phosphorus mixture. The combustion of the latter lasts only a moment; the sulphur, on the other hand, burns slowly, and allows a little more time and opportunity for the wood to catch. Sulphur-coated splints are out of date now, and are met with only in cheap matches of continental manufacture. Instead of sulphur, paraffin is frequently used; it acts similarly as a go-between for the explosive mixture at the tip and the wooden splint.

The use of ordinary phosphorus in matches has many disadvantages. Their dangers have been impressed on many of us by "The Dreadful Story of Harriet and the Matches," and their use has most certainly led to numerous fires. In addition to this objection, there is the fact that phosphorus is poisonous. Workers in match factories, who are exposed to the vapour of phosphorus, are liable to a painful and often incurable disease of the jaw-bone. In the earlier periods of the manufacture of phosphorus matches there was considerable mortality from this cause, but it has been found that when close attention is paid to ventilation and cleanliness the danger is exceedingly slight.

The objections to the use of ordinary phosphorus can, however, be met in another way. Curiously enough, phosphorus is an element which exists in two forms. Just as an actor may represent two different characters in the same play, so phosphorus is sometimes a pale yellow,

waxy solid, very poisonous and very easily inflamed; at other times it is a red powder, not poisonous, and much less readily ignited. Regarded superficially, these two substances are absolutely different, but they are really the same element in different garb, and chemists have found a way of changing yellow phosphorus into red, or red into yellow. This matter has already been discussed at length in Chapter V.

Soon after red phosphorus was discovered, it was suggested that the disadvantages of using the ordinary yellow phosphorus in matches might be avoided by substituting the red form, on account of its being non-poisonous and less readily inflamed. Attempts were accordingly made to tip matches with mixtures containing red phosphorus, but these were not very successful. A certain Swede, however, ultimately proposed that, instead of putting the red phosphorus at the end of the match, it might be put on the surface on which the match was to be rubbed. This idea was worked out with complete success, and has led to what are now known as "safety matches." These matches will not ignite with ordinary friction on a rough surface; they will strike only on the prepared surface on the box, consisting very generally of red phosphorus, gum, and powdered glass. In order still further to diminish risk of fire, the stems of safety matches are frequently soaked in some chemical, such as alum or magnesium sulphate, so that when the burning match is blown out the wood immediately ceases to glow. A splint of ordinary dry wood, on the other hand, will continue to glow for a little after it has ceased to burn. This the reader can easily verify for himself.

The number of matches manufactured nowadays is enormous. It is estimated that in England alone, 300

millions are turned out daily, and that for each million of matches about one pound of phosphorus is required. The forty or fifty tons of phosphorus annually used in England for tipping matches are obtained from bones, which contain a large proportion of phosphate of lime. The high rate at which matches are turned out has become possible only by the introduction of ingenious labour-saving machinery, and no one who has not been through a match factory can realise how much is done in this direction.

Another curious device for the production of fire was brought out by Döbereiner in 1823. The lamp known by his name is no longer used, but it was based on a very interesting principle, and therefore deserves consideration.

We have seen that hydrogen is a combustible gas, and if we bring a light close to a nozzle from which hydrogen is escaping, it will take fire; that is, the hydrogen combines with the oxygen of the air at a high temperature, forming water vapour. At ordinary temperatures, on the other hand, hydrogen and oxygen are generally indifferent to each other. There is, however, one substance which is able to promote the union of hydrogen and oxygen, even under these conditions, namely spongy platinum—that is, platinum in a very finely-divided condition. Platinum is usually a compact white metal, heavier than gold, but by special chemical treatment it can be obtained as a dark, porous powder, and in this condition it is extremely active. If instead of bringing a flame to the nozzle from which hydrogen is issuing, we hold a little spongy platinum in the gas, the metal begins to glow and presently the hydrogen catches fire.

A very pretty instance this of what is known as "catalytic" action, a term denoting the curious effect which

some substances have in promoting a chemical action without themselves being altered thereby. The platinum, for instance, which induces the hydrogen and oxygen to combine so readily, is found to be unchanged at the end, and this is the case also in other processes where finely-divided platinum behaves as a catalytic agent. Its action has evidently something to do with the very large surface which is exposed by the porous, finely-divided metal, but opinions differ as to the correct explanation. Some think that the gases condense in the surface of the platinum, and are thus brought into closer contact—the platinum surface acting as a sort of birdlime for the flying molecules; others consider that the platinum first lays hold of the oxygen molecules to form a compound, and then meekly delivers them over to the hydrogen, with the net result that water is formed, and the platinum is left as it was at the beginning, with nothing to show for its labour.

Although Döbereiner's lamp has gone out in more senses than one, there are some modern devices based on the same principle. Many incandescent burners used to be provided with a little piece of platinum above the jet, so that when the gas was turned on, it would light without the help of a match. This arrangement has gone out of use now, largely because the platinum rapidly deteriorates in efficiency and finally loses its power of igniting the gas.

Another piece of apparatus, based on the same principle, is a cigar-lighter which is sold at the present time. This consists of a small metal vessel provided with a cap; the vessel holds some volatile spirit, and attached to the cap there is a piece of very fine platinum wire. When this is held in the vapour of the spirit,

while air has access to the vessel, the spirit combines with the oxygen under the influence of the platinum, heat is produced, the platinum glows, and finally the spirit bursts into flame.

Reference has just been made to the very high catalytic power of platinum when it is in a finely-divided condition. Generally speaking, it may be said that finely-divided matter behaves differently in many respects from compact matter of the same kind. It is, for example, a consequence of the law of gravitation that solid particles in the air soon fall to the ground, but if they are infinitesimally small they may travel quite a long distance without coming to earth. Thus the beautiful sunsets seen in England in 1883 were attributed to the presence of very fine dust in the atmosphere, carried all the way from a volcanic eruption on the other side of the globe.

In regard also to combustion finely-divided substances have somewhat peculiar manners. Everybody would regard iron and lead as elements of the most staid and sober temperament; and yet it is possible to obtain these metals in a state of such fine division, that when they are thrown out of any vessel into the air, they take fire of their own accord. The finely-divided substance has relatively a much greater surface than the compact substance, and the rate of rusting or oxidation is thereby so much increased that incandescence is observed; the process of combustion, which is slow under ordinary conditions, becomes very rapid. The phenomenon might be described as "spontaneous combustion," but the reader should clearly understand that the chemical change which takes place when finely divided iron or lead take fire in air is exactly the same as when

they rust ; the only difference is that the latter change is spread over a much longer time.

There are other cases in which combustion appears to take place without any obvious cause, and to which the term "spontaneous" is applied. Stacks of hay occasionally take fire of their own accord, and heaps of cotton waste or rags impregnated with oil have been frequently found to exhibit a similar behaviour. But however "spontaneous" the occurrence may seem to be, there is in each case a sufficient reason for the combustion. In the first case the hay has been stacked while still moist, and in these circumstances fermentation sets in. Now fermentation is a chemical change of the constituents of the hay, promoted by the presence of minute organisms, and this change, like most chemical reactions, is accompanied by the evolution of heat. If the hay were lying out in the open, this heat would be dissipated at once, but in the inside of a stack it cannot escape so easily ; it accumulates more and more as the fermentation process goes on and ultimately the temperature rises so high that the hay takes fire.

The explanation is different in the case of the oily rags or cotton waste. Many oils are readily oxidised by the oxygen of the air, and when such oils are spread over the extensive surface of rags or waste the oxidation takes place very rapidly. The rags and waste being bad conductors, the heat generated in the oxidation is rapidly accumulated, and finally leads to the so-called " spontaneous combustion."

In both these cases the chemical change involved is a slow combustion at the beginning, and becomes rapid at the end only because the heat generated in the process has been unable to escape. With rising tempera-

ture a chemical change invariably becomes quicker and quicker, hence as the heat accumulates in the hay or the cotton waste, the chemical forces become more and more impetuous and ultimately lead to a general conflagration. The affair, in fact, resembles the accumulation of money at compound interest.

Haystacks are not the sort of thing that the ordinary individual can experiment with, but there is one very simple example of the way in which the heat effect accompanying a slow combustion may be accumulated. If iron filings are mixed with sawdust and a little water is added, then after a few hours steam will be seen to come off from the mixture. Now the heat evolved during rusting cannot be detected in ordinary circumstances, but in this little experiment the non-conducting sawdust allows the heat to accumulate until it is obvious to the senses.

There was another kind of spontaneous combustion in which people believed at one time, namely, the spontaneous combustion of human beings. It was supposed that a living human body might be consumed by fire spontaneously generated in the internal organs. In the *Philosophical Transactions of the Royal Society* for 1744, for example, one finds a communication to the following effect :—" About seventeen years ago, three noblemen, whose names for decency's sake I will not publish, drank by emulation strong liquors, and two of them died, scorched and suffocated by a flame forcing itself from the stomach." So widespread was the belief in the possible spontaneous combustion of human beings that the great chemist Liebig thought it worth while to deal with the question and to record his view that " while a fat dead body charged with alcohol may perhaps burn, a living

body in which the blood is circulating cannot take fire spontaneously." The story of this curious belief shows how easy it is, firstly, to make wrong observations, and, secondly, even when the facts have been correctly ascertained, to rush at the first explanation which suggests itself.

NATURE'S STORES OF FUEL

IT is all very well to be able to make fire, but our achievements in this direction would be of little use if Nature did not supply us liberally with combustible substances or fuels. So far as combination with oxygen and production of heat and light are concerned, a great many substances might be called fuels, but the name is generally restricted to those which contain the element carbon in some form, and which are obtained in large quantities on or under the surface of the earth. Some reference has already been made to these carbonaceous fuels, but much more remains to be said on this interesting topic. The process of combustion is perhaps the most fundamental chemical change with which we are acquainted, and to our modern world, with all its travel, industry, and social life, the production and maintenance of fire are almost as essential as air and water are to the human body.

In some cases the fuels supplied by Nature are available directly for man's use without any other than the simplest treatment. Wood and peat, for example, need only to be cut and dried before they are in condition for burning, while in the case of coal the only necessary preliminary is the cutting and raising to the surface.

These three fuels, wood, peat, and coal, represent three stages in the history of the vegetable world. Living

wood, apart from the large amount of water which it contains, consists chiefly of cellulose, a compound of the three elements, carbon, hydrogen, and oxygen. If the wood dies and is allowed to lie in the soil where it has grown, a remarkable series of chemical changes sets in. In many cases the fallen forests and jungles of the past have been submerged and then covered over with alluvial deposits of clay and sand, so that what was once a luxuriant vegetation on the surface is now buried many feet below.

Now when wood or any other vegetable matter containing cellulose is kept below water or in a moist soil, the relative proportions of the carbon, hydrogen, and oxygen which made up the cellulose begin to change. Decomposition and fermentation set in, the hydrogen is gradually eliminated in the form of marsh gas—a combustible compound of carbon and hydrogen—and the oxygen in the form of carbon dioxide. Any one who pokes a stick into a stagnant pool at the bottom of which vegetable matter is decomposing will observe bubbles of gas rising to the surface. These bubbles have been examined by chemists, and are found actually to contain carbon dioxide and marsh gas.

The result of these slow changes—extending over a long period—is that instead of cellulose there is left a carbonaceous mass containing a very much higher percentage of carbon than the original wood. If the decomposition has been going on for a very long time and at some depth below the surface, the product is a compact coal, containing relatively small quantities of hydrogen and oxygen. Vegetable matter of more recent date will not have been carbonised to the same extent, and will have reached the stage represented by brown coal or

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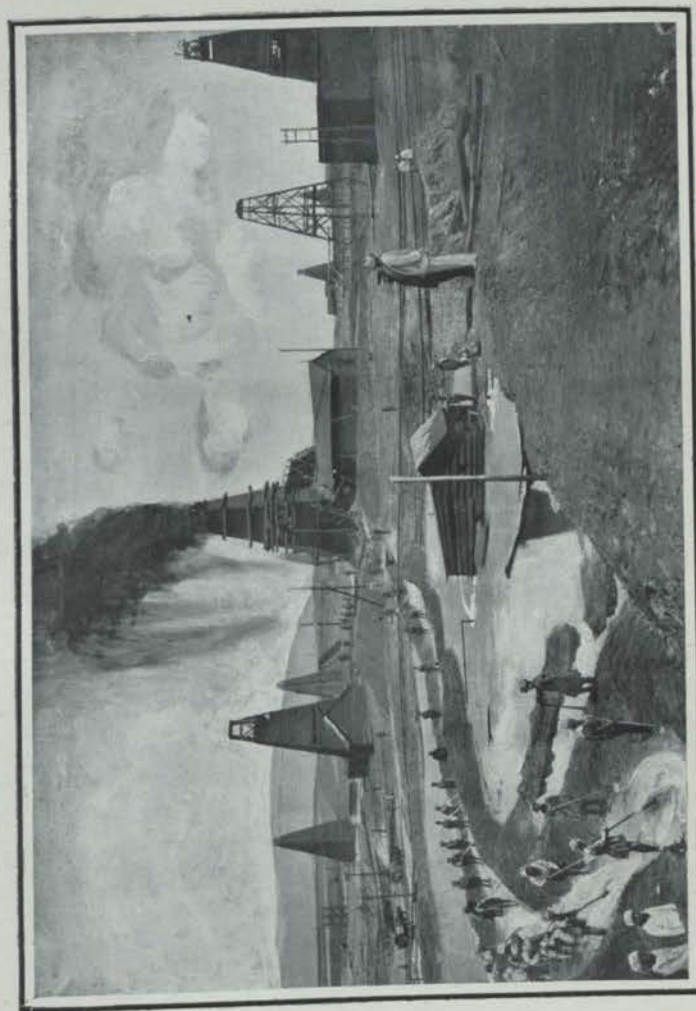
WHERE IT RAINS PETROLEUM

The illustration shows one of the oil-wells or "gushers" at Baku in full swing. The petroleum gushes up like a fountain and then falls into one of the ponds prepared to receive it.

lignite. Peat, again, is vegetable matter—chiefly moss—which has been undergoing decomposition and carbonisation for a very much shorter time, and which, being on the surface, has not been subjected to the same pressure as coal, and is therefore less compact.

A few figures will show how the amounts of hydrogen and oxygen diminish regularly as we pass from wood to a hard coal like anthracite. To make the figures comparable, the amount of carbon is put as equal to 100 in each case.

	Carbon.	Hydrogen.	Oxygen.
Wood	100	12	83
Peat	100	9	56
Lignite . . .	100	8	42
Bituminous coal . .	100	6	21
Anthracite . . .	100	3	2

Corresponding to the gradual alteration in composition, there is a change also in the way these fuels behave when they are burned. For a brightly blazing fire there is nothing like wood, the reason being that, when it is heated, quantities of inflammable gas are given off; hence wood catches fire much more easily than the other solid fuels, and when it has ignited it burns with a larger amount of flame, for flame is simply burning gas. The inflammable vapours given off from heated wood consist to a large extent of hydrocarbons—that is, compounds of carbon and hydrogen. Wood, therefore, which has undergone an age-long decay, and which has in the process lost the greater part of its hydrogen, will be able to yield little or no inflammable gas when heated. Take anthracite, for example—a species of coal which is largely mined in Wales; it contains a very high proportion of carbon, and

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very little hydrogen and oxygen. When heated, it gives off practically no inflammable vapour, and this makes it very difficult to ignite ; for the same reason, even when it has been successfully ignited, it burns with very little flame or smoke. These characteristics make anthracite unsuitable for domestic use ; it can be kept burning only in a strong draught, and is accordingly chiefly employed in boiler furnaces.

The solid fuels which have been considered in the foregoing paragraphs are all directly supplied by Nature, and are to be had more or less for the gathering. In this little island we pick up over 200,000,000 tons of coal every year, and we may well ask how long this will continue to be possible. Shall we be able to draw upon Nature's stores for an indefinite period? Is it time to consider what we should do if the coal supply of the world ran out?

Before attempting to answer these questions, we must recall the fact that Nature supplies us also with liquid fuel, yielding it to us with a very slight expenditure of energy on our part. It has long been known that in certain countries there were indications of the presence of oil in the earth's crust, but it was only forty or fifty years ago that a systematic search was made. About that time a certain American engineer drove an iron pipe from the surface down through the rock, and was surprised to find that when the pipe had gone down about thirty-four feet, oil rose nearly to the top. He had in fact "struck oil." This discovery, of course, led to other attempts to tap the subterranean oil stores, with the result that to-day whole districts in the United States and Russia—the two countries which supply by far the greater part of the world's liquid fuel—are given over to "oil-bearing."

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CAPPING A BURNING OIL WELL

To extinguish a burning oil-well a kind of armoured trolley, fitted with a crane from which the cap is slung, is pushed near the blazing bore-hole. The extinguisher is then lowered.

Sometimes the oil has to be pumped up like water from a well, but in other cases the oil in the internal reservoirs is under pressure, and so soon as an opening is provided it spouts out with great force.

It might be thought an easy matter to collect the oil which comes up these wells, but it is frequently very difficult, especially when the boring has just been made, and the oil is forced out under pressure. A certain well in Baku—the Russian oil-bearing district—tapped in 1886, began to spout with such vehemence that the whole surrounding country was deluged. For a time nothing could be done to stop the outflow, and many thousand tons of oil were lost. The great pressure which sometimes exists in the subterranean reservoirs was well shown by another fountain which burst out a few months later and rose to a height of 350 feet; the escape in this case was so great that it formed an extensive petroleum lake, and overflowed into the Caspian Sea.

The crude petroleum obtained from the American or Russian oil-wells must be subjected to chemical treatment before it is ready for the market. It is distilled, and the volatile portions of the oil are thus separated from the heavier portions. The reader would be quite surprised to find what a number of distinct products can thus be separated from natural petroleum by the simple process of distillation.

The most volatile portions of the petroleum yield naphtha and petrol, the latter substance now largely in demand in those days of motor cars. The petroleum which distils over at a somewhat higher temperature is used for illuminating purposes, and it is in this form of lamp oil that the bulk of the American petroleum ultimately comes into the market. After the petroleum

suitable for lighting has been distilled off, there is next obtained a heavy oily portion which may be used as a fuel or for lubricating purposes, while, last of all, there is a residue from which may be extracted such useful substances as vaseline and paraffin wax, the latter employed very largely in the manufacture of candles.

Closely allied to the petroleum of Pennsylvania or Baku is so-called "natural gas," which, in fact, frequently makes its appearance along with the petroleum. From the chemical point of view, it is extremely similar to petroleum, consisting largely of hydrocarbons; these, however, are still more volatile than the hydrocarbons present in petroleum, and are therefore not found in the liquid condition.

In the United States enormous quantities of natural gas are obtained, so much so that in many districts the manufacture of coal gas for lighting and heating purposes is quite superfluous. We do not, however, require to travel to the United States to find natural gas. There is actually a supply of it in England, although not on a large scale. It was discovered in 1893, as a bore-hole was being sunk at Heathfield, in Sussex, for the purpose of obtaining water. When the boring had reached a depth of over 200 feet, no water had been got, but an inflammable gas issued from the bore-hole. Some three years later another boring was made in the same neighbourhood, and at a depth of 312 feet gas was met with in considerable quantity. The supply was under great pressure, for when ignited it gave a flame 16 feet high. Obviously one of Nature's gasometers had been tapped, and since then this natural gas has been used regularly in the immediate neighbourhood for lighting and heating purposes to the extent of about 1000 cubic feet per day.

The gas consists almost exclusively of methane or marsh gas, the simplest compound of carbon and hydrogen.

The origin of solid fuel has already been discussed and is fairly evident, but it is much more difficult to specify the source of all the petroleum which has been obtained so abundantly during the last forty years. Some authorities assign to it an inorganic origin, and suppose that the hydrocarbons of which petroleum consists have been produced by the action of water on carbides. These substances are compounds of metals with carbon, and are decomposed by water in such a way that the carbon of the carbide forms a new compound—a hydrocarbon—with the hydrogen in the water. Many readers doubtless are familiar with one carbide which is in common use, namely, calcium carbide. This substance on contact with water generates acetylene, a hydrocarbon which has many advantages as an illuminating gas. Bicycle lamps, for example, are made in which acetylene is burned, the gas being prepared in the lamp by allowing water to drop on lumps of calcium carbide. So it may be supposed that water, penetrating through fissures in the crust of the earth, has acted on subterranean masses of carbides with the production of petroleum.

Another explanation, which on the whole has more support, regards petroleum as derived from an organic source, animal rather than vegetable. According to this view, the animal remains of past ages have undergone a change, whereby all nitrogenous and other matters, except the fats, were removed. Subsequently these fats, being subjected to distillation by the combined action of heat and pressure, or of pressure alone, yielded the petroleum which we get to-day.

In connection with all these fuel supplies — coal,

petroleum, and natural gas—a question of the utmost importance arises, to which reference has already been made. We are using up these fuels at an enormous rate, and there is no reason to suppose that the stores are being replenished at anything like the rate at which they are being consumed. In this respect we are, in fact, living on our capital, and, moreover, we do not know what is its amount. Estimates have indeed been made of the probable duration of our coal supplies, and Royal Commissions have dealt with the subject. The authorities are divided, but, on the whole, it seems we may reckon on our coal lasting for the matter of five hundred years or thereabouts, even when allowance is made for the probable increase in the consumption. It must be remembered also, for our comfort, that new coalfields are occasionally discovered, as was the case recently in the county of Kent. The Kentish collieries mean a substantial addition to our coal capital, and they may outlast the older ones in the north, so that some day it may be necessary to carry coals even to Newcastle.

Estimates like the foregoing are based on the actual inspection of the seams of coal which have been discovered, their thickness and extent, but who will be bold enough to say how long the subterranean reservoirs will keep us supplied with oil and gas? Human eyes have never seen, nor ever will see, what these hidden reservoirs contain. As a matter of fact, signs are not wanting that the stock of petroleum and natural gas is beginning to run short. The output of oil, it is true, is increasing, but this is due, not to any natural increase given by the existing wells, but to an increase in their number. The oil-yielding wells are very short-lived, and as new ones are continually being opened, the available oil-fields will soon be entirely covered.

We must not forget to include in our fuel capital the vast stock of timber on the surface of the globe, and the enormous quantities also of peat found in many countries. How far may we regard these as reliable sources of fuel? Wood, is, of course burned in many countries where there is a large extent of forest, but it would be absolute madness to use up all our timber in this way. It is the vegetation of the world which, as we shall see, is the necessary counterpart of animal life, and gradually to cut down all the forests on the face of the globe would be a suicidal policy. Besides, there is a large demand for timber for architectural and constructive purposes, and even as matters are at present, the forest-covered land of North America and Europe is being laid bare at a rapidly increasing rate. Trees do not grow in a hurry, and once the primeval forests are cut down, the keeping up of a supply of timber by planted trees is hardly feasible.

And what about peat? In Ireland alone there are over 1,000,000 acres of peat bogs, and it is estimated that an acre of a bog of an average depth of even 8 feet would yield about 1250 tons of dried peat. In Russia there are about 100,000,000 acres of bogs, so that altogether the fuel stored up in the form of peat must be very considerable. What militates against the use of peat as a fuel is the very large amount of moisture which it holds. When freshly dug it may contain as much as 80 to 90 per cent. of water, and the problem is how best to get rid of this and obtain the fibre of the peat in a condition fit for burning. The usual method of exposing the wet peat to air until it is dry requires much time and space. It is further a very bulky fuel, and, probably owing to these causes, the output of peat has never been much greater than sufficed for local de-

mands. In recent years, however, great advances have been made in the utilisation of peat. Methods have been devised of squeezing out the water by mechanical means, and compressing the combustible fibres into briquettes; these are not only more compact than the air-dried peat, but have also a higher heating power.

It is conceivable that in the distant future of the world's history there may come a time when, apart from timber, the natural stores of fuel—coal, peat, petroleum, and natural gas—are completely or almost exhausted. What then?

Necessity is the mother of invention, and we may be sure that before things shall have come to such a pass, the ingenuity of man will discover a way out of the difficulty. As a matter of fact, there are already indications that alcohol is to be the fuel of the future. In the form of methylated spirit it is used to a very small extent at the present day, but it looks as if it were to survive as a fuel when all others have gone. When every oil-well is dry, when a piece of coal can be seen only in a museum, and when the peat bogs are no more, then alcohol, if no better substance has been discovered in the meantime, will come to its own as a fuel.

"All very nice," the reader may say, "but how is the alcohol to be produced in the large quantities which will be necessary?" By the simple and time-honoured operations of growing potatoes, wheat, rice, beetroot, and similar substances. From these alcohol may be obtained by fermentation, as will be shown in a future chapter. To those who doubt whether alcohol could be used as fuel, say in driving an engine, the best reply is that the thing has been done. Experiments have shown that alcohol can be employed with satisfactory results in place
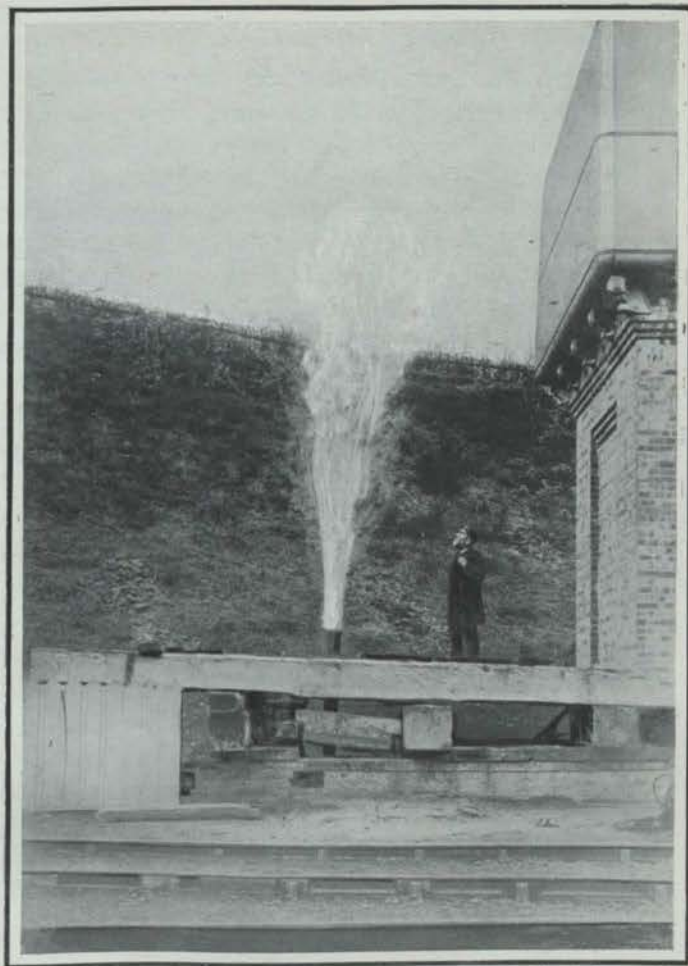
NATURAL GAS IN ENGLAND

Some twelve years ago a supply of natural gas was accidentally discovered at Heathfield in Sussex, while a bore-hole for water was under construction. A strong smell of "gas" had been noticed round the hole, and on the application of a light a flame sprang up to the height of fifteen to sixteen feet. The supply of gas is not yet exhausted and has been used for several years in lighting Heathfield railway station.

of petrol, and it has certain advantages over the latter fuel, such as greater safety in handling. At present, while the natural fuel is so abundant, the price of alcohol will prohibit its general use as a fuel; but it is at least a comfort to know that we have something promising in reserve.

CHAPTER XIII

MORE ABOUT FUEL

IN the foregoing chapter we have discussed the various natural fuels which are available for use without any more than a slight preliminary treatment. There are, however, other substances commonly classed as fuels to which no reference has yet been made—for example, charcoal, coke, and coal gas. Although these substances are to be regarded as fuels, they do not belong to the same category as wood, peat, coal, or petroleum. Unlike the latter fuels, they are not obtained directly from Nature; they are produced secondarily from the natural fuels by special treatment.

Generally speaking, the secondary fuels, charcoal, coke, and coal gas, are obtained by the process of destructive distillation. This operation sounds rather alarming, but it is one which most boys have performed on a small scale, and the principle of it is comparatively simple. In ordinary distillation, where a liquid is converted into a vapour, and this vapour is condensed by passing through a cooled tube, any products obtained in the distillate were already present in the original liquid. The products, however, of a dry or destructive distillation are not present as such in the original substance; they are only produced by its chemical decomposition.

The little experiment in destructive distillation which many readers have probably made consists in filling the

bowl of a clay pipe with little bits of coal, blocking up the mouth of the bowl with clay, and then heating it in a fire. When this is done, a gas will be found issuing from the end of the pipe stem, which will burn with a luminous flame. This gas is essentially the same as coal gas, and the method by which it has been obtained is destructive distillation—the process by which also charcoal, coke, and coal gas are obtained from the natural fuels. It is, of course, necessary that the natural fuels which are undergoing destructive distillation should be excluded from contact with air during the process—otherwise combustion would take place. What occurs then is that the carbon compounds in the natural fuel are chemically decomposed by the action of heat; the atoms of carbon, hydrogen, and oxygen are re-arranged, and new products are formed which did not exist as such in the original fuel.

The chemical decomposition which takes place in the dry distillation of wood or coal is exceedingly complex, and the number of products that can ultimately be obtained is very large indeed. But although this is so, the first crude products are only four in number, namely, gas, watery liquid, tar, and residue, these differing in character according as wood or coal is being subjected to distillation.

In the case of wood the process is sometimes carried out by stacking the wood, burning part of it, and using the heat so obtained to decompose the rest. This is a wasteful method, so far as most of the products are concerned, for no provision is made to catch those which are volatile. The residue is known as wood charcoal, and consists very largely of carbon, with small quantities of hydrogen, oxygen, and nitrogen, and a little ash or

mineral matter. Such a primitive method of converting wood into charcoal is frequently replaced by a more scientific procedure, in which the wood is heated in closed vessels or retorts, and provision is made for collecting or condensing any volatile matter.

In considering the use of wood as a fuel, we have seen that its ready combustibility is due to its giving off inflammable vapour. It is therefore not surprising to find that when wood is heated out of contact with air a quantity of gas is obtained. The main constituents of this gas are carbon dioxide, carbon monoxide, and marsh gas; the two latter are combustible, and although the gas has not much illuminating value, it may be used to heat the retorts. This is a simple example of the way in which the by-products of a manufacturing operation may be utilised so as to diminish the cost of production.

The volatile matter obtained by subjecting wood to dry distillation not only yields a combustible gas, but condenses partly to a tar and partly to a watery liquid. The latter yields acetic acid—the acid of vinegar—and wood spirit; this consists largely of methyl alcohol, and is added to rectified spirits of wine in order to produce methylated spirit. The object of thus "denaturing" ordinary alcohol is to provide a spirit which may be employed for industrial purposes, and which, at the same time, is not drinkable. Whether the latter condition is fulfilled is doubtful, for it is said that such methylated spirit is consumed as a beverage, to the injury of the revenue. Accordingly, the bulk of methylated spirit now sold has a small admixture of mineral naphtha or light petroleum to render the taste more objectionable.

When coal is subjected to destructive distillation the effects are in general the same as those obtained with

wood, but the character of the products differs in some important particulars. The gas which is given off on heating coal is of much more use for illuminating purposes, and is, in fact, after purification, nothing else than the common coal gas used throughout our towns. This consists largely of hydrogen and marsh gas, together with some carbon monoxide and small quantities of heavy hydrocarbons which are responsible for the illuminating power.

In the crude gas which comes from the retorts there are several undesirable constituents which must be removed before the gas can be supplied to the public. In addition to carbon, hydrogen, and oxygen, coal contains small quantities of the elements nitrogen and sulphur, and these appear to some extent in the coal gas in the form of ammonia—a compound of nitrogen and hydrogen—and sulphuretted hydrogen—a compound of sulphur and hydrogen. The ammonia collects mostly in the watery liquid, which accordingly becomes *alkaline*, in contrast with the *acid* watery liquid obtained in the destructive distillation of wood. The last traces of ammonia are removed from coal gas by "scrubbers"— towers packed with coke or brushwood over which a constant stream of water is trickling. The current of gas goes in the opposite direction, and as ammonia is very soluble in water, it is all removed before the gas issues at the top.

The sulphuretted hydrogen resulting from the above process, if it were allowed to remain in the coal gas, would on burning produce sulphur dioxide, and this, in anything more than a small quantity, would be a very objectionable addition to the atmosphere. The gas is accordingly passed through a series of purifiers,

containing slaked lime and iron oxide. The reader is already familiar with the first of these as being an alkaline substance, in virtue of which it readily absorbs anything of an acid nature which passes through the purifiers. Now both carbon dioxide, a little of which is sure to be present in the gas, and sulphuretted hydrogen are substances of an acid nature, and one would therefore expect them to be fixed by the lime. Sulphuretted hydrogen, however, is not absorbed by lime when it is mixed with carbon dioxide, so in order to insure the complete removal of the former the coal gas must also be passed over iron oxide. This substance, generally in the form of Irish bog ore, is at first very active in holding back the sulphuretted hydrogen, but as it absorbs more and more it gets exhausted, being gradually converted into sulphide of iron. A course of fresh air, however, is found to have a beneficial effect on its activity, hence the exhausted or "spent" oxide of iron is taken out of the purifiers and spread on the ground for a time. During this "rest cure" the sulphide of iron enters into a chemical reaction with the oxygen of the air, with the result that the element sulphur is liberated and iron oxide is re-generated. The material is then again capable of actively absorbing sulphuretted hydrogen, and is therefore returned to the purifiers until exhausted a second time. This process of "revivifying" the iron oxide may be repeated a good many times until the material has picked up about half its own weight of sulphur. It will then have lost its effectiveness as a purifier of coal gas, and is accordingly sold to the sulphuric acid manufacturer. As the proportion of sulphur in the original coal is not more than one or two per cent., this is a very instructive instance of the

value of gathering up the fragments; even the very impurities in the coal gas are made to contribute to the cost of its production.

This remark covers also the ammonia which is found in crude coal gas. As has been stated already, the destructive distillation of coal converts some of the nitrogen which it contains into ammonia, and this has turned out to be a very valuable by-product of coal-gas manufacture. From the watery liquid, in which it mostly collects, the ammonia is driven out by a current of steam; it is then passed into sulphuric acid, forming sulphate of ammonia, and the crystals of this substance are fished out from time to time. On the average, a ton of coal yields 20 lbs. of ammonium sulphate; the latter substance fetches a good price as a manure— about £10 per ton—and it makes, therefore, a very substantial contribution to the expense of producing the coal gas.

Other by-products obtained in the manufacture of coal gas are tar and coke. From coal tar so many interesting and useful substances are prepared that a special chapter must be devoted to their consideration, where we shall see that even from this uninviting and unpromising material many beautiful products may be extracted.

Coke is the residue in the retorts after all gas, tar, and ammonia have been driven off. The mineral matter or ash in the original coal is not volatile, so that it remains in the coke, which contains about ninety per cent. of carbon and small quantities of hydrogen, oxygen, nitrogen, and sulphur. Gas coke is used as a fuel, although the reader will understand that since the volatile combustible gases have been removed, it is rather

difficult to burn. In domestic use it must be mixed with coal, but in furnaces where there is a powerful draught, it is very satisfactory by itself and gives off no smoke. Large quantities of gas coke are employed in lime and cement-burning.

Such are the chief products of the destructive distillation of coal in the manufacture of coal gas. As a fuel, coal gas, if not particularly cheap, is comparatively clean, and certainly very convenient. Hitherto it has been used principally for lighting purposes, and we can best appreciate its convenience in that respect from the standpoint of our great-great-grandfathers. What seemed to them the marvel about coal gas was that no wick was required as in the lamps and candles with which they were familiar. So marvellous did they find it, that it was regarded as rather uncanny, and the lighting of gas lamps was at first thought to be a perilous undertaking.

Nowadays, electricity is a competitor with gas as an illuminant, but the latter is being increasingly employed as a fuel, and may be said to hold its own. In England there is a decided preference for the old-fashioned, cheery open coal fire, with all its accompaniments of ash, soot, and smoke; there is little doubt, however, that the gas fire or stove is gradually coming into favour on account both of its cleanliness and its convenience. In estimating the chances that coal gas will hold its own with electricity as a lighting and heating agent, the very important part played by the by-products of the gasworks must not be forgotten. Here, as in so many cases, it is the by-products which settle the question whether a given manufacture will pay or not.

Coke, which has been referred to as a by-product in

the manufacture of coal gas, is prepared in large quantities for its own sake. It is extensively used in metallurgical operations, that is, in the production of metals from their ores. The coke required for this purpose must be specially dense, and as free as possible from sulphur and ash. Gas coke does not adequately fulfil these conditions, and in Great Britain as much as twelve million tons of coal are destructively distilled every year in special ovens in order to get coke suitable for metallurgical purposes. This is frequently described as oven coke.

The use of coke in metallurgical operations is readily understood. In iron-smelting, for instance, the ore consists mainly of iron oxide, and when this is heated in the blast furnace with coke, the oxygen prefers to be in partnership with the carbon rather than with the iron, so that the latter is liberated, and is obtained from the blast furnace as molten metal.

Coal is not the only naturally occurring substance that is subjected to destructive distillation. In Scotland there is a very considerable industry founded on the winning of fuel oil by the destructive distillation of shale. This is a carbonaceous substance which differs from coal in that it contains a very much larger proportion, sometimes as much as 70 per cent., of mineral matter or ash. By the destructive distillation of a ton of shale about thirty gallons of crude oil can be obtained, which by further treatment is made to yield paraffin oil, lubricating oil, and paraffin wax.

Attempts have been made also to subject peat to destructive distillation, but these have generally ended in failure. The difficulties, however, are now being overcome, and quite recently a promising development has

taken place in South Germany, where a plant has been put down beside an extensive peat bog, and is turning out tar, paraffin, ammonia, and coke. If this process should be found commercially sound, we may yet see the peat bogs of Ireland being converted into productive ground, while at the same time a new industry will be available for the people.

Leaving out of account for the moment the tar, ammonia, and sulphur obtained as by-products in the destructive distillation of coal, we may regard the net result of the operation as giving us for fuel coke coal gas instead of coal. Now whereas coal is an exceedingly dirty fuel, both coke and coal gas are clean fuels, burning without smoke. Bearing this in mind, we might ask the question whether it would not be possible to modify the destructive distillation of coal in such a way as to obtain a coke-like product, which would, however, still retain enough gas-producing material to make it readily inflammable, and which would at the same time be a smokeless fuel. Experiments made during the last four or five years have shown that this is possible when the temperature of the retorts, instead of being raised to 1600° or 1700° Fahrenheit, as is usual in gasworks, is kept about 800°. The quantity of gas given off during the heating is not so large, but the half-coked coal left in the retorts, containing as it does a certain proportion of volatile matter, is a smokeless, easily ignited fuel. This product is now on the market under the name of coalite.

The convenience of gaseous fuel for many purposes has stimulated efforts on the part of chemists to convert carbon entirely into combustible gaseous products. It was discovered long ago that when a current of steam is passed through red-hot carbon, an inflammable gas is pro-

duced. The chemical reaction involved is very simple; the water is decomposed by the red-hot carbon, and the latter appropriates the oxygen, forming carbon monoxide. The hydrogen of the water is left in the free state, and issues from the furnace along with the carbon monoxide. Since both these gases are combustible, the reader will perceive that the simple passage of steam over red-hot carbon means the conversion of a solid into a gaseous fuel. The product is called " water gas," a term which must be carefully distinguished from " water vapour "; the latter is of course not combustible.

Simple as the foregoing process may seem to be on paper, many difficulties were experienced in making it work on a large scale. The decomposition of steam by carbonaceous fuel requires a large amount of heat, and it was soon found impracticable to supply this by external heating of the retorts containing the coke or coal. The device was accordingly adopted of heating the fuel internally by its partial combustion. Air is blown into the retort containing the ignited fuel, which is raised to incandescence by the heat given out in its own combustion; then, as soon as this condition is attained, the air blast is shut off and steam is blown into the retort. The formation of water gas at once begins, and is continued until the temperature falls below a certain limit, when the steam blast is shut off and air is once again blown in. It must be understood that the two parts of this operation, the air blow and the steam blow, are complementary to each other, the heat evolved in the first stage supplying the energy required in the second stage.

Water gas, this mixture of hydrogen and carbon monoxide, burns with a non-luminous flame, and, if it is

to be used for illuminating purposes, must either be carburetted—that is, provided with hydro-carbons to render its flame luminous, or used with incandescent mantles. In America water gas is frequently used in place of coal gas; in this country it is never supplied alone for lighting purposes, but is often mixed with coal gas. One objection to its use is the excessively poisonous nature of carbon monoxide, referred to in a previous chapter. On this ground it is considered unsafe to distribute to the public coal gas which contains more than about 16 per cent. of carbon monoxide.

Has the reader ever realised what an enormous amount of energy is stored up in a pound of coal, or a cubic foot of coal gas? When the fuel is burned this latent energy becomes manifest in the form of heat, and it is actually found that the heat given out when one pound of coal is burned would be sufficient to raise the temperature of *seven tons* of water 1° Fahrenheit—say from 60° to 61°. Now heat is convertible into other forms of energy, and may, for example, be transformed into mechanical energy; thus it has been shown that the quantity of heat which would raise the temperature of one pound of water from 60° to 61° would, if converted into mechanical energy, be able to raise a weight of 772 pounds through 1 foot, or, what is the same thing, a weight of one pound through 772 feet. By means of this mechanical equivalent of heat, as it has been called, some one has calculated that if the energy latent in one pound of coal were converted without loss into mechanical energy, it would do as much as five or six horses working for an hour.

But one must admit that this is quite an ideal process. Even in the best engines we can employ to convert the latent energy of fuel into mechanical energy only a

portion of the heat reappears in the form of useful work. In this respect the internal combustion engine, such as is used on a motor car, is much superior to the steam engine, by which we convert only about 10 per cent. of the heat value of the coal into power.

The power of different fuels to give out heat when burned—the calorific power, as it is called—varies very considerably. The heat given out in the combustion of one pound of coal, for example, is nearly twice as great as that liberated when one pound of dried wood is burned. The calorific power of petroleum, on the other hand, is nearly 30 per cent. greater than that of coal. In selecting a fuel, however, many other factors have to be borne in mind besides the calorific power; the prudent engineer has to consider the bulk of the fuel, its cost, its handling, and the readiness with which it may be fed into the engine. It is the total effect of all these factors on the balance-sheet that is the important thing from the commercial point of view.

From what source has all the energy latent in naturally occurring fuels been derived? George Stephenson, when he was asked what drove his locomotive, replied that it was "bottled-up sunshine," and he was not far wrong. The reader will ask how the bottling process was carried out; but that is another story, which must be postponed to a later chapter.

CHAPTER XIV

FLAME: WHAT IS IT?

THE reader will by this time have become fairly familiar with the conception of combustion, and he may be under the impression that, knowing what combustion is, he has nothing more to learn about flame. This would be a somewhat rash conclusion, for, to begin with, the one thing does not always accompany the other; there are cases of undoubted combustion in which there is no real flame. A little piece of charcoal, for example, burning in air or oxygen gives out no flame; it only glows.

As a matter of fact, it is only when the burning substance is in the form of gas or vapour that we get flame produced. It is true that many liquid and solid substances give a flame when they burn, but the production of the flame is preceded by their conversion into vapour. By holding a match to the wick of a candle we first melt and then vapourise the wax which is in the wick; the vapour catches fire and the candle is lit. Once this has been done, the heat of the flame keeps the wax round the base of the wick melted, the melted wax is sucked up the wick by capillary action, and at the top it is vapourised and ignited.

Flame, then, is something different from combustion, and may be defined as gaseous matter which has been raised to such a high temperature that it is obvious to

the eye. Solids begin to emit light when they are heated to about 900° Fahrenheit, but vapours must be raised to a very much higher temperature before they become visible. When a combustible vapour reacts chemically with the oxygen in the air, which is the supporter of combustion, the heat produced is intense enough to raise the vapour to the point of incandescence—a flame is produced.

We have spoken here of a combustible substance and a supporter of combustion as being necessary for the production of flame, but it is well to remember that these terms are purely relative. If we could picture this world and its inhabitants as quite different from what they are, and could imagine that the atmosphere round the globe was one of hydrogen instead of air, then the gas companies would have to supply us with oxygen for lighting and heating purposes. In such a world oxygen would be regarded as the combustible substance, and hydrogen as the supporter of combustion.

FIG. 4.—A sketch of an experiment showing that air can be burned in an atmosphere of coal gas.

It is, in fact, easy to show that air burns in coal gas quite as readily as coal gas burns in air. In the accompanying Fig. 4 the apparatus necessary for this experiment is shown. A lamp glass is fitted at the bottom with a cork, through which pass two tubes. The one which ends just above the cork is connected with the gas supply, the longer
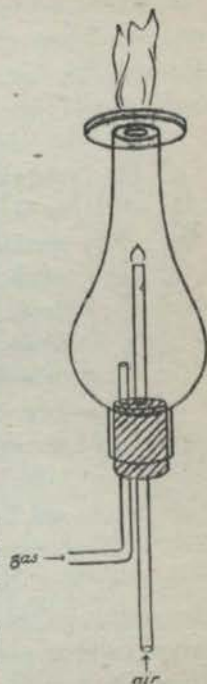
one serves as an air passage. The top of the lamp glass is covered with an asbestos disc, in the middle of which there is a hole. When the gas is turned on, the air in the lamp glass is driven out, and the latter then contains an atmosphere of coal gas, the excess of which escapes through the disc at the top. This escaping gas may be lighted, and g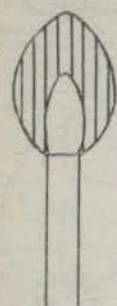ives the ordinary flame of coal gas burning in air. If, now, the long tube which passes through the cork at the bottom is pushed up until it reaches the burning jet at the top, something at the end of this tube is seen to catch fire, and to remain alight, giving a visible flame even when the tube is drawn down again. The explanation of this interesting phenomenon is that air is being drawn up the long tube and is burning in the atmosphere of coal gas which surrounds the end of the tube. This apparatus, then, in which we can see both coal gas burning in air, and air burning in coal gas, shows that the terms "combustible," and "supporter of combustion" are interchangeable. There is no real distinction; the chemical process which goes on is the same in both the flames observed.

FIG. 5.—The flame of burning hydrogen.

When we come to look more closely at a flame we find that it has a structure. It may seem odd to speak of a mobile, elusive thing like a flame as having a structure, and certainly with a mixture such as coal gas being consumed at some ingenious modern burner, it is not easy to detect this structure. But if we take a simple gas such as hydrogen burning at the end of a plain round tube, we find the character of the flame to be exceedingly simple. The actual flame, as will be seen from the accompanying

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sketch, is confined to a certain zone or sheath in which the combustion is going on, and this cone-like sheath is hollow.

That the cone of flame is hollow may be very easily and prettily shown by suspending the head of a match just above the end of the tube before lighting the gas. In spite of the burning gas the match in the inside remains unaffected (see Fig. 6, a). But we can go a step further and show that this hollow part of the flame contains unburnt gas by carefully putting one end of a narrow tube in the centre of the cone and applying a light to the other end some distance away. We get a flame there (see Fig. 6, b) simply because with the tube we have succeeded in leading off some of the unburnt gas from the centre of the cone.

A candle flame and a coal-gas flame differ from a hydrogen flame only in that their structure is a little more complicated; their general characteristics are similar.
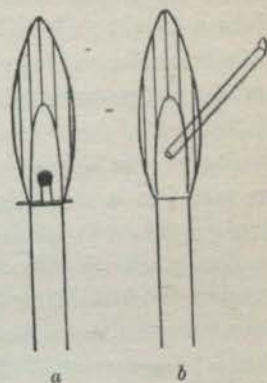
FIG. 6.—The hollow nature of a flame may be shown in various ways. A match-head suspended in the centre is not ignited by the flame, and with a piece of glass tube the unburnt gas from the centre of the flame can be led off and set alight at the end of the tube.

In these two cases the dark hollow cone in which is the unburnt vapour is surrounded by a white, luminous zone, and this again by an outer envelope of flame which is non-luminous and very difficult to see. This outermost sheath is obviously the one for which there is an unlimited supply of oxygen, and anything which has escaped combustion in the luminous zone is there completely burned to carbon dioxide and water.

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The luminosity of flame varies very remarkably with the nature of the combustible substance and with the conditions under which the combustion takes place. A hydrogen flame is quite non-luminous, carbon monoxide burns with a pale blue flame, while a candle or coal gas gives a bright white illumination. One cause of luminosity has been already referred to in a previous chapter, namely, the presence of solids which are made incandescent by the heat of the flame. A coal-gas flame contains in its luminous zone a host of unburnt carbon particles which are raised to a very high temperature and so give out a strong light. By mixing the gas with air before it comes to the nozzle of the burner these carbon particles are completely oxidised, and the flame becomes non-luminous. Such a non-luminous flame may, however, again be rendered useful for purposes of illumination by the artificial introduction of incombustible solids which are made incandescent by the heat of the flame. This is what is done in the ordinary incandescent gas burners and in the lime light.

There are other causes which determine the luminosity of a flame besides the presence of solid particles. There are some flames known which are characterised by very high illuminating power, and in which at the same time there cannot possibly be any solid particles present. For example, phosphorus burning in oxygen produces a dazzling light; but the oxide of phosphorus which results from the combustion is converted into a vapour at a red heat, and it is therefore impossible that it could exist in the solid state in the phosphorus flame, the temperature of which is far above the melting-point of platinum.

The well-known English chemist Frankland, who made many experiments on the nature of flame and the cause of

its luminosity, once took the trouble to carry candles up to the top of Mont Blanc, and was much struck by the comparatively small amount of light which they emitted when burning there. He traced this decrease of luminosity to the small atmospheric pressure prevailing at such a high level, and was able to show subsequently in his laboratory that the illuminating power of a candle is much reduced when it is burning in a partially exhausted vessel.

Since diminution of pressure reduces the luminosity of a flame, it might fairly be expected that increase of pressure would have the opposite effect; and so it turns out. A spirit-lamp, which, as the reader knows, gives practically no light when burning in air under ordinary conditions, gives a highly luminous flame when placed under a pressure of four atmospheres; and Frankland estimated that under a pressure of five or six atmospheres its luminosity would be equal to that of sperm oil burning under ordinary atmospheric pressure.

The influence of pressure on the luminosity of a flame is most strikingly illustrated by the effect of compression on burning hydrogen. This gas burns under ordinary conditions with a pale flame, absolutely useless for illuminating purposes, and it might be supposed that the want of luminosity is due to the absence of any solid product of combustion; water, the compound which results from the union of hydrogen and oxygen, is, of course, a vapour at the temperature of the flame. But if hydrogen is burned in oxygen at ten atmospheres pressure, the light emitted by the flame is sufficient to enable the observer to read a newspaper two feet away.

Plainly, therefore, the presence of solid particles is not the only thing on which the luminosity of flame

depends; the pressure under which the flame is burning has a decided influence.

We must recognise also another factor which has a bearing on the luminosity of a flame, and that is its temperature; the hotter a particular flame is, the higher is its luminosity as a general rule. One way of raising the temperature of a flame is to feed it with oxygen instead of air, and the result of doing this is sometimes surprising. The temperature, for instance, of a hydrogen flame in air is about 3600° Fahrenheit, while the same flame in an atmosphere of oxygen is some 1400° hotter. It is true that in the case of hydrogen no increase in luminosity results from this very remarkable rise of temperature, but the behaviour of hydrogen is exceptional. If a candle burning in air is transferred to a jar of oxygen, the flame shrinks in size but becomes distinctly more luminous, owing to the higher temperature.

We may get a hotter flame also by heating the air and the gas which are supplied to the burner, and such a rise in the temperature of the flame leads to increased luminosity. This was the principle applied in the so-called " regenerative " burners, in which the usual glass chimney was surrounded by a wider one closed at the bottom; the air, therefore, which fed the flame had to pass down between the chimneys, and was very considerably heated by contact with the inner one. Such devices, however, for securing increased luminosity have disappeared before the incandescent burner.

Not only may a flame be made hotter in various ways; it is possible also to lower its temperature. Admixture of an indifferent gas—that is, one which takes no part in the combustion—produces a marked cooling

effect, and a similar result is obtained by introducing into the flame some body which is a good conductor of heat. Indeed the temperature may be so much lowered by this latter device that the flame is extinguished. If, for example, a coil of copper wire is carefully placed over the wick of a burning taper, the flame goes out immediately.

In order to understand the possibility of this phenomenon, we must remember that every inflammable vapour has a certain ignition temperature. That is to say, for each vapour there is a point to which it must be heated in presence of air before it will catch fire and give a flame. Once it has been ignited, the heat given out by the flame as the result of the chemical action raises the incoming gas above the ignition temperature, and so the combustion continues.

Different substances have very different ignition temperatures. The vapour of carbon disulphide can be ignited by contact with a glass rod which has been heated only to 250° Fahrenheit, a little higher than the temperature of boiling water. A current of hydrogen issuing from a tube is ignited by sparks from a flint and steel, whereas marsh gas is quite indifferent to such treatment.

The possibility of cooling an inflamed vapour below its ignition temperature may be demonstrated in a very simple manner. If, as shown in Fig. 7, a, a piece of copper wire gauze is pressed down on a flame of burning coal gas (which, as we have already seen, contains a large proportion of marsh gas), no combustion takes place above the gauze, although it is easy to show that there is inflammable vapour there by bringing up a lighted match. Again, if we hold the gauze an inch

or two above a nozzle from which coal gas is issuing, we may light the gas above the gauze without the flame passing through to the lower side (see Fig. 7, *b*). The
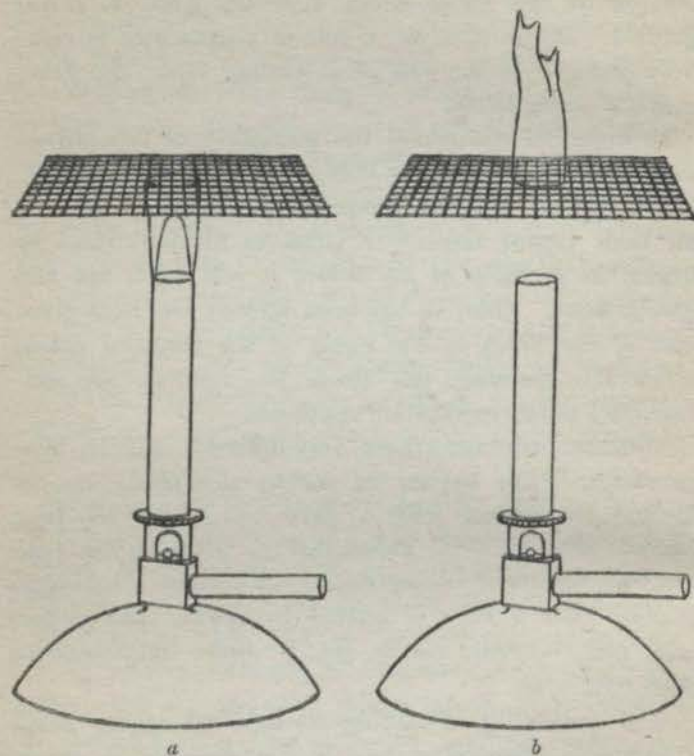
FIG. 7.—Showing the difficulty which a flame has in passing from one side to the other of a wire gauze.

reason of this curious result is that copper is an excellent conductor of heat, and the interposition of the gauze has such a cooling effect that the inflammable vapour on the other side from the flame is kept below its ignition temperature.

As already stated, the ignition temperature of hydrogen is lower than that of marsh gas, and if we attempted to obtain with hydrogen the results just described, we should not succeed. In all cases the hydrogen flame would strike through the gauze.

The remarkable power of metal gauze to limit the extension of a marsh gas flame was utilised long ago in the well-known miner's safety lamp devised by Sir Humphry Davy. Coal measures are frequently highly charged with marsh gas, and large quantities of this gas find their way into coal mines. Since this "fire-damp," as it is called, is inflammable, and forms a very explosive mixture with air, its presence in these mines is a source of great danger, and has repeatedly led to serious disasters.

The risk of using naked flames in such "gassy" mines had to be got over somehow, and Davy was able to show that if the oil flame in the miner's lamp was surrounded by wire gauze the danger of explosions was very much reduced. An explosive mixture of fire-damp and air will not as a rule be fired by such a lamp, but will indicate its presence by burning inside, and so warn the miner of danger. The action of the gauze in conducting away the heat prevents the explosive mixture outside reaching its ignition temperature.

The old form of Davy lamp has been found defective in some respects, and has been continuously improved; thus the wire gauze cut off a great deal of the light, so the lower part was replaced by a glass cylinder. Then it was found that a strong draught might blow the flame against and even through the gauze, with the result that an explosive mixture outside would be ignited. The newest form of the safety lamp

is therefore fitted, not only with a glass cylinder at the bottom to let the light out, but with an iron cylinder above to shield the lamp from draughts.

When the Davy lamp is brought into an atmosphere in which fire-damp is present, a so-called "cap" of pale blue flame is seen surmounting the ordinary luminous
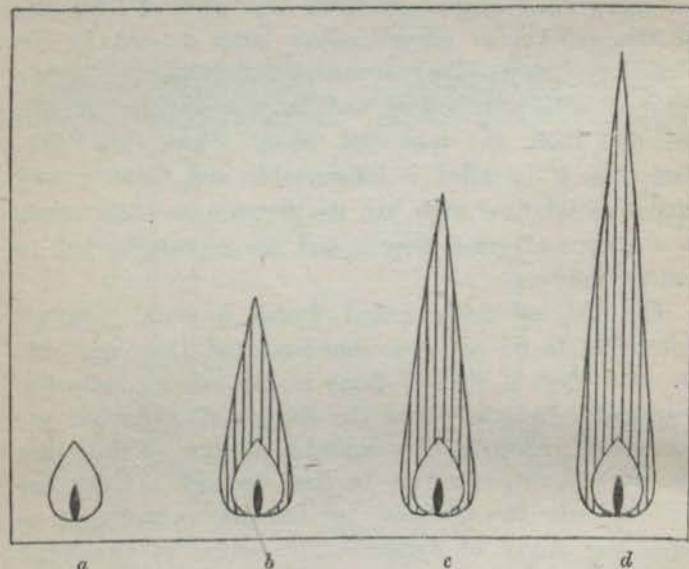
FIG. 8.—A flame of burning hydrogen is shown at (a). When this flame is brought into an atmosphere charged with fire-damp or marsh gas it is surmounted by a "cap," the length of which indicates the amount of dangerous vapour present. The caps shown at (b), (c), and (d) represent what is seen when the atmosphere surrounding the flame contains one-half, two, and three per cent. of marsh gas.

flame in the lamp. The length of this "cap" increases as the percentage of fire-damp in the surrounding atmosphere rises. Hence it will be seen that to the experienced eye the appearance of the Davy lamp flame serves as a

means of estimating the amount of fire-damp. It is only a rough estimate, however, which can be made in this way.

In recent years a much more accurate method of estimating the amount of fire-damp in mines or of petroleum in air has come into vogue. The apparatus used is really a safety lamp in which hydrogen is burned instead of oil. In an atmosphere containing fire-damp "caps" appear on the hydrogen flame just as in the ordinary safety lamp, but owing to the fact that the hydrogen flame is much less luminous than the oil flame, the "caps" are more easily seen and measured. The accompanying Fig. 8 shows the nature of these "flame caps," and the way in which their length varies with the amount of fire-damp in the atmosphere.

The gradual development of the Davy lamp is an interesting example of the way in which scientific work has been directed to the detection of danger and the preservation of life. It would indeed be difficult to estimate the saving of human lives which has resulted from Davy's discovery of the valuable properties of metal wire gauze in relation to a marsh gas flame.

CHAPTER XV

EXPLOSIONS AND EXPLOSIVES

THE reader may at some time have seen or handled those curious little things known as "Prince Rupert's drops." These are obtained by allowing drops of molten glass to fall into cold water, where they solidify in a tadpole-like shape. If the tip of the tail of one of these drops is nipped off with the fingers, the whole thing breaks up into dust with a loud explosion. The reason is that the glass which forms the solid drop is in a state of intense strain owing to the very sudden cooling which it has undergone; the outside and the inside of the drop have cooled at different rates, the particles of the glass are in a state of unstable equilibrium, and the slightest jar upsets the whole structure.

There are many chemical compounds which exhibit considerable analogy with Prince Rupert's drops. The molecules of these compounds have been formed by the combination of a number of atoms, but the equilibrium between the latter is an unstable one, liable to be disturbed by the most trivial exciting cause.

An example of this curious behaviour is furnished by nitrogen iodide. This extraordinary substance is prepared by the action of iodine on ammonia, and although generally quite stable in the moist state, it has been known to explode even under water. As usually obtained, it is a chocolate-brown powder which explodes violently
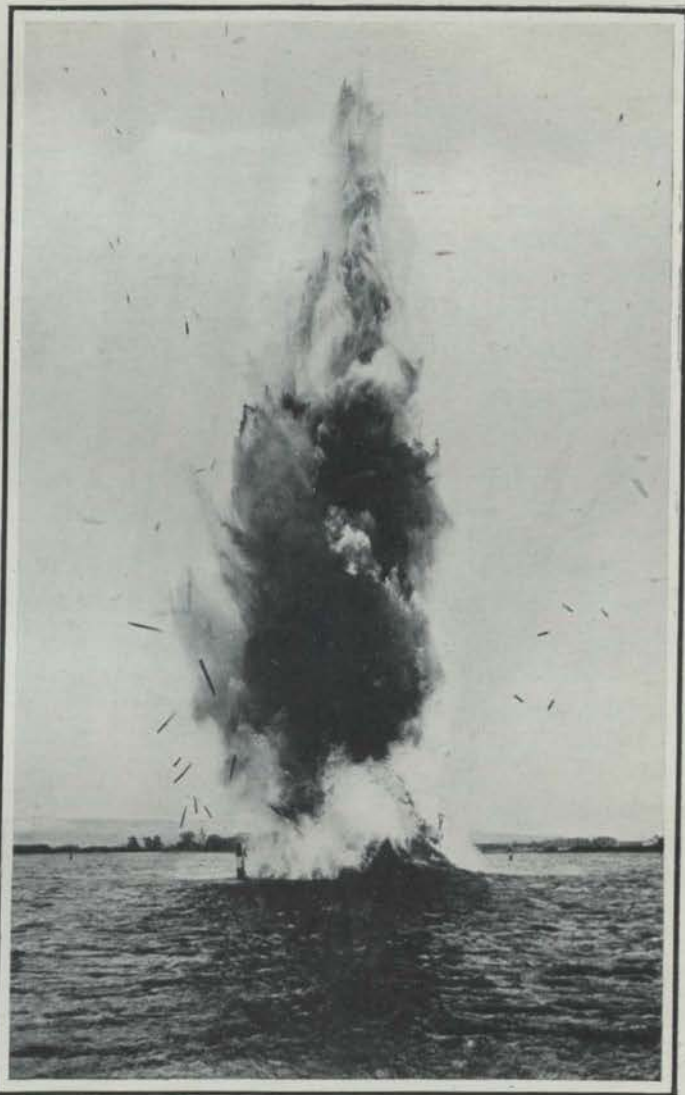
WHAT MODERN HIGH EXPLOSIVES CAN DO

A wooden boom has been blown up and completely disintegrated. Noteworthy also is the immense body of water raised by the force of the explosion.

on the slightest provocation; if it is dry, the falling of dust particles, the tread of a fly, or the merest touch with a feather, will be sufficient to make it go off with a bang. The molecules fly to pieces, and a quantity of nitrogen gas and iodine vapour is generated, occupying much more space than the original solid substance.

Such a sensitive material is obviously most dangerous to handle, but there are other compounds which exhibit the same character of unstable equilibrium, and which yet can be manipulated safely if due care is taken. As we shall see later, these readily exploded substances fulfil a useful function. One which is extensively employed, and which on that account deserves special notice, is mercury fulminate.

This is prepared from mercury, nitric acid, and alcohol, and when pure is a shiny white, crystalline substance containing the elements mercury, carbon, oxygen, and nitrogen. It cannot be kept in a glass-stoppered bottle, for the mere friction between the stopper and the neck would cause it to explode. When struck with a hammer mercury fulminate goes off with a very sharp report, evolving a large quantity of gas—nitrogen, carbon monoxide, and mercury vapour. It is, of course, one of the essential characteristics of an explosive that a small quantity of the substance should yield suddenly a very large volume of gas. In the case of fulminate it is estimated that the gas produced by its explosion would occupy at the ordinary temperature 1300 to 1400 times the bulk of the substance itself. But the actual volume of the gases produced is even much larger than that, for in the explosion of the fulminate a great amount of heat is liberated, in virtue of which the gases are raised to a high temperature, and occupy a much larger space.

The fact that mercury fulminate when it decomposes produces heat is worthy of notice, for it is a phenomenon rather different from what might be expected. We have seen that as a rule the chemical combination of elements is accompanied by the evolution of heat; the process is said to be "exothermic." This being so, we may confidently anticipate that the reverse process, the decomposition of the compound into its elements, would use up heat, and therefore, if it took place spontaneously, it would be accompanied by an absorption of heat. This is quite a sound conclusion, but it is obvious that mercury fulminate, the decomposition of which leads to the production of much heat, must belong to a different category.

The secret of the explanation is that, although the formation of most compounds is accompanied by the evolution of heat, there are some—"endothermic" compounds, as they are called—the formation of which is accompanied by absorption of heat. In this case the reverse process, in which the compound decomposes into its constituent elements, will be accompanied by the evolution of heat. So it is with mercury fulminate, which is an endothermic compound, and, like others of this class, is peculiarly liable to sudden decomposition.

As a matter of fact, the explosion of mercury fulminate is accompanied by the evolution of more heat than is involved merely in the splitting of it into the constituents, for two of the elements liberated in this primary decomposition, namely, the carbon and the oxygen, immediately unite to form carbon monoxide, and as this combination is an exothermic process, the heat produced by the explosion is much augmented.

The explosive disruption of the molecules of nitrogen iodide and mercury fulminate is due to the want of

cohesion between the constituent atoms; it is the old story of a house divided against itself. But most of the explosions which come about, intentionally or unintentionally, depend on an altogether different principle; they are simply combustions which take place with excessive rapidity, and which result in the production of quantities of gas. In such explosions the element oxygen plays an essential part.

In the first place, any inflammable gas or vapour will form an explosive mixture with air. The reader must carefully distinguish between "inflammable" and "explosive"; it is not correct to speak of coal gas as "explosive"; it is certainly inflammable, and when ignited at a suitable nozzle, burns quietly as long as the supply lasts. Combustion takes place only where air and gas meet. A mixture of coal gas with air is, however, a very different thing; it is inflammable at every point—explosive, in fact: combustion once started is rapidly propagated through the bulk of the mixture. Hydrogen similarly forms an explosive mixture with air, and illustrations of this fact are not infrequent in a chemical laboratory. For it often happens that a beginner, preparing hydrogen in a flask by the action of an acid on a metal, applies a light to the issuing gas before all the air has been expelled. The result of this will probably be that part of the flask will adhere to the ceiling, and the rest will be converted into fine dust.

That coal gas becomes explosive when mixed with air we are frequently reminded, as from time to time we read of some one who has gone to look for a leak of gas with a lighted match or candle, and has thereby brought disaster on himself and his surroundings. When we can smell gas through a house, the atmosphere there is a

mixture, possibly explosive, of coal gas and air, and if we were to carry a naked flame in search of the leak, we should be as foolish as the miner who goes into a "gassy" mine with a lighted candle. To produce an explosive mixture of air and coal gas about 6 per cent. of the latter is sufficient, so that one cannot be too careful. The only safe course is to begin by ventilating the house thoroughly, so that the proportion of gas may be reduced below the explosive limit.

In explosions of this kind, where both parties to the combustion are gaseous, the amount of gas produced by the explosion is relatively less than in those cases where the original unexploded substance is a solid. The increase in volume is in fact due solely to the high temperature caused by the heat of the combustion. If coal gas and air, in the proportion of 1 to 5 by volume, are exploded in a very strong closed vessel so that no expansion is possible, a pressure of 7 to 8 atmospheres is developed, and the maximum temperature reached is nearly 3500° Fahrenheit.

Explosions in which the oxygen necessary for the combustion is supplied in the form of air are actually employed as sources of energy in gas- and motor-engines. The pressure developed when a mixture of gas or petroleum with air is exploded is used to move a piston, and the longitudinal motion of the piston is converted into circular motion as in a steam-engine. It has been said that fire is a good servant but a bad master, and the remark is true in reference to explosive as well as to ordinary combustion.

If instead of using a mixture of two gases we take a solid combustible material, and mix it intimately with some other substance which not only contains a large proportion of oxygen but is fairly ready to part with

ONE STAGE IN THE MANUFACTURE OF AN EXPLOSIVE

The women are picking cotton waste preparatory to its conversion into guncotton.

By permission of Sir Frederick Nathan

Photo: Reinhold Thiele & Co.

EXPLOSIONS AND EXPLOSIVES

some of it, then, on the supposition that the combustible material yields gaseous products when it is burned, the mixture of the two solids will be a compact explosive. It will be compact because its bulk will be small in comparison with the volume of the gases produced by its explosion.

Common gunpowder is an explosive of this kind. It is an intimate mechanical mixture of the three substances—potassium nitrate (nitre or saltpetre), charcoal, and sulphur. The first and second of these are the essential constituents of gunpowder; the sulphur is present in a smaller proportion, and is added for a special purpose which will be explained later.

The charcoal and the sulphur, as the reader will understand, are the combustible constituents, and the saltpetre, which forms about three-quarters of the gunpowder, is a compound which contains a high proportion of oxygen, and which, moreover, is easily induced to part with some of it; this being so, saltpetre may be regarded as a compact form of oxygen. Anyhow, it is easy to show that charcoal and saltpetre, while quite ready to lie down peacefully together at the ordinary temperature, act violently on each other when heated; any one can convince himself of this by throwing a pinch of saltpetre on a glowing coal fire.

It is very easy to extract the potassium nitrate from gunpowder, and it is worth the reader's while to try this, since the process illustrates very forcibly what was said in an earlier part of this volume about the separation of the constituents of a mechanical mixture, and shows, too, the kind of simple operations of which the chemist makes daily use. If the gunpowder is boiled with water, and the liquid is then filtered through a paper cone made of

blotting-paper, the sulphur and the charcoal, being insoluble in water, are held back, and a colourless solution runs through the blotting-paper into a vessel placed to receive it. This solution, when allowed to cool or when evaporated a little, will deposit white crystals of saltpetre.

What takes place when gunpowder is fired is essentially a combustion of the charcoal, as a result of which large quantities of gas—carbon dioxide, carbon monoxide, and nitrogen—are suddenly evolved. The presence of the sulphur makes it more easy to fire the gunpowder, a lower temperature being sufficient to set it off; the function of the sulphur is therefore similar to that which it used to fulfil when employed in coating matches. In addition, however, the presence of the sulphur contributes to the rapidity with which the explosion is propagated, and its oxidation by the saltpetre adds materially to the heat evolved in the reaction.

The advantage of having the explosive material in a compact solid form can be seen from the fact that when gunpowder is fired in a closed space the pressure developed is about 2000 atmospheres, quite a different magnitude from the pressures obtained in the explosion of coal gas and air.

Gunpowder is the oldest explosive known, but it is largely displaced nowadays by so-called " high explosives," which, in addition to several other points of distinction, are practically smokeless. Any one can understand the long-cherished desire of the military and naval specialist to find some substitute for gunpowder, which when fired envelops the operator of a gun in a dense cloud of smoke. In the chemical action which accompanies the explosion the potassium from the saltpetre forms other salts, potassium carbonate and potassium sulphate. These

substances are dissipated by the force of the explosion in a state of fine division, and form the smoke. From such salts the modern high explosives are free, and they are consequently smokeless, or very nearly so. The applications of gunpowder are therefore more restricted than they once were. For firearms, large and small, it has been replaced by smokeless powders, but it is still largely employed for blasting purposes. It enters also into the composition of fireworks, in which, however, potassium chlorate frequently acts as the oxygen-supplying constituent instead of saltpetre.

In the manufacture of modern high explosives a new and interesting principle has been introduced. Gunpowder, as we have seen, is an intimate mixture of three solids, two of which are readily combustible, while the third supplies the oxygen necessary for combustion. In order that gunpowder may be a good explosive it is manifestly essential that the mixing of the constituents should be very thorough; provision must be made, as it were, for each combustible molecule finding near at hand another molecule out of which it can get the necessary oxygen, so that when the powder is fired no time may be lost, and the explosion may be as rapid as possible. As a matter of fact, great pains are taken in the manufacture of gunpowder to secure the most thorough mixing of the constituents.

Now in the modern high explosives the oxygen is introduced, not in the form of a compound which lies alongside the combustible constituent, but actually in the same molecule. In other words, chemical compounds are used as explosives instead of mechanical mixtures such as gunpowder is. This device secures an almost perfect mixing of the combustible elements with the oxygen, and the

natural result is that these modern explosives go off with much greater rapidity than gunpowder. It may seem strange to the reader that we can prevail on atoms of carbon, hydrogen, nitrogen, and oxygen to form for a time a peaceable combination which is ultimately to be rent asunder with such violence, and it must be confessed that the arrangement into which they are coaxed is somewhat of the nature of an unstable equilibrium, easily upset by any irritating cause. In this respect these high explosives have some resemblance to nitrogen iodide and mercury fulminate, but the process of explosion in the former cases is a real combustion, which the explosion of nitrogen iodide and fulminate is not.

Gun-cotton, nitro-glycerine, and picric acid, which either alone or in combination with other substances form the majority of the high explosives, are obtained by the action of nitric acid on cellulose, glycerine, and carbolic acid respectively. Nitric acid is a substance which contains a large proportion of oxygen, and its action on these materials is such that new substances are formed provided with a good deal of the oxygen which was previously in the nitric acid. The various explosives just mentioned are alike in containing a particular grouping of nitrogen and oxygen atoms known to chemists as the "nitro" group, and gun-cotton and the rest of them are therefore frequently referred to as the "nitro-explosives."

It is indeed very remarkable that a harmless thing like ordinary cotton when treated with nitric acid should undergo such a fundamental change, and be converted into a powerful explosive. Great care has to be taken in the process of manufacture, and only the best white cotton waste, perfectly free from grease and dirt, can
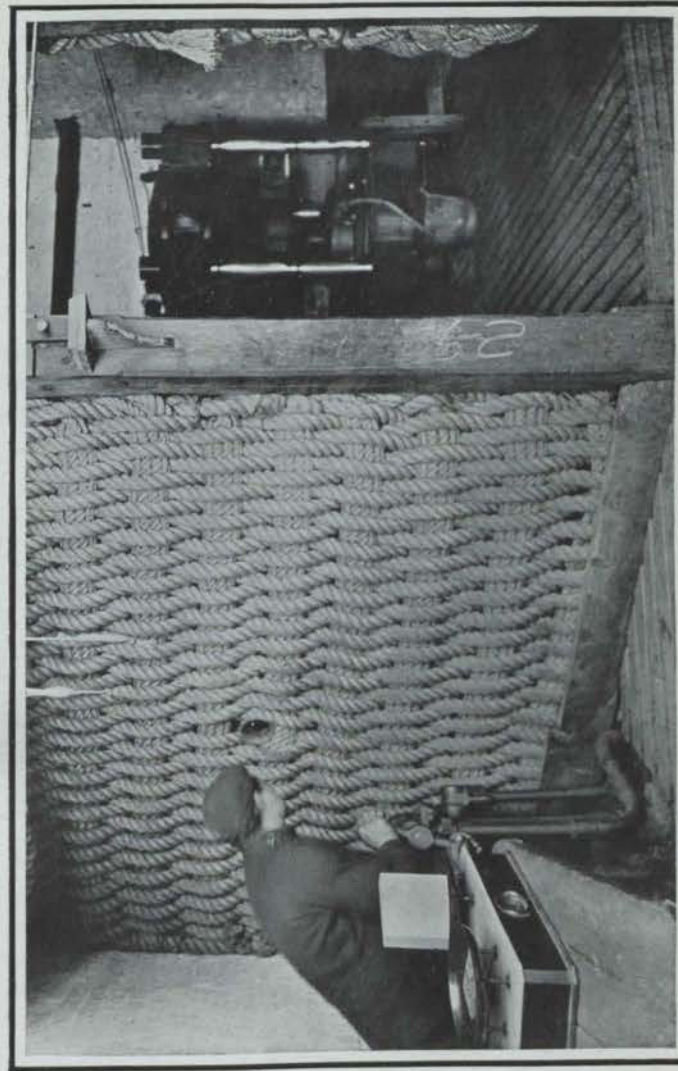
By permission of Sir Frederick Nathan   WORKING UNDER COVER   *Photo: Reinhold Thiele & Co.*

The machine in the background is a guncotton press, and the workman who operates the machine is protected, in case of accident, by a rope screen.

be employed. During the time the cotton is in contact with the nitric acid the temperature must be kept down, and subsequently every trace of acid must be washed away with water. It was owing to want of attention to this last simple precaution that many of the explosions which attended the early manufacture of gun-cotton were due. Any trace of acid left in the finished article acts like an irritant, and leads sooner or later to the decomposition of the explosive.

Gun-cotton is a most curious substance. It takes fire much more easily than gunpowder, and the rate at which it burns altogether depends on the way in which it has been ignited, and the conditions to which it is subject. A piece of loose gun-cotton may actually be burned on the hand without scorching the skin, merely by touching it with a hot glass rod ; it can be fired on the top of a heap of gunpowder without igniting the latter. Under such conditions the combustion of the gun-cotton is rapid, but not explosive. When, however, it is fired in a confined space, and the flame from the portion first ignited is driven into the remaining mass, the temperature is forced up and the combustion becomes an explosion.

It was therefore very naturally thought for a long time that in order to utilise the explosive force of gun-cotton it must be enclosed in some strong casing. Some forty years ago, however, the very interesting discovery was made that this was unnecessary, and that gun-cotton which was merely compressed, not confined in an enclosed space, could be exploded by a detonator, such as mercury fulminate. It is indeed a curious fact that if a little of this latter substance is exploded in the immediate neighbourhood of a mass of unconfined, compressed

gun-cotton, the gun-cotton explodes with extraordinary violence.

It is well known that if a violin is made to emit a particular note, the string of a second instrument in the immediate neighbourhood, if tuned to that note, will take it up and vibrate spontaneously. Some chemists have thought that something analogous to this takes place when mercury fulminate is exploded in contact with gun-cotton; the vibrations set up by the detonator are supposed to excite similar vibrations in the gun-cotton, so much so that the latter undergoes what might be called a sympathetic decomposition.

Whether this is the correct explanation or not, there is no doubt that gun-cotton fired by a detonator gives a much greater effect than the same material fired in the ordinary way. This increased effectiveness is due to the greater rapidity of the explosion induced by the detonator. Thus if a train of ordinary gun-cotton is touched with a hot rod the resulting combustion advances only a few feet in several seconds, whereas if a train of compressed gun-cotton is detonated by mercury fulminate it is estimated that the explosion is propagated along the train at the rate of 200 miles a minute.

Perhaps still more curious and valuable was the discovery that wet gun-cotton, which is not explosive under ordinary conditions, could be detonated as easily as the dry material. A red-hot iron may be put into a mass of wet gun-cotton without setting it on fire; and a Government Committee, in order to demonstrate incontestably the possibility of safely storing this explosive in the moist condition, once instituted experiments in which an iron case, containing a ton of wet gun-cotton was put in a magazine and surrounded with shavings and other in-

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flammable material. This was then ignited, and when the combustion was over the case of wet gun-cotton was recovered, none the worse for its baptism of fire.

Wet gun-cotton, however, can be at once exploded by detonation, provided only that a little of the dry material is in contact with the detonator. The old saying, therefore, "Keep your powder dry," is applicable only in a very limited sense to gun-cotton. It is, as a matter of fact, always stored in the wet state, containing about twenty per cent. of water; and it may be used in this condition in torpedoes and submarine mines.

A more dangerous explosive than gun-cotton is nitro-glycerine, a liquid obtained by the action of nitric acid on glycerine. The most extraordinary precautions have to be taken in the handling of this material, and it is only by a strict observance of these that a repetition of the disasters which marked the early years of nitro-glycerine manufacture is avoided. So serious were the accidents which occurred with nitro-glycerine some forty years ago that several governments went the length of altogether prohibiting the use of the explosive. Chemists soon discovered, however, the necessary precautions that have to be taken in the manufacture and handling of nitro-glycerine, and at the present day large quantities of this explosive are prepared.

In a nitro-glycerine factory the sheds in which the various operations are carried on are well separated from each other, and surrounded by banks of earth or sand. In order to avoid any risk of a spark being produced and setting off the nitro-glycerine, all workers have to wear special clothing. Boots with iron nails are absolutely prohibited, and in their place shoes of rubber, felt, or sown leather are employed. Girl operatives

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are forbidden hairpins, and no one is allowed to carry any article made of iron, such as knives or keys, for these by friction might give rise to a spark.

Such precautions being necessary, the reader will understand that the handling and transport of nitro-glycerine by the uninitiated person is fraught with great danger. Hence before it leaves the factory it is converted into various forms which involve less risk. The commonest of the explosive materials thus based on nitro-glycerine is dynamite. Certain substances have the power of soaking up or absorbing nitro-glycerine, and one of these which has been found very satisfactory is an infusorial earth known as *kieselguhr*, which takes in as much as three times its weight of nitro-glycerine. The resulting product is dynamite, a material which is less violent than the parent substance, and more easily and safely handled. Indeed, it was not until the little device of employing absorbent *kieselguhr* was adopted that the manufacture of nitro-glycerine assumed practical and commercial importance. This may be gauged from the fact that in 1870 the world's output of dynamite was only 11 tons, while twenty years later it had risen to 12,000 tons.

Dynamite, like gun-cotton, burns without danger when loose and in small quantity, but when fired by a detonating fuse of mercury fulminate it explodes with extreme violence and rapidity. Indeed, it is estimated that the time occupied in the explosion of a dynamite cartridge is only $\frac{1}{24000}$ of a second. One consequence of this is that when dynamite is used for blasting rock, the usual bore-holes may frequently be dispensed with, and the explosive may be laid on the top of the rock, covered merely with a little earth or clay.

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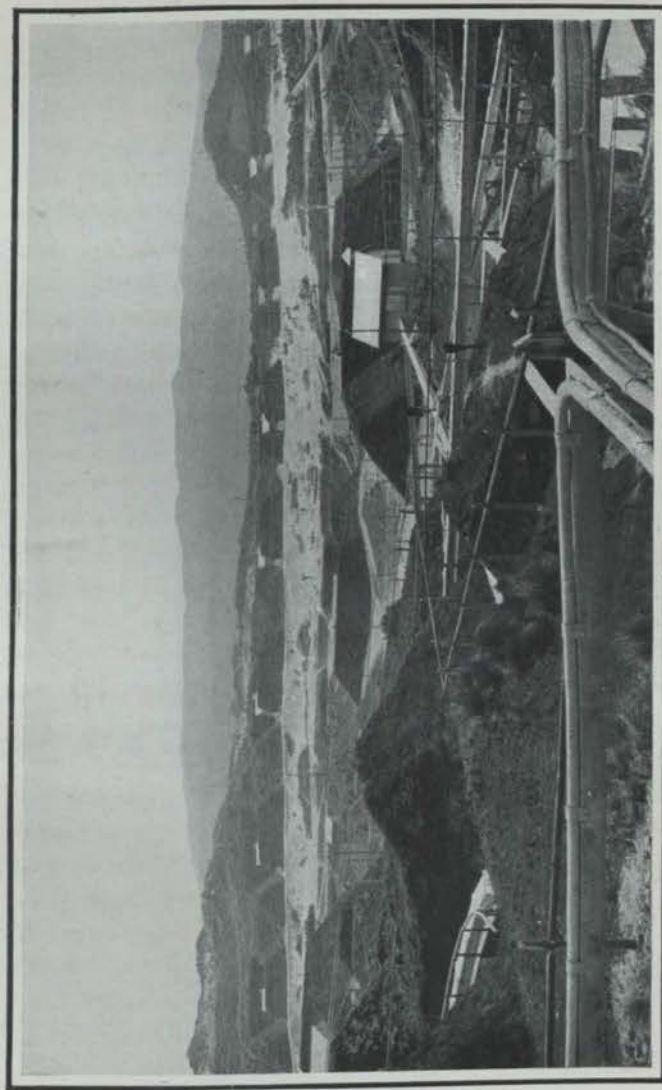
A DANGEROUS AREA

This represents a dynamite factory in Cornwall. The scattered sheds for the various stages of the manufacturing process are separated from each other by earthworks, so that in the event of any explosion the damage is localised. The pipes shown in the illustration convey water and acids to the separate sheds.

The greater sensitiveness of dynamite as compared with gun-cotton is well illustrated by their different behaviour when fired at with a rifle. If a wooden box filled with dry compressed gun-cotton is exposed to this treatment, the contents of the box are generally inflamed but never exploded. Dynamite, on the contrary, and other explosives derived from nitro-glycerine, cannot contain themselves when treated in such a fashion, and go off with great violence.

CHAPTER XVI

BELOW ZERO

IT is an old tale that Fahrenheit took as the zero of his thermometer the lowest temperature which was observed by him at Dantzic during the winter of 1709, and one of his contemporaries remarks that Nature never produced a cold beyond zero. This is quite a mistaken view, for plenty of cases are on record in which considerably lower temperatures have been observed as the direct result of natural cold. By artificial methods it is possible to realise a much greater degree of cold, and within the last ten years temperatures of about −400° Fahrenheit have been reached. As the mercury in our thermometers freezes at about −40° Fahrenheit, the reader will see that a lowering of the temperature to −400° brings us to altogether new conditions.

The way in which chemists and physicists have gradually pushed forward into the region of low temperatures is very remarkable, and their discoveries are not only of fascinating interest to the student of Nature, but have in some cases proved of practical and commercial value. The ambition to get "farthest north" has led to many thrilling adventures, but the Arctic exploration carried out recently in the laboratories of England and the Continent is not a whit less romantic.

The first step in the direction of low temperatures is taken when we can start with substances at the

ordinary temperature, and either by utilising some inherent property of these substances, or by treating them in some special way, induce the temperature to fall, say, below the freezing-point of water.

The mere bringing together of two substances may lead to either a rise or a fall of temperature. The reader may remember the reference made in a previous chapter to the fact that when sulphuric acid and water are mixed, so much heat is produced that the containing vessel becomes too hot to hold. The opposite effect is frequently observed when other substances are mixed with water. When saltpetre or sal ammoniac, for example, is stirred into water, the cooling effect is very noticeable, and by this simple method quite a considerable fall of temperature is produced. A mixture of these two salts, added to an equal weight of water at 50° Fahrenheit, brings the temperature down to 10° Fahrenheit.

More marked and more persistent cooling effects are obtained, if, instead of adding salts to water, we mix them with powdered ice or snow. Any one who procures common salt and snow, stirs them up well in the proper proportions, and puts a thermometer in the mixture will see the mercury fall below zero Fahrenheit. Such a freezing mixture may be used not only for getting a low temperature in scientific experiments, but also for the equally practical, if less exalted, object of making ices.

The question may very naturally be put: "Why should the mere bringing together of salt and snow result in such a marked fall of temperature?" The answer to this question is very closely connected with what was said in a previous chapter about the melting-point of alloys. Attention was then directed to the fact that the melting-point of any metal is lowered by the presence of another

metal. To the case of ice and salt a similar rule applies. Every schoolboy knows that pure water freezes at 32° Fahrenheit (0° Centigrade), but it is a curious fact that water containing salt does not freeze until a lower temperature has been reached. That means that a mixture of snow and a little solid salt should, strictly speaking, be in the liquid condition at 32° Fahrenheit; there cannot therefore be true equilibrium between snow and salt at this temperature.

Now, in Nature, things are always trying to get into the most stable condition possible, in other words, to reach their true equilibrium. Water finds its own level, a hot and a cold object put side by side gradually and of their own accord assume the same temperature, while positive and negative electricity unite whenever they get the opportunity. Similarly snow and salt, when mixed together at 32° Fahrenheit, do their best to get into that condition which Nature has prescribed as the most stable one for them at that temperature; the result is that the snow melts and the salt dissolves in the melted ice.

Now both these processes use up heat; as they take place spontaneously, this heat is taken from the surroundings, and the temperature of the mixture and of the containing vessel falls. The reader will at once admit that heat is required to melt snow, and he will see that the addition of salt is an ingenious way of persuading the snow to melt, and so to abstract a definite amount of heat from its surroundings. For the same quantity of heat is always required to melt a pound of snow, whatever be the way in which we cause the melting to take place.

So far as we have gone, then, methods of producing cold depend either on dissolving a solid in a liquid, or on making a solid melt by a little scientific stratagem. But

just as we can utilise the change of solid into liquid as a means of reaching lower temperatures, so we can employ another change of state for the same purpose—the change, namely, in which a liquid passes into the condition of a vapour. We usually convert a liquid into a gas or vapour by heating it; for the conversion of water at 212° Fahrenheit into steam at 212°, heat is as necessary as it is for the conversion of ice or snow at 32° Fahrenheit into water at the same temperature. Evaporation, then—that is, the process by which a liquid is changed into a vapour—only takes place when heat is supplied. If by any means we can cause evaporation to take place without the external application of heat, then the necessary heat will be taken from the evaporating liquid itself and its surroundings. Under these circumstances evaporation produces cold.

A very simple way of causing a volatile liquid to evaporate rapidly without heating is to blow a strong current of air through it. That by this method a considerable reduction of temperature may take place can be shown by a very simple experiment. A small pool of water is made on the top of a flat wooden block, and in this pool is set a flask containing strong ammonia solution. A strong current of air is then blown through the liquid with the aid of a bellows; the ammonia evaporates rapidly, and before long the flask is frozen hard to the block.

With these two general ways of producing cold at their disposal, Faraday and other chemists after him have been able to obtain in the liquid state many substances which exist ordinarily as invisible gases. The point to which the temperature of a gas must be lowered before it begins to liquefy will, of course, vary from one case to another. If we could imagine the temperature of our

globe as being normally about 250° Fahrenheit, then water would exist only in the form of vapour or steam, and in order to liquefy it we should have to bring the temperature below 212°, the boiling-point of water. At any temperature lower than 212° steam will condense under the ordinary pressure of the atmosphere. Now we must remember that every other liquid has its own boiling-point, and substances which we know as gases are simply liquids whose boiling-points are at a temperature lower than that prevailing on the surface of the globe.

Sulphur dioxide, for example, the colourless, choking gas which is produced when sulphur is burned, is very easily obtained as a liquid at temperatures not much below the freezing-point of water. The boiling-point of this liquid sulphur dioxide is 18° Fahrenheit under the ordinary pressure, so that when the gas is passed through a tube surrounded by a freezing mixture of ice and salt, it condenses to the liquid form just as steam would do if it were passed through a tube surrounded by cold water. It is, in fact, quite easy to obtain liquid sulphur dioxide, and it is now sold in syphons, just as if it were so much soda water.

When we come to gases like ammonia and carbon dioxide, which are less easily condensed, it is found advisable to use high pressure as an aid to liquefaction. The reader will understand the object of this if he remembers that the boiling-point of a liquid gradually rises with the pressure to which it is exposed. For example, water boils at 212° Fahrenheit under a pressure of one atmosphere, but at 250° when the pressure is two atmospheres. Conversely, then, when a gas is kept under high pressure, less cooling is necessary to bring it below its boiling-point.

By the combined application of cooling and compression both ammonia and carbon dioxide are readily obtained in the liquid form, and they are now commercial articles, sold in steel bottles or cylinders. With the aid of liquid ammonia and liquid carbon dioxide we are able to go a long step farther in realising low temperatures, for the cold produced by their rapid evaporation is very intense. This is well shown by what happens when the tap of a liquid carbon dioxide bottle is opened. The liquid is forced out in a fine jet by the high pressure which prevails in the bottle, and the cold produced by the evaporation of the outer portion of the jet is so great that the inner portions are solidified to a white, snow-like powder. If a coarse canvas bag is tied over the nozzle of the bottle while the liquid is escaping, a quantity of this curious solid carbon dioxide may be collected.

"Carbonic acid snow," as we may call it, can be placed on the hand without danger, but if pressed into the skin a serious blister is produced, the effect being pretty much the same as that caused by a red-hot metal rod. A number of interesting experiments can be made with solid carbon dioxide; if, for example, some of it is placed on the top of a little mercury in a dish, and some methylated spirit or ether is added, the mercury is very quickly frozen to a hard mass. In fact the temperature reached in this way is as low as −112° Fahrenheit; and if a mixture of ether and carbonic acid snow is made to evaporate very rapidly by connection with a suction pump the temperature reached is considerably lower still.

The temperature of −112° Fahrenheit just mentioned is the boiling-point of liquid carbon dioxide under atmospheric pressure; this substance is a conspicuous example of what may be called "cold boiling liquids,"

and the reader will see that boiling does not necessarily mean a high temperature. That liquid carbon dioxide, kept in an open vessel, is very cold can be simply shown by thrusting a piece of metal into it. There is a hissing and a bubbling exactly similar to what is observed when a red-hot poker is thrust into water; so that, relatively to the piece of metal, which is at the ordinary temperature, liquid carbon dioxide is exceedingly cold.

For purposes of refrigeration, in ice-making and cold storage, liquid ammonia is very largely used nowadays; rapid evaporation of this liquid under a suction pump gives a very low temperature, and if brine is circulated round the pipes in which the evaporation is taking place, it is rendered so cold that water may be frozen by it in large quantities.

The success of chemists in liquefying such gases as carbon dioxide and ammonia is now overshadowed by the greater achievements of the last ten or fifteen years, during which period liquid air and liquid hydrogen have been produced in quantity. This has become possible by the introduction of an altogether new principle in gas-liquefying machines—a principle which deserves a few words of explanation.

We regard a gas as consisting of an enormous number of separate particles or molecules moving rapidly in all directions; under ordinary conditions the total volume of the molecules is very much less than the space in which they move—in other words, the molecules are, relatively and on the average, not very close to each other. When, however, the gas is compressed, the molecules are crowded together, and they come within range of each other's attraction. Each molecule exerts an attractive force on its neighbours, and is in turn attracted

by them, so that when a highly compressed gas is allowed to expand, there is a social force resisting the separation of the molecules which is involved in the expansion. In overcoming this social force, work must be done, and for the performance of this work heat is required. This heat is taken mostly from the gas itself, which therefore exhibits the phenomenon of "self-cooling."

All this may be put more definitely and practically by saying that when highly compressed air is allowed to expand through a small nozzle or a porous plug, it becomes slightly colder. In the actual machines for making liquid air the device is further adopted of allowing the expanded and slightly cooled air to circulate round the coil of tubing through which the next lot of compressed air is approaching the nozzle. In such a regenerative process the cooling effects are accumulated, and the air which circulates through the machine, alternately compressed and expanded, becomes gradually cooler until at length it condenses and drops into a vessel placed to receive it.

A vessel which is to contain liquid air or liquid hydrogen must be specially constructed if it is to be of any use at all. If we were to put liquid air, which boils at −347° Fahrenheit, in an ordinary glass vessel we should very shortly see the last of it, owing to the heat communicated through the walls of the vessel. That is, in fact, exactly what would happen if we put a glass of water in a hot-air bath kept at 400° or 500°. Such a communication of heat, however, may be very much diminished, as Professor Dewar has shown, by using double-walled vessels and removing the air from the space between the walls. Sections of two such vessels, a tube and a flask, are shown in Fig. 9.

The importance of removing the air from the space between the walls will be realised when it is remembered that under ordinary circumstances that space is filled with molecules of oxygen and nitrogen rushing hither and thither. With the outer wall near the temperature of

the atmosphere, and the inner one in contact with liquid air, these molecules act like an army of heat-carriers. Each molecule as it strikes the outer wall will take up so much heat, which sooner or later it delivers up to the inner wall, only to return for a fresh supply. When the air is left in the intervening space the transfer of heat is therefore very rapidly effected, and the liquid air in the vessel soon evaporates. When this space, however, is rendered free from air, the heat-carrying molecules are removed, and the inner tube is more perfectly cut off from any heat exchange with the atmosphere. The insulation of the inner tube is made still more complete by silvering the inside of the outer one, for at such a bright surface the heat rays are reflected.
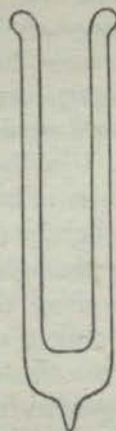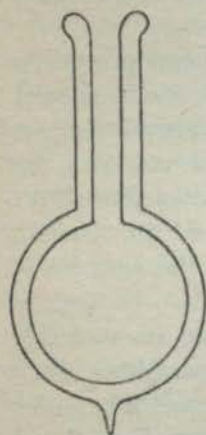
FIG. 9.—Double-walled glass vessels—so-called vacuum vessels. Owing to the absence of air between the walls, hot liquids put in such vessels remain hot, cold liquids remain cold, for a remarkably long time.

In a Dewar vacuum flask, surrounded by a non-conducting material like cotton-wool, liquid air may be kept

for over twenty-four hours, and the examination of its properties is thus rendered possible. Not only is it possible to study the properties of liquid air itself, but we can see how other substances behave when cooled to the temperature of liquid air. Their behaviour then is frequently quite different from what it is under ordinary conditions. Grass, leaves of plants, and indiarubber, for example, become so brittle when kept for a short time at the temperature of liquid air that they can easily be powdered in a mortar. An egg, after immersion in this wonderful medium, becomes so "hard-boiled" that it may be severely knocked about without being damaged. Chemicals, too, which react vigorously at the ordinary temperature, become mutually callous when cooled to the boiling-point of liquid air.

It has just been stated that liquid air boils at −347° Fahrenheit, but by boiling under reduced pressure the temperature is lowered to a point at which the air of the atmosphere will condense straight away. This may be very simply and very beautifully shown in the following manner. A Dewar vacuum tube (see Fig. 10), filled to the extent of two-thirds with liquid air, is provided with a cork. Through this cork there are passed (1) an empty glass tube, A, closed at the bottom and dipping into the liquid air; (2) a bent tube, B, open at both ends and
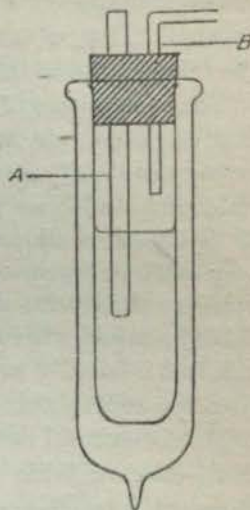
FIG. 10.—The apparatus sketched here serves to show the intense cold which is produced by boiling liquid air under diminished pressure.

leading to the vacuum pump. When the latter is turned on, the liquid air in the vacuum vessel begins to boil vigorously under the reduced pressure, and in consequence of the low temperature thus produced, air gradually condenses and collects as a liquid in the previously empty tube A. That, of course, is the natural result of bringing the temperature of the air in A below its boiling-point.

The composition of liquid air is not quite the same as that of gaseous air, for the simple reason that oxygen is rather more easily condensed than nitrogen, so that liquid air contains a higher proportion of the former. Further, if liquid air is allowed to evaporate slowly, it becomes very much richer in oxygen, for the nitrogen is the more volatile constituent, and passes off more readily, leaving behind a liquid with a higher proportion of oxygen. On this fact is based a method for the extraction of oxygen from the atmosphere.

More wonderful even than liquid air is liquid hydrogen. It is more difficult to prepare, for in applying the regenerative cooling process to hydrogen, it is necessary first of all to cool the compressed gas to a low temperature by means of liquid air before it is allowed to issue from the nozzle of the apparatus. Dewar, however, has made considerable quantities of liquid hydrogen, and on one occasion over a gallon of the substance, made in his laboratory, was carried through the streets of London to the rooms of the Royal Society. This quantity would weigh only about eleven ounces, for liquid hydrogen is by far the lightest liquid known to the chemist; bulk for bulk, it is only one-fourteenth as heavy as water.

Some very interesting experiments have been made at these extremely low temperatures on the vitality of bacteria and seeds. Typical bacteria were exposed for

a number of hours to the temperature of liquid air, but their vitality was not destroyed by this treatment. Barley and peas have been kept for six hours in the liquid itself, and yet when they were sown subsequently in the ordinary way no falling off in the power of growth could be detected.

It is possible to get a very high vacuum in a closed glass tube by simply immersing one end of it in liquid hydrogen. The boiling-point of the latter is about 100° Fahrenheit lower than the boiling-point of liquid air, and the mere contact of one end of the tube with the liquid hydrogen is sufficient to condense the air which it contains so completely that none is left in the upper part.

The attainment of such low temperatures has raised the very interesting question as to what prospect there is of ever reaching the "absolute zero." On various grounds, chemists and physicists believe that at a certain temperature, $-460°$ Fahrenheit, the existence of a gas as such would cease to be possible; the movements of the molecules, which we have learned to regard as characteristic of a gas, would be so paralysed by the intense cold as to stop altogether; the chill of death would settle on their activity. This temperature is called the "absolute zero," and is in the eyes of low temperature investigators what the North Pole is to Arctic explorers.

In this connection the year 1908 will be remembered as the year in which helium, the most obstinately gaseous substance known, was reduced to the liquid state. The labour expended in procuring even so little as 2 ounces of liquid helium can hardly be appreciated by the lay reader, but it may be mentioned that the preliminaries consisted in the preparation of 16 gallons of liquid air and 4½ gallons of liquid hydrogen! By boiling the

liquefied helium under reduced pressure the temperature of $-454°$ Fahrenheit was reached—only 6° from the absolute zero. It might therefore be thought that this interesting point was practically within reach, for an interval of 6° does not seem a very serious obstacle. At these low temperatures, however, an advance of even 1° is a very great matter, and it must be confessed that there is no immediate prospect of reaching the chilly goal.

CHAPTER XVII

CHEMISTRY AT HIGH TEMPERATURES

IT is not only into the region of low temperatures that such a surprising advance has recently been made. Much has been achieved also in the other direction, and it has lately become possible to realise within a limited space a degree of heat far beyond what can be produced with the aid of ordinary fuel alone. This attainment of extremes of heat and cold has immensely widened the range of temperature over which the chemist can study the properties of matter, and as a result many new substances, as well as new methods of making old substances, have been discovered.

One result of low temperature research, as we have seen, is that all the known gases have been reduced to the liquid state, and in many cases even solidified. Similarly, by the recent application of very high temperatures, the most refractory solids have been melted and even vaporised.

Apart, however, from the extremely high temperatures reached by recent methods, there are easily attainable temperatures at which many substances, existing ordinarily as stable solids, are first melted and then converted into vapour. Now the possibility of changing any substance into vapour without decomposing it involves a great deal ; for it means that a distillation can be carried out, and as a method of separating and purifying chemical compounds,

this is one of the most ancient and valuable laboratory operations. When, for instance, a salt solution—in other words, a mixture of salt and water—is boiled and the steam condensed, it is found to be pure water, perfectly free from salt. This operation of boiling and then condensing the vapour—"distillation," as it is called—obviously makes it possible to separate salt and water, simply because the water is easily vaporised, in contrast to the salt. The same principle may be applied in numberless other cases. Metals, for instance, which are comparatively volatile, such as mercury and zinc, may be separated by distillation from others, such as copper and iron, which are mixed with them and which are much less easily vaporised.

A rise of temperature, however, not only makes it possible to melt and then vaporise many solid substances, but it has also the general effect of weakening the bonds which hold together the atoms in a molecule. On heating a chemical compound the chances are that when a certain temperature is reached it begins to break up into simpler compounds, or even into the constituent atoms. This change is known as decomposition or dissociation. The former term is applied to the case in which the atoms or simpler molecules, having been once separated by heat, show no signs of coming together again on cooling; they have done with each other for good and all. But in many cases the interesting observation has been made that the separation caused by heating the compound molecule is spontaneously reversed on cooling, and the compound is re-formed, provided, of course, that the atoms or simpler molecules have been allowed to remain side by side. The effect of heating such a compound is described as "dissociation," and this is followed on cooling by an "association" of the separated atoms or molecules

These cases of dissociation are of great interest, and there are many common substances which undergo this change on heating. Carbonate of lime in its various forms—limestone, chalk, and marble—is one of them. When heated it breaks up into quicklime (calcium oxide) and carbon dioxide. If the latter were left in contact with the quicklime, then, on cooling, re-combination would take place, and the carbonate of lime would be regenerated. This being so, the reader may ask how it is possible to convert limestone into lime by heating or "burning" in kilns. The explanation is quite simple, for in the lime-kilns the carbon dioxide is constantly being removed by the draught, so that when the lime begins to cool, the carbon dioxide with which it would gladly have combined is not there.

This interesting phenomenon of a chemical change taking place in one direction at a particular temperature, and in the opposite direction at another temperature, is very well illustrated by one of the common methods for obtaining oxygen from the atmosphere on the large scale. There is a solid compound, somewhat similar to quicklime, known as barium oxide, which at a temperature of 1100° Fahrenheit or thereabout readily takes in more oxygen, forming a new substance —barium dioxide. The grip of the latter, however, on the extra atom of oxygen is not very secure, and by raising the temperature to 1560° it can be so weakened that the gas is released and may be collected. In the actual manufacturing process a current of air is pumped into retorts heated to 1300° Fahrenheit and containing barium oxide, which takes up the oxygen and allows the nitrogen to pass on. When the charging is completed, the current of air is shut off, and the retorts,

which now contain a certain proportion of barium dioxide, are connected with a suction pump. The effect of this diminution of pressure is the same as that of a rise of temperature, and from the engineering point of view it is better to alter the pressure than to alter the temperature. The barium dioxide accordingly gives up the extra oxygen which it extracted from the air, and the oxygen so obtained is compressed in steel bottles under a pressure of 120 atmospheres and sent into the market. The barium oxide may be used over and over again in the same fashion, and, theoretically at least, a given quantity of this substance should suffice for the winning of unlimited quantities of oxygen from the air, by alternate association and dissociation.

The highest temperatures reached in furnaces fed with ordinary fuel—the furnaces employed for technical purposes—lie about 3200° Fahrenheit, but it is possible to get a few hundred degrees beyond that with the oxy-hydrogen blowpipe. When we feed a coal-gas flame with a blast of air as in an ordinary blowpipe, we get a very high temperature, but the effect is wonderfully increased by substituting oxygen for air. The reason of this is not far to seek. Roughly speaking, air consists of one part of oxygen to four parts of nitrogen; the latter gas, although it takes no part in the combustion, yet passes through the flame and has to be warmed up, thereby absorbing a considerable proportion of the heat produced by the combustion. In the oxyhydrogen or oxy-coal-gas flame the nitrogen is not there to dilute the active oxygen, so that the temperature reached is very much higher.

The increased heating effect secured in this way makes it possible to melt platinum, and the operation is actually

carried out in the winning of this metal from its ores. The furnace in which the platinum is melted must obviously be of some material which has a higher melting point still, and quicklime is found to fulfil this requirement. Pipe-clay, when put in the oxyhydrogen flame, is immediately fused to a sort of glass, while gold and silver not only melt, but vaporise into a dense smoke.

Even the temperatures of the oxyhydrogen or oxy-coal-gas flame, however, are comparatively chilly in comparison with those which are now attainable in the electric furnace. Within the last fifteen or twenty years the efficiency of this furnace has been so improved that temperatures of 6000° Fahrenheit can be reached, and under these conditions many common substances are found to behave in a most extraordinary manner. Such a furnace consists essentially of a hollow box made of some non-conducting material, into the cavity of which project two carbon rods. An electric arc is established between these rods, with the result that an extraordinary degree of heat is attained in the cavity of the furnace.

As was said in a previous chapter, electricity is generated as a rule in a dynamo, driven by an engine, which in its turn depends for its power on the chemical process of combustion. In the electric furnace we merely get back a certain fraction of the heat which was produced in the combustion, and the reader might be inclined to consider the whole affair a wasteful cycle of operations. Economical it certainly is not, but the advantage lies in this, that in the electric furnace the heat, which originally was distributed over a considerable space, is concentrated in a fraction of a cubic foot. The effect is locally intensified, the temperature is higher, and this

is of the utmost importance, as it turns out, for certain processes. It must be remembered too, that these objections on the score of economy lose their force in cases where water-power is available for driving the dynamos, as it is, for example, at Niagara and in Norway.

One of the chief difficulties in working at such high temperatures as are reached in the electric furnace is to find a suitably refractory substance out of which the enclosing box may be constructed. Up to a certain point quicklime is an excellent material. As its employment in the oxy-hydrogen lime-light shows, it is not easily fused, and it has further the recommendation of being a very poor conductor of heat. This latter property was well demonstrated in an experiment carried out by the French chemist Moissan, whose name will always be associated with the utilisation of the electric furnace. In one of the lime furnaces which he employed, the top consisted of a slab of quicklime rather less than $1\frac{1}{4}$ inch thick. The electric arc was allowed to play for ten minutes in the cavity below the slab, the temperature rising probably to over 5000° Fahrenheit. In spite of this, the slab could be handled on the outside without discomfort, while examination of the lower surface, which had been in contact with the arc, showed that the quicklime had actually been melted over an area of several square inches. The tremendous heat, therefore, which had been generated in the cavity of the furnace had been completely kept in by a layer of lime $1\frac{1}{4}$ inch thick.

With bigger currents and more powerful arcs even lime furnaces become useless; the lime fuses and runs like water, and ultimately it boils, producing clouds of smoke. The difficulty may be partly surmounted

by enlarging the cavity of the lime furnace, and making a little platform of $\frac{1}{2}$-inch plates of magnesia and carbon, arranged alternately. Using a device of this sort, Moissan was able to study the behaviour of a large number of substances at temperatures up to 6000° Fahrenheit.

In the earlier part of this chapter it was said that, compared with zinc at least, copper was not volatile. Things are quite different, however, at the temperature of the electric furnace, as appeared from Moissan's experiments. A piece of copper weighing nearly four ounces was put in a carbon crucible in the furnace, which was then warmed up for five minutes by a big current. Soon after the current was turned on, dazzling flames, 18 inches long, burst out violently through the openings at the ends of the furnace. These flames were due to copper vapour burning in the air; and it was found after the experiment was over that the copper left in the furnace now weighed only 3 ounces, 1 ounce of the metal having been converted into vapour. Similar and equally surprising results were obtained with such refractory metals as silver, gold, and platinum.

One of the most surprising things accomplished in Moissan's electric furnace was the vaporisation of silica. This substance, as the reader may already be aware, is the oxide of the element silicon, and is the main constituent of sand and quartz. Indeed, quartz is nearly pure silica. It is melted with the greatest ease in the electric furnace, and after seven to eight minutes issues through the openings as a bluish smoke or vapour— another proof of the really fervent heat which is generated in this way.

While the electric furnace has astonished us by revealing the volatility of even the most staid and refractory

materials known to the chemist, it has at the same time brought to light a number of substances which are quite at home at these high temperatures; indeed it is the electric furnace alone which has enabled us to prepare them. Among these substances are the carbides—compounds of the metals with carbon—and it is in the preparation of one of these, namely, calcium carbide, that the electric furnace is most extensively employed at the present time. Moissan showed that by heating a mixture of pure lime and carbon in the electric furnace calcium carbide could readily be obtained, and this is the method now employed on the manufacturing scale, except that limestone and coke are used as crude materials instead of lime and carbon. The use of limestone instead of lime does not really involve any difference, for at the high temperature employed the limestone loses its carbon dioxide and is converted into lime. The other material, the coke, is at best a very impure form of carbon, so that the calcium carbide obtained in the manufacturing process is not a pure product.

The essential chemical change which goes on in the electric furnace during the formation of carbide is an extremely simple one. Lime is a compound of two elements, calcium and oxygen, but this union is broken by the interposition of carbon at the high temperature of the furnace. This latter element combines with both the calcium and the oxygen, so that these two are separated. The new compounds formed, calcium carbide and carbon monoxide, are quite distinct in their properties, for the former remains in the furnace in a fused condition, while the latter is a gas, and escapes at once.

As the reader probably knows, the characteristic feature of calcium carbide is that it gives off an inflammable

gas, acetylene, on contact with water. One usually regards flame and water as essentially antagonistic, but here is a case where water is a *sine quâ non* in the production of an inflammable gas. The curious action between the water and calcium carbide molecules consists simply in a change of partners. The hydrogen of the water unites with the carbon of the carbide, forming acetylene, while the oxygen of the water combines with the calcium of the carbide, forming quicklime, which promptly slakes in excess of water.

Acetylene, when burned at specially constructed nozzles, gives a very brilliant flame, more like sunlight in its character than any other artificial illuminant. On this ground there is much to be said for the use of acetylene for lighting purposes. The portable nature of calcium carbide, and the ease with which the gas can be obtained from this material, are circumstances also which have favoured the introduction of acetylene as an illuminant, especially in places where electricity and coal gas are not available.

The eagerness of carbon to unite with both calcium and oxygen at the temperature of the electric furnace, as illustrated by the formation of calcium carbide, has found a recent interesting application in the manufacture of phosphorus. The chief source of this element is bone ash, which consists to a large extent of calcium phosphate, a compound of calcium, phosphorus, and oxygen. In the older process for obtaining phosphorus from bone ash, it was put through quite a number of distinct operations, but nowadays, with the aid of the electric furnace, a much more straightforward plan is feasible. By simply mixing the bone ash with carbon and heating in the furnace, the carbon annexes both the calcium and the oxygen,

forming calcium carbide and carbon monoxide; the phosphorus, on the other hand, escapes as a vapour, and is condensed under water in the usual manner.

It is not only in the electric furnace that the high temperature of the electric arc has been utilised, but also in connection with the interesting problem of the utilisation of nitrogen from the atmosphere for agricultural purposes. For the fertilisation of the soil large quantities of nitrogenous material are required, which are at present derived to a great extent from Chili, where extensive deposits of sodium nitrate—Chili saltpetre, as it is called—are found. Those who should know best are of opinion that these nitrate beds will be exhausted in thirty years or thereabout, and hence it was that Sir William Crookes, in his presidential address to the British Association in 1898, insisted on the necessity of discovering some way by which the great store of nitrogen in the atmosphere could be made available. The problem is by no means easily solved, for nitrogen is very slow to enter into combination with other elements. With the aid of the electric arc, however, it is possible to induce some of the oxygen and nitrogen in the air to unite, forming nitric oxide, which in its turn can easily be converted into nitric acid or nitrates. This has been known to chemists for a long time, but it is only recently that the difficulties in the way of making the process a commercial success have been overcome. Within the last few years the necessary plant for carrying out this process on the large scale has been set up in Norway, where power is cheap; the factories there are now turning out large quantities of nitrate of lime, suitable for fertilising purposes, and capable of replacing the natural nitrate brought from Chili.

CHAPTER XVIII

CHEMISTRY OF THE STARS

FROM a study of the electric furnace and of the curious effects which very high temperatures have on the various substances known to the chemist, it is but a short step to a consideration of the conditions which prevail on the sun and other heavenly bodies, where Nature herself has concentrated so much heat. What is the constitution of the sun and stars? Do the elements of which they are composed differ from those with which we are familiar? How is their condition affected by the high temperatures which prevail there? Such are some of the questions which occur to us in this connection.

To these and similar inquiries the older astronomy had no reply. It displayed a marvellous power of calculating times and seasons, of accurately predicting the movements of the celestial army, but as to the materials of which these other worlds were built up, it had nothing to say. At one time, indeed, it looked as if astronomical science had come to the end of its tether; it had attained such a thorough mastery of the problems connected with the movements, the size, and the distances of the heavenly bodies, that no very startling advance was to be expected in that direction, and there was no hope that the constitution of these bodies would ever be discovered by working on the old lines.

How different is the outlook nowadays! Much information is available as to the actual elements of which the sun and stars are composed, and it may with truth be said that we know more about the chemical composition of the heavens above than about that of the earth beneath. For man, with all his wonderful achievements, has scratched only the surface of the globe, and we can but speculate about the materials of which the interior is composed. It is, indeed, exceedingly probable that large quantities of iron exist in the interior of the earth, firstly, on account of the fact of terrestrial magnetism, and secondly, because the average density of the earth as a whole is considerably greater than the average density of the crust—pointing to the presence of some heavy metallic material at lower depths. But no direct evidence is forthcoming as to the actual composition of the interior of our globe.

If a scientist were asked, however, to name some of the materials of which the sun is composed, he would be ready with an unhesitating answer, and this would be the case also in regard to many of the stars. How has this come about? How is it that we can speak now so confidently about the constitution of heavenly bodies, whose distance is measured in millions of miles, and whose very presence in the sky speaks so eloquently of the unattainable and the mysterious?

We certainly cannot travel to the heavenly bodies in order to study their chemical composition, but we do have occasional visitors to our planet from celestial spaces. These are the meteorites, the falling of which from the sky has excited both fear and wonder in the breast of man, and the life-history of which scientists so much desire to know. Some consider that meteorites are

terrestrial in their origin, and have been projected into space from active volcanoes in long-past ages of the earth's history; but the opposite opinion is most widely held, namely, that they are genuine samples of celestial matter.

An inspection of the fine collection of meteorites in the Natural History Museum at South Kensington will show that many of them consist to a large extent of iron, or rather of an alloy of iron with a small percentage of nickel. Other meteorites contain but little iron, and are more like stones in their composition. Altogether there is considerable similarity in the composition of meteorites which have fallen at different times and in different places, and this uniformity has suggested to some scientists that most meteorites, if not all, have come from a common source, and are possibly chips of one heavenly body.

No single element has been found in a meteorite which is not obtainable also from terrestrial sources. The ones which occur most commonly in these other-world chips, in addition to iron and nickel, are aluminium, calcium, carbon, magnesium, oxygen, phosphorus, silicon, and sulphur, all in a state of combination. Some, indeed, of the compound minerals occurring in meteorites are new, and it is curious that quartz, the most common of terrestrial minerals, should not be found in meteoric stones.

The study of the composition of these celestial visitors is of the greatest interest, but it is not from them that our trustworthy information about the constitution of the sun and stars is derived. This information is obtained in a much more wonderful fashion; it is based, not on any laboratory examination of celestial specimens, but on a

study of the light which comes to us from the heavenly bodies, in other words, on the use of spectrum analysis.

When white light, such as is obtained from the upper part of a candle flame, is passed through a slit at the end of a telescope, and then through a glass prism, it is seen as a strip which is red at one end, violet at the other, and between these two extremes passes continuously through the various shades of orange, yellow, green, and blue. This strip of graded colour is known as a continuous spectrum, and it results from the splitting up of white light into its various components, which is effected by the prism. The apparatus consisting of all the necessary parts for the production and observation of a spectrum is known as a spectroscope, and this is the instrument which has yielded such marvellous results in the study of the sun and stars.

If we were to examine with a spectroscope the light given out by a red-hot poker we should see only the red end of the spectrum. If the poker were put in the fire again and its temperature were raised, the spectrum observed would show some orange and yellow as well as red, while if we brought the poker to a white heat and examined it in this condition with the spectroscope, we should see a spectrum perfectly continuous from the red to the violet end. Molten iron also would exhibit a continuous spectrum, and one can say generally that the spectrum of the light emitted by any incandescent solid or liquid is continuous.

It is quite easy, however, to get an incomplete spectrum, one which consists only of isolated lines or bands of different colours. In order to do that we have merely to examine with the spectroscope the light which is emitted by an incandescent *vapour*. One of the simplest spectra

of this kind is obtained by introducing a little common salt (sodium chloride), say on the previously charred and moistened end of a match, into the non-luminous flame of a spirit-lamp or a Bunsen burner. To the naked eye the
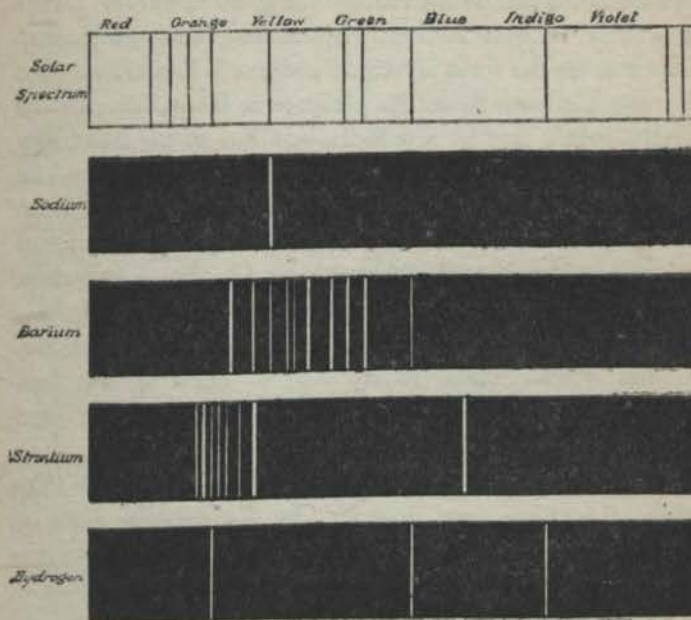

FIG. 11.—The spectrum at the top is diagrammatic only, and serves to show that the sun's spectrum consists of dark lines on a coloured background. The actual solar spectrum contains an infinitely greater number of lines than are represented here.

flame will assume an intense yellow colour, and if the spectroscope is directed towards it, the spectrum is seen to consist of a single yellow line, as shown in Fig. 11; the flame, in fact, is giving out only one particular kind of light. With a first-class instrument, this line turns out to be two distinct lines very close together, but this

division is not apparent with an ordinary spectroscope, and need not concern us here.

Suppose now we were to introduce into the Bunsen-burner flame some other salt of sodium—washing soda, for example—we should get exactly the same spectrum. This is a fact of the greatest significance, indicating that whatever be the form in which sodium is introduced into the non-luminous flame, its presence is invariably marked by the yellow line at a definite position in the spectrum. From this simple case the reader will easily appreciate the power of detection with which the spectroscope equips the chemist. For if the question arises whether a given substance contains sodium or not, he has but to introduce some of it into a Bunsen-burner flame and see whether that incriminating yellow line appears in the spectrum. It has actually been found that as little as one ten-millionth of a grain of a sodium salt can easily be detected in this way.

Other incomplete spectra, generally more complex than that of sodium, are observed by introducing salts of various metals into the non-luminous flame of a Bunsen burner (see Fig. 11). Barium salts, for example, impart a green colour to the flame, and their spectrum is characterised by a number of green lines; strontium salts, on the other hand, tinge the Bunsen flame a brilliant crimson, and their spectrum contains a series of lines and bands mostly at the red end. It is probable that every reader, perhaps without knowing it, has seen the colours which barium and strontium salts impart to a flame, for the green and red lights which figure so largely in firework displays are produced by adding these salts to combustible mixtures containing sulphur.

For the detection of sodium, barium, or strontium the

reader might think it sufficient to observe the colour which a substance under examination imparts to the Bunsen flame. So it would be, provided only one of the metals was present; this condition, however, will not always hold good, and when two or more are present the colour of the flame will give no certain indication. But it is just here that the full value of the spectroscope becomes apparent, for each constituent in a mixture contributes to the spectrum its own quota of lines, uninfluenced by the others which are present.

This marvellously sensitive spectroscopic method of analysis can be applied not only to metallic salts which are volatile in the Bunsen flame, but also to substances like hydrogen, which are gases at the ordinary temperature, and to refractory metals such as iron. Ingenious devices have been adopted for bringing these into the state of incandescent vapour, from which alone we may expect to obtain a characteristic discontinuous spectrum. Hydrogen, for example, is filled into a glass tube at low pressure, and an electric discharge is passed through the rarefied gas; the spectrum of the glowing hydrogen is then found to be characterised by three main lines, red, green, and blue respectively (see Fig. 11). To obtain the spectrum of iron, on the other hand, the metal or one of its compounds is placed between the poles of an electric arc. At the high temperature of this discharge, the iron is partly converted into incandescent vapour, and its spectrum, containing an enormous number of lines, is visible. When once the characteristic spectra of the elements, obtained by one or other of the methods just described, have been properly mapped out, then each line which we observe in any new spectrum may be referred to the element which is responsible for it.

All this is more or less by way of introduction, and we come now to the celestial problem. If a telescope is directed towards a star, a nebula, or a comet, and the light proceeding from this heavenly body is examined spectroscopically, we find, in a certain number of cases at least, a spectrum consisting of definite lines or bands, and on comparing these with the spectra already mapped, we can with confidence affirm that such and such elements are present in the far-off heavenly body. A bold step this, right out to the confines of space, and yet one which is fully warranted by the scientific evidence.

In the spectrum of a nebula there are bright lines which are identical with the characteristic hydrogen lines, so that the latter element must be one of the constituents of a nebula. The spectrum of a comet is closely similar to that of the element carbon, as obtained by examination of the blue base of a candle flame; cometary matter, therefore, contains carbon. Curiously enough, as a comet approaches the sun, its spectrum alters in character, and evidence is obtained that sodium and iron also enter into its composition.

Surprise is in store for us when we come to examine spectroscopically the light which comes from the sun and the great majority of the stars. Instead of getting isolated coloured lines or bands on a dark background, we observe a complete reversal of this, namely, dark lines on a coloured background (see Fig. 11).

The explanation of this puzzling phenomenon is best understood perhaps by reference to an actual experiment. If we were to direct a spectroscope towards an electric arc light, in which there is incandescent solid carbon, we should observe a continuous spectrum. Suppose now that between the spectroscope and the arc light

we interpose a Bunsen flame coloured yellow by incandescent sodium vapour, the effect on the spectrum is rather surprising. The continuity of the spectrum is seen to be broken by a dark line which occupies the exact position of the bright line in the ordinary sodium spectrum, as might easily be shown by momentarily screening off the arc light behind. The arc light is at a much higher temperature than the Bunsen flame, and what has happened is that the sodium vapour in the latter has absorbed or picked out of the light from the hotter source exactly those rays which it itself usually emits. The light which passes on is therefore bereft of those particular rays, and the spectrum shows the deficiency.

The reader must remember that light is a species of vibration, and that just as the string of a musical instrument will respond alone to that particular note out of many which has its own pitch, so an incandescent vapour will absorb exactly those rays which it emits. Provided, therefore, that the source of white light behind is hot enough, the passage of the light through various incandescent vapours at a lower temperature will be revealed by a number of dark lines on the spectrum exactly at those positions which bright lines from the vapours themselves would occupy.

The solar spectrum, then, consisting as it does of a very large number of dark lines on a coloured background, tells us that the centre of the sun is at a white heat, and that this incandescent core is surrounded by an atmosphere of incandescent vapour at a somewhat lower temperature. By comparing the positions of the dark lines in the solar spectrum with the bright lines in spectra which have already been mapped, we learn

what is the composition of the sun's atmosphere—the chromosphere, as it is called. Among the elements which are thus proved to be present in the sun are hydrogen, sodium, calcium, barium, magnesium, iron, zinc, and copper. The reader will see that so far as the mere elements go, there is nothing very strikingly novel about the composition of the sun, but there is probably a considerable difference between the earth and the sun in the extent to which the elements are combined. On the earth the elements just named are almost without exception found in the form of compounds, but at the high temperature of the sun all ordinary compounds will have undergone dissociation into their constituent elements. It appears pretty certain that the temperature of the sun is not below 10,000° Fahrenheit, in comparison with which the electric furnace, our best attempt at producing a high temperature, is miserably cold.

Similar conclusions as to the composition of the stars have been drawn from their spectra, and it appears that the elements entering into their composition are pretty much those with which we are familiar. Astronomers have actually ventured a step farther, and endeavoured to estimate the approximate temperature of each star from the character of its spectrum. This attempt is based on the observation that the spectrum of an element varies somewhat according to the way in which it is vaporised. According as the substance is exposed to the action of a flame, of the electric arc, or of the electric spark, a different spectrum is produced. The conclusions which astronomers have drawn from these observations are deeply interesting; but that is another story.

A very curious fact in connection with the application

of spectrum analysis has been the discovery of an element in the sun before it was known on the earth. In 1868 attention was drawn to a conspicuous bright line in the spectrum of the sun's atmosphere which did not correspond to a line of any element which was then known. Lockyer and Frankland did not hesitate to assert that there must be a new element in the sun, and immediately proceeded to its christening: they called it "helium" (Greek, ἥλιος, the sun).

This is an excellent illustration of the confidence which scientists have in the trustworthiness of the spectroscopic method, a confidence which in this particular case was justified after the lapse of nearly thirty years. In 1895 Sir William Ramsay, working with the rare mineral cleveite, discovered a gas the spectrum of which contains a line coincident with the mysterious bright line already mentioned. This gas is, in fact, helium, and although it is an element of comparative rarity on our globe, it appears to play an important part in the constitution of the sun and stars.

Examples of the wonderful detective power of the spectroscope might be multiplied. One might quote, for instance, the discovery of two new alkali metals, rubidium and cæsium, by Bunsen and Kirchhoff, some fifty years ago. These workers, whose names are so closely associated with the marvellous development of spectrum analysis, detected some new lines in the spectrum of a liquid obtained by concentrating a certain German mineral water. They boldly concluded that there was in this water some previously undiscovered element, and they forthwith proceeded to search for it. And this element, cæsium, took some finding! *Forty tons* of the mineral water had to be evaporated and operated on before as much as one-

quarter of an ounce of cæsium chloride could be collected. A splendid tribute this, not only to the sensitiveness of the spectroscopic method, but also to the confidence and patience of the searchers.

Among the many problems raised by the spectroscope is that concerning the peculiar light of the Aurora Borealis. Its spectrum is characterised specially by a bright yellowish-green line, which has given rise to much discussion, and which for long could not be referred to any known element. Again the discoveries of chemists have supplied the clue, and it appears that krypton, one of the recently detected gases of the atmosphere, is the responsible party.

CHAPTER XIX

CHEMISTRY AND AGRICULTURE

IT is becoming more and more obvious as time goes on that there is scarcely any department of Nature's activity, scarcely any useful art practised by man, in which the laws and principles of chemistry are not involved. In the delicate processes which go on in our bodies, in the roaring of the blast furnace, in the silent growth of the tiniest blade of grass, chemical forces are at work, merely on atoms and molecules, and yet producing changes which in their sum total can be described only as mighty and marvellous. The activity of these forces has often remained unsuspected for long ages, and man's skill in many useful arts has been acquired, not from any scientific knowledge of the underlying principles, but by long experience and practice.

Agriculture is a case in point. Since Adam delved, the art of tilling the soil has been a common occupation, and a vast store of practical knowledge of agriculture has been gradually accumulated. In these days of competition, however, rule-of-thumb methods, handed down from father to son, are not sufficient to command success, and the aid of the chemist has to be invoked. We can well imagine how ancient and hoary Agriculture might resent the in-trusion into its domain of the modern upstart Chemistry. As if it had any right to teach Agriculture why and how it ought to do this and that! This struggle between the

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practice of the past and the knowledge of the new age is always recurring, and we are slow to learn the lesson that the science of the laboratory cannot in the long run be kept out of the field, the factory, the workshop, or even the kitchen.

Suppose, then, we consider for a little what chemistry has to teach us about the growth and culture of the vegetable world, about the yearly marvel of wood and field and garden. For it is a marvel. Look at the fields in the time of sowing; they are brown and bare and dead. Look at them five months later; they are clothed with an abundant garment of living green or gold. In the interval no influence but that of soil and sun, of wind and rain, has played upon the seed and the growing plant. Whence, then, all this wealth of fresh material? Is it a new creation, or is it an equally marvellous transformation? If the latter, what are the substances which have been changed, as by a magician's wand, into stem and leaf and flower?

Surprising as it may seem, it is only three hundred years ago since a chemist of repute endeavoured to show that vegetable substances were produced from water alone. The experiment by which he sought to prove this was a very simple one, and is worth rehearsal. The story shows how easy it is for any traveller into the unknown to miss the right path.

This chemist took a willow weighing 5 pounds and planted it in a quantity of dried earth which weighed 200 pounds. For five years he did nothing to the willow except water it occasionally. At the end of that time it was pulled up and found to weigh 169 pounds 2 ounces. The earth in which the willow had grown was dried as before, and was found to be only 2 ounces lighter than at
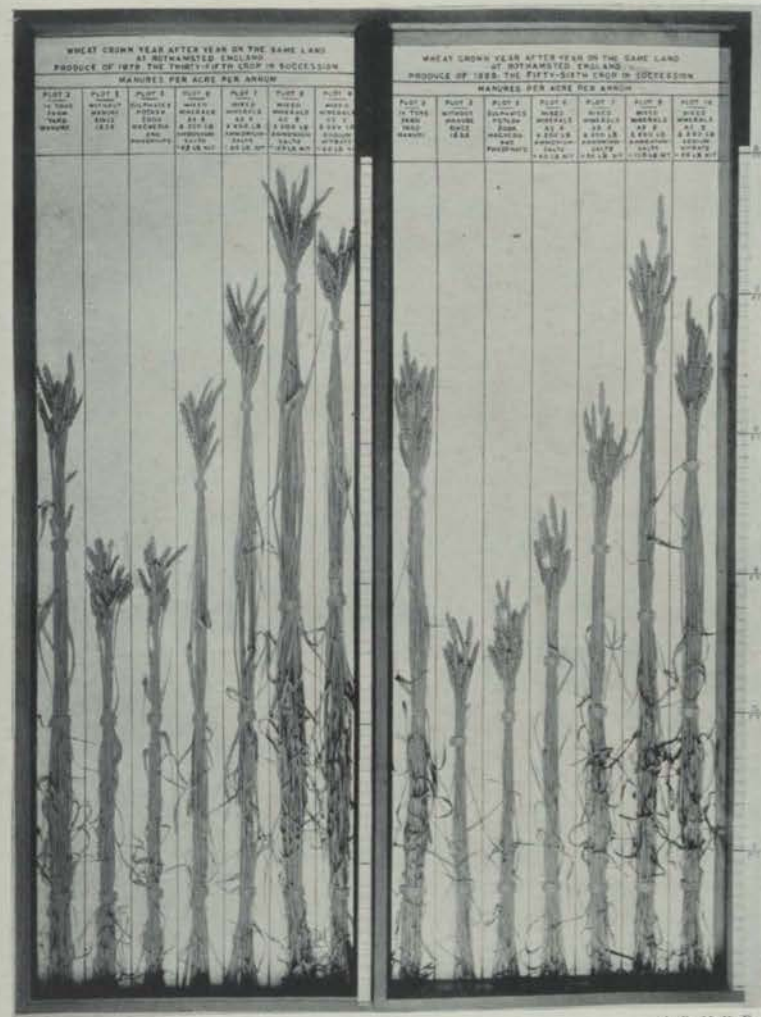
A. D. Hall, Esq.

THE INFLUENCE OF VARIOUS MANURES ON THE GROWTH OF WHEAT

These samples were grown on the famous experimental farm at Rothamsted, where the influence of various manures has been observed and recorded for more than half a century. The photograph shows clearly that unmanured soil is greatly impoverished, and that to get the best results nitrogenous as well as mineral manure is required.

the start. Our chemist therefore drew the conclusion that 164 pounds of wood, bark, roots, and leaves had been produced from water alone ! The experiment was straightforward enough, and at that time, before the composition and influence of the air were discovered, it was quite convincing.

Even now, when we know for a fact that the solid part of a plant is largely derived from the carbon dioxide in the atmosphere, the average person may find it difficult to realise that a gas which is present in the air only to the extent of 3 parts in 10,000 should really be responsible for all this. But so it is. Under the influence of light, the green colouring matter in the leaves—the chlorophyll, as it is called—has the power of dealing with the carbon dioxide which is taken in from the atmosphere, liberating the oxygen, and converting the carbon into various compounds which form the substance of the plant. It is difficult to appreciate the prodigious quantity of carbon dioxide which is consumed by the vegetable world in this way, but some idea of it may be gained from the fact that an acre of a good wheat crop obtains from the atmosphere in the course of four months as much as 1 ton of carbon.

Plants, then, are the great purifiers of the air ; if it were not for their activity in removing the carbon dioxide, there would very shortly be an unhealthy excess of this gas in the atmosphere. From the lungs of men and animals, and from our house and factory chimneys, huge quantities of carbon dioxide are being constantly poured out, and with all this the vegetable world must deal. It has been estimated that an acre of forest will just about balance fifteen men, and although the fifteen men are very seldom in the same place as the

acre of forest, the winds of heaven secure a wonderfully rapid and even distribution of the carbon dioxide.

To be strictly accurate, we must also bear in mind the fact that plants resemble animals in contributing to the contamination of the air; they, too, use up oxygen and breathe out carbon dioxide. In daylight, however, this process of plant-breathing is quite outbalanced by the reverse operation—a characteristic of plants alone —whereby they give out oxygen and purify the air. It is only when they are kept in the dark that the action of plants in giving out carbon dioxide becomes noticeable. Taken altogether, their services in purifying the atmosphere quite outbalance what they contribute to its contamination.

The fact that a plant is really able, under the stimulating influence of light, to liberate oxygen from carbon dioxide may be demonstrated by a very simple experiment. A bit of a growing plant—a sprig of mint, for instance—is put in a glass tube, which is then filled with tap water and inverted in a dish also containing tap water. The latter is employed in preference to distilled water in this experiment, because it is charged to some extent with carbon dioxide. This simple piece of apparatus is then exposed to sunlight for several hours. It will be noticed that gas bubbles are formed on the surface of the leaves, and that these frequently ascend and collect at the top of the tube. After a few hours have passed the gas which has collected in the tube may be examined. To do this, the thumb is put on the end of the tube while it is still under water, the tube may then be taken out and inverted, the gas in this way being brought to the mouth of the tube. If a glowing slip of wood is thrust into the gas while

the thumb is removed for a moment, it will be relit, showing that the gas which was collected was oxygen.

So much, then, is fairly established, that the carbon dioxide of the atmosphere is taken in by the plant, and that the carbon is retained while the oxygen is given off. But chemists have not been able to discover the actual chemical process to which the carbon dioxide is subjected in the mysterious laboratories of the plant leaf. It is, indeed, certain that water also is involved, so that the leaves may be said to feed mainly on carbon dioxide and water, a simple life diet which produces the most extraordinary results. When we speak of the carbon of the carbon dioxide being retained in the plant, we must not suppose that it is actually found in that form; it is no sooner extracted from the carbon dioxide than it passes into some form of combination with hydrogen and oxygen, probably formaldehyde in the first instance. As to the methods by which the living plant subsequently builds up more complicated products, such as starch, sugar, and cellulose, we know very little.

The experiment which convinced the scientists of three hundred years ago that vegetable matter could be produced from water alone has been shown to be incomplete and inconclusive; but we must admit at the same time that water does enter very largely indeed into the composition of living plants. Some succulent vegetables contain over 90 per cent. of their weight of water, and even trees felled in the driest period of the year will have as much as 40 per cent. If we suppose the plant's supply of water completely removed, the remainder, which we may call the "dry material" of the plant, consists partly of combustible and partly of incom-

bustible matter. In the combustible part there are
to be found five chemical elements, namely, carbon,
hydrogen, oxygen, nitrogen, and sulphur, the first three
of which are present in by far the largest proportion.
These three, combined in a variety of ways, constitute
the woody matter or cellulose, the sugar, the starch,
and the fats of the plant. Other ingredients of the
combustible part of the plant are (1) the nitrogenous
bodies, which contain nitrogen as well as carbon, hydro-
gen, and oxygen, and (2) the albuminoids, in which
sulphur is found as well as the other four elements.

In the incombustible ash of the plant there are also
five elements found, namely, potassium, magnesium,
calcium, iron, and phosphorus; these are essential to
the life of the plant, and exist in its tissues largely
as carbonates, sulphates, and phosphates. These con-
stituents, as well as some others which often occur but
are not essential, are derived from the soil in which
the plant grows, so that the nature and composition
of the soil are all-important factors in the vitality of
the plant. In order that the reader may get an idea
of the relative proportions of the water, the ash, and
the combustible matter in such a common vegetable
product as meadow grass, the following figures are quoted.
The crop to which the figures refer weighed 5 tons
when freshly cut, and produced 1½ tons of hay. Out
of the 5 tons—that is, 11,200 pounds—of meadow
grass, 8378 pounds were water, while the combustible
matter weighed 2613 pounds, and the ash 209 pounds.

We have discussed the marvellous way in which the
living plant procures its carbon, but the origin of some
of the other constituents is also full of interest. Let us
consider first the nitrogen, which, although it is present

in vegetable tissue only to a small extent, is an important
and indeed essential constituent. The reader might
suppose that the natural source of nitrogenous food for
the plant would be the atmosphere, with its vast stock of
nitrogen. It is conceivable that the leaves might take in
and assimilate the nitrogen of the air, just as they deal
with the carbon dioxide, which is so much more scarce.
There are some who have supposed that this really takes
place, but the bulk of the evidence shows that the leaves
of plants generally are unable to digest nitrogen when it
is presented to them in the form of the element itself.

Atmospheric nitrogen, however, does ultimately reach
the tissues of some plants, but by a very indirect road,
viâ the soil and the roots. Leguminous plants, such
as peas and vetches, are provided with exceptional
apparatus for assimilating nitrogen, in the shape of
swellings or "nodules" on their roots. These nodules
contain micro-organisms which have the power of taking
in atmospheric nitrogen, and so manipulating it as to
render it suitable for use as food by the plant. The
majority of plants, however, are destitute of these para-
sitic attendants, and are unable to utilise atmospheric
nitrogen directly; they appear to find this element most
digestible when it is presented to them in the form of a
salt, such as a nitrate. Nitrates are readily taken up
from the soil by plants, and the nitrogen is subsequently
transformed into the complex nitrogenous constituents of
the plant tissues by various chemical processes which at
present are not within our knowledge, far less our power
of imitation. In comparison with the practical chemistry
which goes on in the cells of plants, the methods of the
chemist are elementary and crude, and he may well feel
humble in view of the complex and delicate processes

which are carried out in the wonderful little laboratories of the plant.

All very well, the reader will say, the plant may take in the bulk of its nitrogen in the form of nitrates from the soil, but how do the nitrates come to be there at all? To understand this it is necessary to remember that the atmosphere contains small quantities of nitrogen in the combined form, namely, as ammonia, a compound of nitrogen and hydrogen, and as nitric acid, which, as already stated, is a compound of nitrogen, hydrogen, and oxygen. The ammonia in the atmosphere has been given off from decaying organic matter, and the nitric acid is due to the power of an electric discharge, such as lightning is, to induce the nitrogen and oxygen of the air to combine to some small extent.

Now these two nitrogenous substances, ammonia and nitric acid, the one an alkali and the other an acid, dissolve easily in water, and are either absorbed by the soil direct, or are washed down into it by the rain. Quite a large amount of combined nitrogen gets into the soil in this fashion, in addition to what is already there as the remains of earlier vegetation. Experiments carried out at Rothamsted have shown that the total quantity of nitrogen carried to the soil by rain in one year is between four and five pounds per acre. When ammonia compounds get into the soil their latter end is near, for there they are tackled by micro-organisms whose object in life it is to convert all other nitrogenous bodies into nitrates. Since, from the point of view of the plant, a nitrate is a much more digestible form of nitrogen than any ammonia compound, these nitrifying bacteria are valuable agents in the nourishment of the plant.

Apart from the carbon, nitrogen, hydrogen, and oxygen,

the origin of which we have discussed, the elements which are essential to the building up of the plant are derived from the soil itself. Compounds containing potassium, magnesium, calcium, iron, sulphur, and phosphorus are found in the rocks of the earth's crust, and it is through the breaking down of these rocks that the various ingredients of soils have been produced, except, indeed, the humus, which has quite a different origin. The humus is that part of the soil which represents the decayed vegetation of an earlier age; it is organic in origin, and contains the ruins and remains of the nitrogenous compounds which were built up in that vegetation. Hence arises the fertility of virgin soil from which no crops have ever been taken; it is rich in nitrogenous humus, and is practically a storehouse of food for the first crop which the new settler grows upon it.

When the crops which grow on a given piece of ground are removed year after year, the soil must obviously become impoverished in the chemical materials on which the crops have fed. There need be no anxiety about the supply of carbon; the source of this element is the atmosphere, and fresh quantities of carbon dioxide are always being produced. Nor is there likely to be any shortage of hydrogen and oxygen; they come from water, and we are not often seriously troubled, in this country at least, with a deficiency of that commodity. It is really in regard to nitrogen, phosphorus, lime, and potassium that the soil becomes most rapidly impoverished, and if the crops are to be kept up in quality and quantity we must replenish the store of these elements; that is, manuring becomes essential. The necessity for this was, of course, recognised long before the agricultural chemist came on the scene, but since his appearance the materials

which must be added to the soil have been definitely ascertained and their effects on various crops have been studied.

The waste products of the animal body contain much of the material which is required for the enrichment of the soil, and hence farmyard dung is an excellent general manure. Guano, the dried excrement of sea-birds, also contains nitrogen, phosphate, and potash, and so has been largely employed for the same purpose. Occasionally, for special crops and in special circumstances, it becomes necessary to supply to the soil a particular plant food— nitrogen, for instance. In this case one may use as manure either sulphate of ammonia from the gasworks, or nitrate of soda from Chili. The nitrogen from ammonium sulphate is not so rapidly available for the use of the plant as the nitrogen from the Chili saltpetre, inasmuch as the ammonia in the former has first to be interviewed by the nitrifying bacteria and converted into nitrate.

The approaching exhaustion of the Chili saltpetre beds has stimulated chemists to discover ways and means of utilising the nitrogen in the atmosphere for plant-feeding purposes, and the reader may remember the reference made in a previous chapter to the work already done in this direction. At the high temperature of the electric arc the nitrogen and oxygen of the atmosphere combine to a small extent, and the compound so formed is easily converted into nitric acid. As already indicated, the small amount of nitric acid occurring in the atmosphere is to be traced to the influence of electric discharges, so that the method now in vogue for the manufacture of nitric acid from the atmosphere depends really on the production of artificial lightning.

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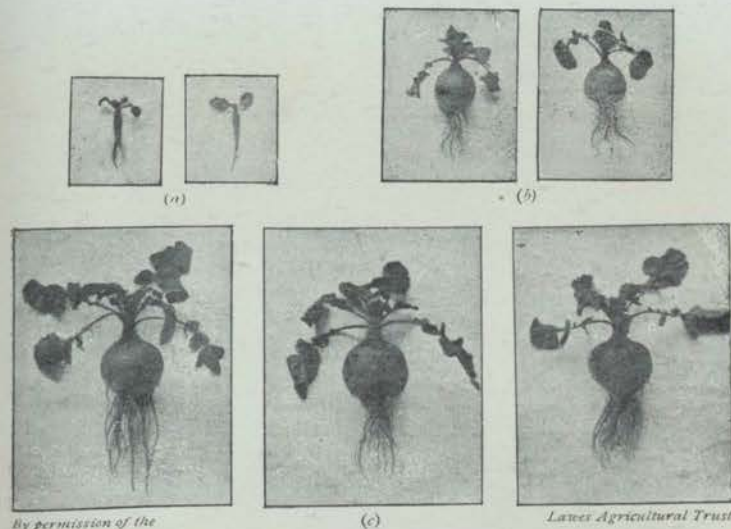
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THE RESULTS OF ASSISTING NATURE

Typical specimens of Swedish turnips grown in the same year on adjacent plots of land. In case (a) the plot had been unmanured for many years; in case (b) the plot had been treated with mineral manure alone; in case (c) both mineral and nitrogenous manure had been used.

By permission of the Royal Agricultural Society of England

AN OVER-DOSE AND ITS REMEDY

The whole of the plot of land shown in the illustration has been manured to excess with ammonium salts. As a result the crop of barley sown on the land is a complete failure, except on the left-hand part of the plot, where the crop has been restored by the addition of lime.

Mention should also be made of another modern electrical method of capturing the nitrogen of the atmosphere for agricultural purposes. This method results in the production of a compound known as calcium cyanamide, which readily yields up its nitrogen for the use of crops.

For certain soils and particular crops it is not necessary to manure with nitrate so much as phosphate. One of the simplest ways of supplying this constituent is to grind bones and scatter the bone dust in the soil. Phosphate of lime, of which there is a considerable proportion in bones, is an insoluble substance, and as the plant prefers to have its food in dissolved form, the effect of bone dust is not obvious at once. Such a phosphate manure, however, may be made more readily available by treating the bones or other substances containing phosphate of lime with sulphuric acid; this brings some at least of the phosphate into a soluble condition, and the product—" super-phosphate," as it is called—is extensively employed as an ingredient of artificial manures.

It does not sound very probable that any product connected with a blast furnace could assist the growth of plants, but here again it is the unexpected that happens. The slag produced in presence of lime when molten pig-iron containing phosphorus is subjected to a blast of air, and so purified, is relatively rich in that element. It is accordingly used to a large extent as a phosphate manure, for which purpose it must be very finely ground.

By such artificial additions to the soil as the foregoing we are able to stimulate the growth of the plant. But we must not run away with the idea that we are masters of the situation. Although the processes which go on during the growth of a plant seem to be purely

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chemical changes, the fact stares us in the face that we cannot turn out a plant in our laboratories; the thing is absolutely beyond us. The attempts so far made to imitate the processes of plant growth can scarcely be called successful, and our failure seems to be most complete in connection with the most important and wonderful process of all, namely, the assimilation of carbon dioxide. The chemistry of plant life and growth is, in fact, one of these mysterious chambers which have as yet been only partially explored. In spite of failure, however, to imitate the actual processes of growth, chemists have been wonderfully successful in producing by artificial methods the substances which are found in plants. The story of the interesting advance that has been made in this direction will be told in another chapter.

CHAPTER XX

SUGAR AND STARCH

CHEMISTRY is an all-pervading science. Its scope is not confined to the laboratory or the chemical factory. There is a chemistry of daily life as well as a chemistry of the stars; a chemistry of foods as well as a chemistry of fire. We have already seen that many common phenomena really depend on the operation of chemical principles, and chemistry has a good deal to say also about our food and the changes which it undergoes.

Sugar and starch are two of the main components of our food, and belong at the same time to an interesting class of chemical compounds known as "carbohydrates." Each member of this class contains the elements carbon, hydrogen, and oxygen, and the characteristic feature, to which reference is made in the part *hydrate* of the word "carbohydrate," is that the proportions of the hydrogen and the oxygen are the same as in water.

The constituents of our food belong to one or other of the three classes—carbohydrates, fats, and proteids or albuminoids. The last-mentioned include all the nitrogenous products, a certain proportion of which is essential to the health of the body. Most ordinary food-stuffs do not belong exclusively to one class, but are mixtures. Wheat meal, for instance, contains 9 per cent. of proteids, 1 per cent. of fats, and 74 per cent. of carbohydrates,

mostly starch; in addition, there is about 15 per cent. of water and a little mineral ash. As another example of a common food, we may take potatoes, which contain 75 per cent. of water, 21 per cent. of carbohydrates, and 2 per cent. of proteids; they contain only a trace of fat. The pea differs from the potato in having a relatively large proportion of nitrogenous substances—as much as 22 or 23 per cent.—while the carbohydrates amount to about half the weight of the pea. Cheese, again, is a case of a food containing very little carbohydrate and a high proportion of proteid; an average composition is 34 per cent. of water, 28 per cent. of proteid, 33 per cent. of fat, and 2 per cent. of carbohydrate. As opposed to these mixed food-stuffs, sugar is a pure carbohydrate, and butter is practically nothing but fat with an admixture of water.

All carbohydrates are ultimately obtained from the vegetable kingdom, and of the numerous substances which belong to this class, none is better known than sugar. It must, however, be pointed out at once that the meaning which the ordinary person attaches to "sugar" is not quite what the scientist understands by it. The chemist speaks of "sugars," for there are several distinct substances known to him which go under this name; there are, for instance, cane sugar, milk sugar, malt sugar, and grape sugar or glucose. To these the reader might be inclined to add beet sugar, but this would be a mistake. The substances just mentioned are indeed named from their different sources, but it is not on that account that they are regarded as distinct members of the sugar class. Investigation has shown that they are chemically different; even although in some cases the proportions of carbon, hydrogen, and oxygen are equal, the arrange-

ment of the atoms in the molecules is not the same. The sugar, however, which is obtained from the beet is chemically identical with that which comes from the sugar cane; beet sugar, in fact, is simply cane sugar from another source.

What we refer to in ordinary conversation as "sugar," the article which appears on the breakfast- and the tea-table, is cane sugar, although in reality a great deal of it has been manufactured from beetroot. The inhabitants of these islands ought to be specially interested in this article, for the annual consumption per head of the population of Great Britain is about 80 lbs., which is equivalent to eighteen pieces of ordinary lump sugar per diem. This is nearly three times as great as the corresponding figure for France or Germany.

Up till a hundred years ago there was practically no sugar produced except from the sugar cane, whereas now more than half the world's production of sugar is derived from the beet; the name "cane sugar," therefore, is not quite so accurate a description of this compound as it once was. Much energy has been devoted to the scientific cultivation of the beetroot, and to the proper extraction of the sugar which it contains. The advance which has been made in this way is very well illustrated by some published figures showing that whereas in 1836 a ton of beetroot yielded 124 lbs. of sugar, the same quantity in 1871 was made to yield 204 lbs., in 1900 300 lbs. of sugar.

In the old methods of extracting sugar from the canes, these were crushed, and the juice which was thus pressed out was clarified and then boiled down until the sugar crystallised. Another and modern plan, which is similar to the method used in extracting sugar from beetroots,

is to immerse the canes in water and soak out the sugar. The juice obtained in this way is then concentrated to its crystallising point. The crystals are not pure, and are spoken of as "raw" sugar; the uncrystallisable juice which is separated from the crystals—uncrystallisable because of the mixture of substances which it contains—is used as food in the form of treacle or molasses.

Although a good deal of raw cane sugar finds its way into the market as "Demarara," the bulk of it is first refined. The process of refining consists in dissolving the raw sugar in water, filtering the brown solution through cotton bags, and then decolorising it by keeping it in contact for some hours with animal charcoal.

Contrary to what one might expect from the name, animal charcoal contains only one-tenth of its weight of carbon. It is got from bones in the same way as coke is obtained from coal, that is, by heating strongly in a retort. The organic matter in the bones is charred by this treatment, and the resulting carbon is distributed in a finely divided condition over the phosphate and carbonate of lime which constitute the bulk of the mass.

In this state of fine division the carbon has the remarkable property of absorbing any colouring matter from a solution with which it is left in contact for a time. Red wine, for instance, if shaken with animal charcoal and then filtered, runs through as a colourless liquid, like water. A coloured sugar solution is similarly affected, and pure sugar is then obtained by concentrating the decolorised liquid to the crystallising point, as already described. It is somewhat startling to reflect that a heap of uninviting-looking bones may be destined

to purify our best lump sugar, but this is frequently the case.

The reader need not trouble himself much about milk sugar, which forms 5 per cent. by weight of ordinary milk, or about malt sugar, which is formed from grain in the preliminary stages of brewing beer; but grape sugar or glucose is quite an important carbohydrate, and is worth a little attention. The very name suggests one of its sources, and as a matter of fact grapes contain 13 per cent. of glucose; the percentage present in dried fruits is much higher, and in figs is over 50.

The bee must not be forgotten as an agent in the collection of glucose, for honey contains 70 to 80 per cent. of this sugar. It comes originally, of course, from the flowers, and an estimate of the sugary matter in these has shown that the bees must visit several hundred thousand heads in order to collect one pound of honey. We pride ourselves, and justly, on the methods by which minute amounts of a precious metal can be extracted from large masses of rock and earthy material, but the remarkable achievement of the bee in the accumulation of almost microscopic quantities of sugar is probably unequalled.

Glucose is not nearly so sweet as cane sugar, yet in the olden days, before cane sugar had been introduced, honey was the material used in sweetening dishes for the table. Later on, glucose was obtained from grapes, but nowadays it is made by boiling starch with dilute sulphuric acid; it is then known as "starch sugar." It must be admitted that the names of the various sugars are a little confusing; already we have seen that beet sugar is the same as cane sugar, now it appears that starch sugar is nothing else than grape sugar.

The starch required for the manufacture of glucose by

this method is generally derived from potatoes or maize; it is made into a cream with water, and then run into boiling dilute sulphuric acid. In these circumstances the starch undergoes a gradual change, which the chemist describes as "hydrolysis," and the boiling is continued until starch can no longer be detected in the liquid. The test is made by taking a sample out of the boiler, cooling it, and adding a little iodine, which gives a blue colour so long as unchanged starch is present. Possibly the reader may at some time or other have accidentally dropped a little tincture of iodine on a starched article, say a shirt-cuff, and noticed that a deep blue stain was produced. This is a very characteristic peculiarity of starch, and always serves for its detection.

The solution of glucose obtained after hydrolysis is complete must, of course, be freed from the acid, which would be a most undesirable constituent of any food-stuff. The cooled liquid is accordingly neutralised with chalk or whiting, and the insoluble sulphate of lime which is formed is filtered off. It is further necessary to de-colorise the solution by means of animal charcoal, and to concentrate by evaporation until the solid can be obtained.

The glucose produced in this way will be a white sub-stance, provided sufficient care has been taken to de-colorise the solution thoroughly by animal charcoal; otherwise the substance will have a light brown tinge. If the conversion of the starch should have been in-completely carried out, then a *liquid* glucose syrup is finally obtained, which, although not so pure as the solid glucose, may be used, and is extensively used, both in confectionery and brewing.

Other carbohydrates as well as starch can easily be

converted into grape sugar. Cane sugar itself is changed into glucose and another similar sugar called "fructose," merely by heating a solution with an acid—sulphuric acid, for example; the cane sugar is said to be "inverted," and the resulting mixture of glucose and fructose is known as "invert sugar." This product is obtained in the form of a thick syrup, and is extensively employed in brewing.

This reminds one that it was the use of sulphuric acid in the manufacture of glucose and invert sugar which led to the "arsenic in beer" scare of 1900. In Manchester during that year a number of cases of arsenical poisoning occurred, and were ultimately traced to the beer drunk by the patients. Arsenic was found also in the glucose and invert sugar from which the beer had been brewed, having got into these materials from the sulphuric acid employed in their manufacture. It must be remembered that the sulphur required for making sulphuric acid is generally in the form of iron pyrites, a natural product which is invariably contaminated with arsenic. Unless, therefore, submitted to special purification, commercial sulphuric acid is liable to contain arsenic; and it was the use of such an impure acid in the manufacture of glucose and invert sugar that was at the bottom of the "arsenic in beer" trouble.

The conversion of other carbohydrates into glucose can be brought about by certain ferments without the aid of acids at all. When moist barley, for instance, is allowed to germinate, a ferment called "diastase" is pro-duced. This subtle agent upsets the equilibrium of the starch molecules in the barley. Under its influence they are converted into sugar molecules, and the latter, unlike starch, can be fermented by yeast, and so produce alcohol.

Again, the conversion of starch into sugar is a chemical change of which the reader himself is the scene. As already pointed out, much of our common food contains carbohydrates, and of these starch is the one which is present in the largest proportion. Now starch itself consists of fine granules which are insoluble in cold water. On this account any form of starchy food should first be boiled, or baked in the presence of moisture. This treatment secures the bursting of the granules; they are dissolved or at least softened, and are so rendered amenable to attack by the digestive juices. This attack begins in the mouth, where a ferment, lying in wait in the saliva, begins the conversion of starch into sugar, a process which is completed by the juices in other digestive organs.

This important ferment in the saliva is not developed until several months after birth; the disadvantage, therefore, of giving starchy food to infants will be apparent. If such food is given it is not assimilated, for all other carbohydrates must be converted into glucose if they are to be made available for the nourishment of the body. For the further utilisation of the glucose the liver is responsible, and if this organ is not doing its duty, the sugar goes through the body unchanged and unassimilated; the presence of glucose in the urine is, in fact, taken as evidence of diabetes. In cases of this disease the patient should abstain from the use not only of sugar itself, but also of all starchy food-stuffs, for these latter, as we have seen, are rapidly converted into glucose by the digestive juices.

Another interesting carbohydrate which is worthy of mention is dextrin, or British gum. This compound is a sort of half-way house between starch and glucose, and is

formed when starch is heated either alone or with a little acid. Although dextrin has the same chemical composition as starch, it gives a reddish brown colour with iodine, instead of the blue colour which is so characteristic of starch. Dextrin is applied to some curious purposes—for example, as an adhesive on envelopes and postage stamps, in giving a gloss to paper and cardboard, and in producing a head on beer and ærated liquids.

The possibility of converting the various carbohydrates into glucose is further illustrated by the changes which vegetable fibre, or cellulose, may be made to undergo. This is a carbohydrate of the same chemical composition as starch, but differs from the latter in being indigestible except by herbivorous animals, which have a special apparatus for dealing with it. Cotton-wool and Swedish filter-paper are nearly pure cellulose, from which it will be obvious that this carbohydrate is not a suitable article for human food. When eaten, it simply passes through the body without being digested.

Cellulose, in either of the forms just mentioned, is dissolved by strong sulphuric acid; if the solution is diluted with water, and subjected to prolonged boiling, the cellulose, like starch, only less readily, is converted into glucose. Bearing in mind that the fermentation of this sugar yields alcohol, the reader will perceive that it is actually possible to prepare spirituous liquors from linen or cotton rags, for these consist very largely of cellulose. From rags to alcohol, however, is a transformation which is a chemical curiosity rather than a practically applied process.

The name " cellulose " suggests the commercial article known as " celluloid," which is indeed derived from cellulose. In chapter xv. it was shown that when cotton-

wool—that is, cellulose—is treated with nitric acid, the explosive gun-cotton is obtained. If a weaker acid is employed, and the time during which it acts is shortened, another compound is produced, intermediate between cotton and gun-cotton. This product, when mixed with camphor and properly worked up, is celluloid. Although not explosive like gun-cotton, it is highly inflammable, and numerous burning accidents have been caused by the ignition of combs made of this material.

Attempts have been made to render celluloid un-inflammable, but this can be done only by sacrificing some of its valuable properties. One of these is its plasticity; separate pieces of celluloid, when heated to a temperature a little above the boiling-point of water, can be welded together by pressure, just as two pieces of red-hot iron are welded under the blacksmith's hammer. Then, again, celluloid can be planed, carved, or turned on the lathe, and the appearance of the articles so produced leads to its name of "artificial ivory." It is employed not only in combs, but in the manufacture of such various things as piano keys, billiard balls, dolls, and photographic films.

At the beginning of this chapter carbohydrates were spoken of as important constituents of food, but it will now be evident that this important class of chemical compounds figures largely in common life apart from food-stuffs. They are to be detected in our stationery, in our clothes, on our postage stamps, and indirectly in celluloid and the many useful articles which are made of this material.

CHAPTER XXI

FATS AND OILS

THE romantic element about suet, candles, butter, soap, and linseed oil is, it must be confessed, not particularly prominent, and yet there is perhaps no class of natural products which ministers in a more wonderful and varied fashion to the needs and comforts of man than the fats and oils. Versatility in an individual, the ability to do half-a-dozen things of the most diverse description is always interesting, and the study of the way in which the stream of natural products is diverted by the wit of man into all sorts of useful channels is similarly fascinating, if not romantic.

Fats and oils are natural products, their name is legion, and there is an inexhaustible supply. The oils, however, with which we shall chiefly deal in this chapter, are those which can be described as liquid fats. There will indeed be a brief reference to the so-called "mineral" oils, which are derived from the petroleum springs of Russia and America, already described in chapter xii., but the "volatile" or "essential" oils, like oil of nutmeg or oil of lemons, will be left out of account, at least for the present.

If we omit consideration of the mineral and the essential oils, we may say that the numerous fats and oils derived from both the animal and the vegetable kingdoms are remarkably similar in chemical composition,

however diverse their origin. A fat or fatty oil is a substance analogous to a salt, which, as already shown, is a neutral compound produced by the combination of an acid and a base. The constituent of the fats and oils which corresponds to the base of a salt is *glycerine*, while the acid is very often stearic, oleic, or palmitic acid. The compound formed by the union of glycerine and one of these " fatty " acids is termed a " glyceride," and the commonly occurring fats and oils are to be looked on as mixtures of different glycerides.

That fats and oils are obtained from an extraordinary variety of sources is shown by the fact that hogs' kidneys, cotton seed, milk, hazel nuts, cod livers, and cows' feet, are among the raw materials requisitioned for the purpose. Fats and oils of a vegetable origin are obtained mostly from fruits, which in some cases contain a high proportion of fatty material. The fruits of the olive tree contain about half their weight of oil, used, for instance, in packing sardines, while in the seed of the flax plant there is 30 to 35 per cent. of oil, familiar to every one as linseed oil.

A vegetable oil is extracted from the seed in one of two ways. The seed is either crushed under pressure, so that the oil is squeezed out, or it is heated with some volatile liquid such as petroleum or carbon disulphide, which dissolves out the oil and can afterwards be boiled away. When the first method is employed the expressed oil is collected in suitable vessels, and the compressed residue, still containing a small proportion of oil, is sold as oil-cake for feeding cattle. This way of utilising the residue is obviously an economical one, for the unextracted oil is ultimately recovered from the cow or bullock in the form of butter, tallow, or neat's-foot oil.

The process most in vogue for obtaining animal fats and oils is known as " rendering " ; the fatty matter is boiled with water or steamed, and the oil which floats on the surface is removed. In this way it is obtained free from adhering tissue.

Attention was drawn in the previous chapter to the fact that fats are one of the principal constituents of human food. Butter, lard, suet, olive oil, and cocoa butter may be mentioned as fats which are used either directly as food or in the preparation of dishes for the table. In this country we import over £20,000,000 worth of butter alone per annum, in addition to the butter made and consumed at home.

Butter, however, is not the only fat which is used directly as human food. Margarine, an artificial mixture of animal fats, with possibly a small amount of vegetable fat, is manufactured in large quantities nowadays, the annual consumption in this country being estimated about £5,000,000 worth. Its manufacture dates back to the time of the Franco-German war, when the inhabitants of Paris were hard up for butter. This fact would seem to indicate that margarine is to be used only by those who are reduced to their last resources, but really no reasonable objection can be taken to this material when made under satisfactory conditions and sold under its own name. A member of Parliament, referring on one occasion to margarine, spoke of " all the greasy rubbish of the world which is being dumped down in this country " ; but this description is now quite out of date.

Other edible fats turned out in large quantities are the so-called vegetable butters, which are valued by our vegetarian friends, and appear in the market under all sorts of fancy names. In India, where, on religious

grounds, the natives will have nothing to do with animal fat of any description, vegetable butter is prepared in large quantities from cocoa-nut oil and palm-nut oil. The Greenlander, on the other hand, who has no such scruples, revels in blubber.

The preparation of edible butters and oils is only one of the many industries which depend on the utilisation of fats and oils. If it were not for their disguise, for the chemical processes to which they have been subjected, we should detect these materials in many an unsuspected place. They may be traced not only in the butter on our bread, but also in the candles which light our tables, on the artist's canvas, in the linoleum on our floors, and in the " matchless cleansers" which delight the house-wife's heart.

The chemical processes which have been referred to as disguising the obvious characteristics of fats and oils are not all carried out by the manufacturer. There is one class of oils, the so-called " drying" oils, the value of which is due actually to their own instability and to their sensitiveness to atmospheric influences. Common linseed oil, obtained from the seeds of the flax plant, is the typical member of this class.

If a film of linseed oil is exposed to air it absorbs oxygen with great avidity, becoming gradually more and more sticky and viscous during the absorption, until at last it dries to an elastic skin. The amount of oxygen thus absorbed by the oil may be as much as twenty per cent. of its weight. In this respect linseed oil is abso-lutely different from, say, olive oil, which remains liquid however long it is exposed to the air, and is therefore described as a " non-drying " oil.

The complete drying of a thin layer of linseed oil

occupies about three days, but the process may be con-siderably accelerated by a certain device, as was shown long ago by a Dutch artist. He found that if the ordinary or raw linseed oil were previously heated to a high temperature with lead oxide, the time required for drying was shortened to six or eight hours—an observation which has turned out to be a very valuable contribution from art to practical science.

At the present day linseed oil which is to be used in the manufacture of paints is subjected to a preliminary treatment of the kind suggested by the Dutchman, the only differences being that the temperature now employed is not so high (only about 300° Fahrenheit), and other " driers " besides lead oxide may be used. The product is known as " boiled " oil, although, strictly speaking, it has never been boiled at all, but only heated; fatty oils would, as a matter of fact, decompose if we attempted to boil them. The name " boiled " oil is one of those little inaccuracies of terminology which one comes across occasionally in the technical world—a " terminological inexactitude," the politicians would call it. The case is parallel to " black lead," which, as the reader will have learned from chapter v., contains no lead at all.

As already indicated, boiled oil is extensively used in the preparation of paints and varnishes. The colour-ing material, white lead, lampblack, ultramarine, or red lead, as the case may be, is first ground with a small quantity of linseed oil and then mixed with more oil, generally of the boiled variety, and with oil of turpentine. When a layer of the paint is spread on a surface of metal or wood it dries quickly, and a pro-tective skin is left. The drying of wet paint, the reader will now perceive, is quite different from what takes

place when a newly washed cloth is hung out on the clothes-line. In the latter case simple evaporation of water, a purely physical process, takes place, while the drying of paint involves a chemical change, the combination of the oil with oxygen from the air.

Like the painter, the glazier depends on the drying qualities of linseed oil when he fixes up a new pane of glass with putty. This dough-like material is obtained by grinding up whiting with linseed oil, and it is the latter ingredient which is responsible for the gradual hardening of the mixture on exposure to air.

This curious drying power of linseed oil is made to contribute to the equipment of our houses, not only in paint, but also in linoleum. Linseed oil is the raw material of the linoleum manufacture, and the first operation in the factory is the drying of the oil on a large scale; this is effected by hanging up sheets of textile material and allowing the oil to run slowly over them; under these circumstances it dries gradually to a tough, gelatinous mass. This oxidised and solidified linseed oil is then mixed with rosin and ground cork, spread on a canvas backing and sent into the market as linoleum.

One purpose for which drying oils are obviously not suited is lubrication. If linseed oil were put into the bearings of a machine, it would get viscous and tough in the manner already described, and the running of the machinery would be hindered instead of helped. For lubricating purposes a non-drying oil is required, such as tallow oil, lard oil, neat's-foot oil, olive oil, rape oil, or castor oil. The metallic variety of palm oil, which travellers frequently find necessary to stimulate official activity or to produce temporary blindness

in the official eye, might be classed as a lubricant, but the naturally occurring variety, which, by the way, is a solid, not a liquid, finds only a limited application in this direction.

The use of fatty oils for lubricating purposes has been greatly restricted in recent times by the introduction of mineral oils, obtained from petroleum wells. It must be borne in mind that the fatty oils are compounds of glycerine and an acid, and that under certain conditions—when exposed, for instance, to the action of high-pressure steam—they may be split up into these constituents. This means that the use of a lubricating fatty oil may lead to the formation of free acid on the bearings, a result which, in view of the corrosive action of acids on metals, is highly undesirable. No objection of this sort can be urged against the petroleum or mineral oils, for these are simply hydrocarbons, compounds of carbon and hydrogen, and as such are unaffected by air or steam. Hence it comes that for lubricating purposes fatty oils have been largely displaced by mineral oils. As a matter of fact, most of the lubricating oils used at the present time are mixtures of the two varieties.

The discovery of petroleum has very notably restricted the use of fatty oils in another direction, namely, in their application as illuminants. It is not so very long ago since paraffin oil was a novelty, and up to that time vegetable oils, such as olive and rape oils, were largely employed as sources of light. Nowadays, we may say with confidence, the private individual uses nothing except paraffin as a burning oil. It is the railways which furnish the most conspicuous example of adherence to the old custom, the lamps used on

signals being still fed with rape oil. In lighthouses, too, there is a certain extent of adherence to the old kinds of burning oil, inasmuch as whale and seal oil are largely employed in the lamps; it is true these are animal oils, in contrast to olive and rape oils, but they belong to the same class of chemical compounds.

Fats and oils are made available for illuminating purposes not only directly, in the way just described, but indirectly also, after being subjected to chemical treatment by the manufacturer, and being made to yield up the fatty acids which they contain in combination with glycerine. In connection with the subject of lubrication it was said that under the influence of high-pressure steam a fatty oil might be decomposed into fatty acid and glycerine. Now, although this may be undesirable behaviour in the case of a lubricant, yet it is precisely the change which the manufacturer brings about on a large scale in order to produce candles.

Our forefathers, it is true, used unchanged fats in the manufacture of candles; we have all heard of "tallow dips," and the "snuffers" which went along with them. Tallow is the rendered fat of cattle and sheep, and consists chiefly of two fatty acid glycerides, those of stearic and oleic acids, together with a small quantity of the glyceride of palmitic acid. The mixture is easily melted, and the "dip" was made by repeatedly dipping a cotton wick in molten tallow.

The wick in a modern candle, on the other hand, is made of yarn, plaited in such a way that the end of the wick bends over and is burned at the side of the flame, as the reader has doubtless observed himself. Such a wick cannot be employed in a tallow candle,
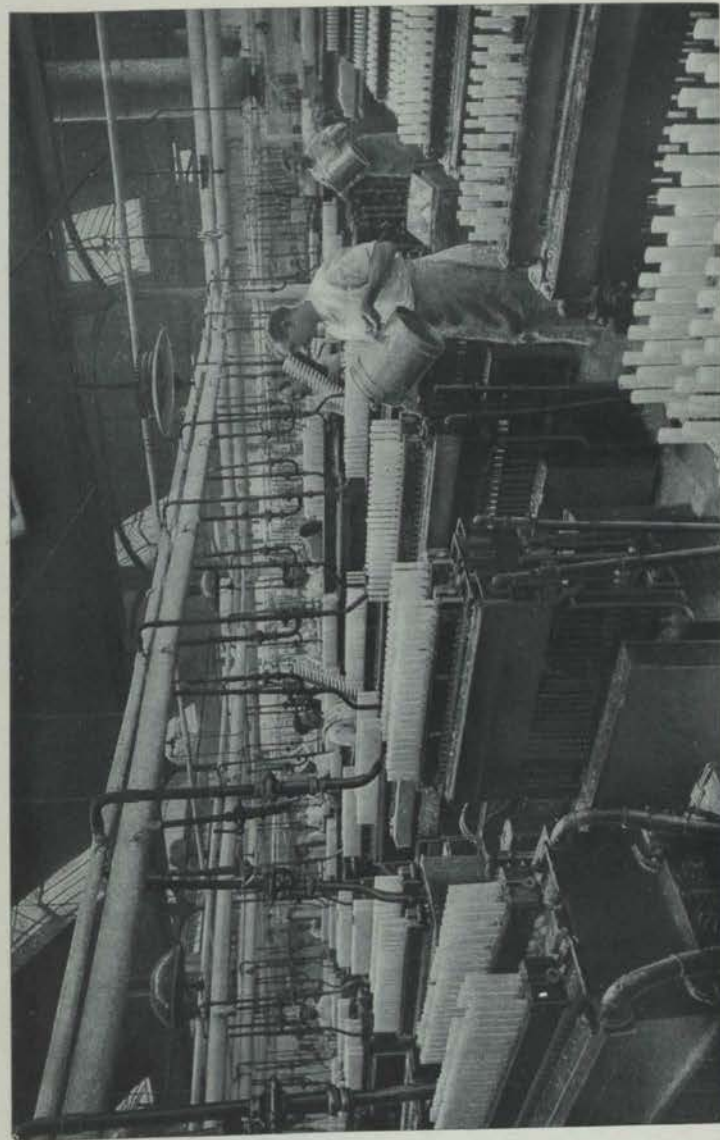
By permission of   **CANDLE MOULDING ON A LARGE SCALE**   *Price's Patent Candle Co., Ltd.*

The melted material is poured into moulds surrounded by hot water. When the moulds are full the hot water is replaced by cold water under the influence of which the candles solidify. They are then pushed up out of the moulds by hollow pistons.

for the curving over of the end of the wick would shift its lower portion out of the centre of the candle, tallow being such a plastic material. The end of the wick in a tallow dip keeps straight, and soon gets into the top of the flame, where it is charred, but cannot get enough oxygen for complete combustion; it interferes with the proper burning of the candle and the flame is rendered dull and smoky. From time to time, therefore, the tallow candle must be "snuffed"; that is, the end of the wick must be removed.

When tallow is treated with high-pressure steam it is split up, or "hydrolysed," to use the technical term, and the three acids mentioned above are liberated from the sway of the glycerine. At this stage they are crude and dark in colour, and are therefore subjected to distillation in a current of superheated steam. The nearly colourless mixture of the purified acids obtained in this way is subjected to pressure, so that the liquid oleic acid is squeezed out; the remaining product, known as "stearine," and consisting mainly of stearic acid, is cast into candles in suitable moulds.

Stearine does not melt below 160° Fahrenheit, so that candles made of this material will keep erect even in tropical countries. For use in temperate climates, candles are usually made of a mixture of stearine and paraffin wax, the latter being obtained in large quantities (about 24,000 tons a year) by the destructive distillation of Scottish shale. Candles are, as a matter of fact, made from paraffin wax alone, but they are rather soft and given to collapsing in hot weather. The tallow candle has been nearly ousted from the market by these modern competitors, but even yet the annual output of the former in this country amounts to a good many hundred tons.

In addition to tallow, stearine, and paraffin wax, beeswax also is used in the manufacture of candles. From the chemist's point of view, beeswax is quite different from paraffin wax, but similar to tallow; like the latter, it is analogous to a salt, and results from the union of fatty acids and an alcohol, only in this case it is another alcohol than glycerine.

The hydrolysis of a fat or oil into *glycerine+fatty acid* is effected, as we have seen, by the action of super-heated steam. By a modification of this procedure we can obtain *glycerine+soap* instead, for a soap is nothing more than the sodium or potassium salt of stearic or palmitic acid. For the production of soap, therefore, the fat, instead of being treated with superheated steam, is boiled with caustic soda or caustic potash. If soda is employed, a hard soap results, potash, on the other hand, yielding a soft soap. For the separation of the soap from the glycerine advantage is taken of the fact that although soap is soluble in water, it is not soluble in a solution of common salt. The boiling of the fat with caustic soda is therefore followed up by throwing a quantity of salt into the boiler; the soap separates, rises to the top, and is removed to iron moulds.

Although the chemistry of soap-making was not understood until about a hundred years ago, the art has been practised for many centuries. At the present time, soap-making is one of the leading chemical industries, and this country is ahead of all others both in regard to scientific methods of production and amount turned out of the factories. We not only make most of our own soap, but send over £1,000,000 worth annually to other countries.

The candle and soap industries have this in common,

that they both use fats as their raw material, and turn out glycerine as a by-product. Until the last quarter of a century, however, comparatively little attention was paid to this latter material; the soap-maker, indeed, simply ran the spent liquors containing the glycerine, "lyes," as they are called, into the nearest water-course.

Nowadays, because of its use in the manufacture of nitro-glycerine for dynamite and blasting gelatin, glycerine has become a valuable product, and successful efforts have been made to recover it from the spent liquors of the soap-works. This utilisation of what was formerly run to waste has, of course, cheapened the production of soap. Indirectly, therefore, the discovery and manufacture of nitro-glycerine and the explosives into which this dangerous substance enters may be regarded as promoting cleanliness.

It has been stated on good authority that the flourishing condition of the soap industry in this country has been chiefly due to the profits arising from the recovery of the glycerine. In any case, there is no doubt that the utilisation of waste products is very often of the greatest importance to the industry concerned. More than that, the history of by-products is a subject of the most fascinating interest even to the general reader, and a subsequent chapter will accordingly be devoted to this matter.

CHAPTER XXII

HOW MAN COMPETES WITH NATURE

EVERY one has doubtless observed that in the growing infant the bump of destructiveness is early developed, and that it is only at a later stage that this impulse to take things in pieces is succeeded by the desire to put together—to construct. In the gradual development of the science of chemistry we can detect similar stages. In one of these the energies of chemical workers were mainly directed to breaking down all the various substances found in nature, and discovering the simplest elements of which matter consists. At another and later stage attention has been chiefly directed to building up from simpler materials the various products of the earth.

We might, in fact, speak of the one method of work as destructive and of the other as constructive. Such destructive work, or analysis, as the chemist calls it, has, however, served a very useful purpose; it was necessary to demolish the fantastic structures of the alchemists, and to get down to the bed-rock of fact, before a building could be reared worthy of the name of science. Once the foundation was well and truly laid, the constructive work of building—synthesis, as the chemist calls it—could be taken in hand.

Why, the reader may ask, should we trouble ourselves to build up substances which Nature readily supplies?

Why not accept her gifts gratefully, and cease worrying about "synthesis"?

Now in at least one case which has already been mentioned, the reply to these questions is quite simple. The value of nitrate of soda as a nitrogenous manure has been emphasised, and at present the beds of this material in Chili are largely requisitioned for the purpose. But this is a case where Nature's stores are limited, and the prospect that in thirty or forty years the supply from this source will come to an end has stimulated the discovery of some method of utilising the vast stock of nitrogen in the atmosphere. The way in which this is being effected has already been described, and it is sufficient to point out that the artificial production of nitrate, regarded as an attempt to imitate Nature, has a very practical object.

However it may be now, there is no doubt that in the earlier stages of synthetic chemistry, the work was undertaken and carried out purely in a spirit of scientific investigation, without any reference to utility and without the expectation of favours to come, in the shape of hard cash returns. Innumerable chemists have spent their years in unremitting toil, striving only to let the light into many an obscure corner; their labours may have led in after years to applications of great commercial value, but all that these early pioneers had was the love of their work, the honour and the glory! Nowadays the commercial side of chemistry is very much in evidence, and the laboratory is in many cases a necessary part of the factory—its brains, in fact. Investigation and research carried out with the definite object of making money is a little less romantic than heroic attempts to win Nature's secrets for the sake of knowledge alone, but the former is

more immediately practical, and we must recognise that it has been very productive in results.

Synthetic chemistry may be said to date from a certain red-letter day in 1828, when Wöhler succeeded in producing carbamide (urea) artificially. This bald statement does not sound very stirring, but Wöhler's achievement was big with meaning for the years to come. It must be admitted that if the general reader were to listen to the long tale of Wöhler's discoveries, he would probably not select the artificial production of carbamide as the most useful or the most interesting. A boy would be interested in Wöhler as the first who described the curious behaviour of mercury thiocyanate, which swells up into a worm-like shape when heated—a scene familiar to all who have looked at "Pharaoh's Serpent." But Wöhler's fame does not rest on the discovery of Pharaoh's Serpent, or even on the preparation of aluminium, which he was the first to accomplish, but mainly on the production of carbamide from inorganic materials.

Now carbamide is essentially an animal product. The cast-off nitrogen of the human body is thrown out in the form of carbamide, and the average adult produces about 1 ounce of this substance every day. It is got rid of in the urine, which contains 1 to 2 per cent. of carbamide in the dissolved condition.

At the time of Wöhler's discovery the view was everywhere held that the complex substances occurring in plants and animals were produced only by the action of a special vital force; it was therefore vain to hope that these products of the organism—organic substances, as they were called—could possibly be obtained from the dry bones of inorganic material. Wöhler's success in producing carbamide in the laboratory from purely inorganic sub-

stances gave a severe blow to these old ideas; in fact, it upset them altogether. "Vital force" was evidently not necessary for the production of organic substances—a conclusion which has been abundantly confirmed since Wöhler's time, and is being daily confirmed in every chemical laboratory.

Suppose, now, we try to fill in the details of this epoch-making discovery, and to see how by mere laboratory operations it is possible to build up or synthesise carbamide from its elements. The inorganic substance which is most nearly related to carbamide is a compound of carbon, hydrogen, oxygen, and nitrogen called ammonium cyanate, and Wöhler discovered that by merely evaporating to dryness a solution of this compound in water a large proportion of it was changed straight away into carbamide. If, then, we show that ammonium cyanate can be made from its constituent elements in the laboratory, we are justified in saying that carbamide can be produced artificially.
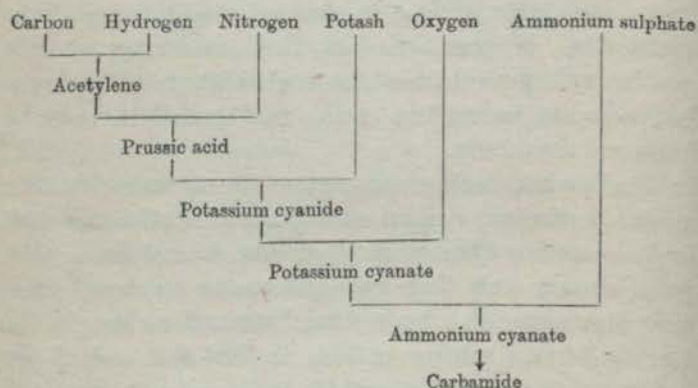
The first link in the chain between the separate elements, carbon, hydrogen, oxygen, and nitrogen at the one end, and ammonium cyanate at the other, is acetylene. We have already seen that this gas can be produced from inorganic materials; by heating lime and carbon in the electric furnace calcium carbide is produced, and to get acetylene from calcium carbide only water is required. But a more direct synthesis of acetylene is possible by making an electric arc between carbon rods in an atmosphere of hydrogen; under these conditions acetylene, which is a compound of carbon and hydrogen, is produced in small quantity.

Now acetylene gas, when mixed with nitrogen gas and exposed to the action of electric sparks, combines with

the latter element, forming prussic acid, or hydrocyanic acid, as the chemist calls it; and when prussic acid is neutralised with potash we obtain the salt potassium cyanide, a very poisonous compound of potassium, carbon, and nitrogen. Potassium cyanide can be very easily melted in an iron dish, and in the molten state readily absorbs oxygen from the air, forming a salt called potassium cyanate, a compound of potassium, carbon, nitrogen, and oxygen. If this substance is dissolved in water and sulphate of ammonia added, we get a double exchange taking place, whereby ammonium cyanate and potassium sulphate are formed.

This gradual building up of carbamide may be represented graphically in the following manner :—

Carbon   Hydrogen   Nitrogen   Potash   Oxygen   Ammonium sulphate
|_____|
Acetylene
Prussic acid
Potassium cyanide
Potassium cyanate
Ammonium cyanate
↓
Carbamide

It may be objected that besides the four elements, carbon, hydrogen, oxygen, and nitrogen, three compounds have been introduced into this synthesis, namely, potash, water, and ammonium sulphate. If space and the reader's patience permitted, it might, however, be shown that these compounds also can be built up out of their constituent elements, so that the whole chain is complete,

from the simple carbon, hydrogen, oxygen, and nitrogen to the organic compound carbamide.

Wöhler's wonderful discovery was interesting not only because carbamide was the first organic compound to be prepared in the laboratory from inorganic materials, but also because it consists of the same elements as are present in ammonium cyanate, and, more than that, the carbon, hydrogen, oxygen, and nitrogen are present in exactly the same proportions in the two compounds. The extraordinary fact that two chemical compounds which are quite distinct in external appearance and behaviour may contain the same elements united in the same proportions was very puzzling to chemists at that time, although nowadays it is taken quite as a matter of course. Later workers have shown that such differences are due to a very subtle distinction in the way in which the atoms are arranged in the molecules; the internal anatomy of the molecule is different in the two cases.

Since that red-letter day in 1828 synthetic chemistry has made gigantic strides, and we have learned to produce artificially hundreds of naturally occurring products. In many cases such an imitation of Nature has very little interest for anybody outside of a chemical laboratory, but, on the other hand, the synthetic product does occasionally come into the market as a competitor of the natural substance. An interesting example of this is furnished by the history of alizarin.

For centuries this valuable dye-stuff was obtained from the madder root, and large areas of France, Holland, Italy, and Turkey were given over to the growth of the plant. Cloth dyed with alizarin has been found on Egyptian mummies, so that its use goes back to a remote age. Yet within the short space of forty years this

ancient product of the vegetable world has been unceremoniously hustled out of the market by the artificial dye. The latter can now be produced more cheaply than the natural alizarin, with the result that the cultivation of the madder plant has almost ceased.

The magnitude of the trade revolution thus due to the synthetic production of a natural dye may be gauged from the fact that for ten years previous to the discovery the value of the annual import of madder into Great Britain averaged £1,000,000, while ten years later the value had sunk to £24,000. All this meant unemployment and privation to the people engaged in the cultivation of the madder plant, but indeed it is frequently the case that the advance of science, although beneficial to society as a whole, involves suffering to many individuals.

In explaining the synthesis of carbamide we were at pains to follow the successive steps by which it is possible to build up the final compound from the component elements. It must not be supposed, however, that the manufacturer of alizarin starts with the elements of which that substance is composed. As a matter of fact, the chief raw material of alizarin is anthracene, a hydrocarbon which is extracted from coal tar. It has been shown that this hydrocarbon can be synthesised in the laboratory, and as everything else used in the manufacture of alizarin can be similarly built up from inorganic materials, it follows that we have here an instance of the artificial formation of a complex natural product. The manufacturer, however, who has to consider the price of raw material and the cost of labour, starts with some other natural product, in this case anthracene, which is at once cheap and easily obtained.

Natural alizarin has gone down before the artificial

product, and a similar fate seems to be in store for another well-known dye-stuff, namely, indigo. It is some time now since chemists managed to produce indigo synthetically in the laboratory, but, as is frequently found, it is quite a different thing to turn out products profitably on the manufacturing scale. Dividends become a prime consideration, and the question arises whether the artificial product can be manufactured cheaply enough to compete successfully with the natural article. In the case of indigo the interval of time between the laboratory synthesis and the successful manufacture on a large scale was considerable. Years elapsed before all difficulties were overcome, but Science prevailed in the end and the artificial production of indigo on commercial lines is an accomplished fact.

The raw materials on which the manufacture of indigo depends are (1) the hydrocarbon naphthalene; (2) ammonia, both obtained from coal; (3) acetic acid, obtained from wood; (4) oxygen, from the air. Starting with these, chemists have elaborated a process whereby artificial indigo is turned out sufficiently cheaply to compete with the natural dye-stuff. Already the latter has been hard hit, and the cultivation of the plant from which it is obtained is apparently doomed. The value of the indigo exported from India was £3,570,000 in 1895, and only £556,500 in 1904, while of the total quantity of indigo consumed in the various countries of the world at the present time, between 80 and 90 per cent. is the artificial product. This latter, it must be clearly understood, is not a mere substitute; it is exactly the same chemical compound as is derived from the plant.

The synthesis of indigo on a manufacturing scale is indeed one of the most remarkable achievements of modern

chemistry. It has been spoken of as "a monumental example of scientific skill, patience, and resourcefulness," and as "absolutely unparalleled in the recent history of chemical industry."

The reader will perceive that the advance of chemical science, while it is to the interests of the community as a whole, may involve serious trouble, and possibly extinction, to special industries. There is no partiality in the business. At one time it is France's turn to suffer from artificial alizarin, then India feels the competition of synthetic indigo; now it looks as if Japan and China were to find out in a similar way what the advance of science may mean in connection with camphor.

True Japanese camphor is obtained from a tree which belongs to the laurel family, and which is native to China and Japan. The wood is cut into small pieces and subjected to the action of steam, whereby the volatile camphor is carried off and condensed in a cool vessel. The amount of this crude camphor annually exported from China and Japan has in recent years run to about 3000 tons. Most of the camphor supplied from these sources is employed in the manufacture of celluloid, but a certain quantity is used up in medicinal preparations and in explosives.

An enormous amount of labour has been expended in the study of the chemical nature of camphor, and this has at last borne fruit in the synthetic production of the substance. The starting-point is turpentine—a resinous liquid which exudes from various trees belonging to the pine family. When turpentine is boiled, a liquid known as "oil of turpentine" distils over, and from this liquid camphor is produced by laboratory processes into which we cannot enter here. Synthetic camphor is identical

with natural camphor in all ordinary physical and chemical properties, and provided that a plentiful supply of turpentine at a moderate price is available, the next few years may witness a repetition of what has already occurred in the cases of alizarin and indigo.

It is a very confusing circumstance that there is also on the market a product known as "artificial camphor," which, indeed, has an odour resembling that of true camphor, but which is chemically quite a different substance. Synthetic camphor, on the other hand, is chemically identical with the natural product.

Another and quite different direction in which we have been trying with success to imitate Nature is in the manufacture of rubies. In an earlier part of this volume it was stated that Moissan had been able to produce real diamonds, so small, however, as to be of no ornamental value. The specimens commonly known as "artificial diamonds" are spurious; the "paste" used in their manufacture is chemically quite different from the diamond, which, as the reader knows, is simply crystallised carbon. Artificial rubies, however, are chemically identical with the natural gems, and are indistinguishable from them.

Rubies and sapphires are practically pure alumina in the crystallised condition; they consist almost entirely of this compound of aluminium and oxygen. Alumina itself is a colourless substance, and the colours of the natural stones are due to the presence of small quantities of the oxides of chromium and iron. If the crystallised alumina is free from these other materials, we have the mineral known as corundum, which in hardness is second only to the diamond, and with which, in an impure form, we are familiar as emery. So that the useful and the

ornamental, in the shape of emery and ruby, are very closely related.

The artificial production of rubies depends simply on the careful fusion of alumina at a high temperature, and the addition of a small quantity of dichromate of potash to produce the colour. Great care must be taken in the cooling of the fused alumina; if allowed to solidify and cool very rapidly, it is in an unstable condition, like glass which has been similarly treated. It is therefore annealed, by putting the artificial ruby while still at a high temperature in a bed of silver sand, so that the cooling takes place very slowly.

Sapphires may be made in a similar fashion, except that the colouring material added is oxide of cobalt instead of potassium dichromate. The artificial production of sapphires, however, has not been so successful as that of rubies.

A new and very striking way of making these gems has been tried lately. It has been found that when natural colourless crystals of corundum—white sapphires, as they are called—are exposed to the action of radium bromide, they undergo a gradual change of colour. Some specimens assume a blue tint, others a pink, and others still a brownish orange; so that stones of any desired tint may be obtained.

In these and many other ways, then, man has been trying, and is trying, to imitate and compete with Nature. When we look back to that day in 1828 when the artificial production of carbamide was first accomplished, we are filled with wonder at the marvellous advance which has been made in the interval. Not only have we learned how to obtain artificially numbers of valuable natural products, but we can turn out of our laboratories

and factories many useful chemical compounds which, so far as we know, do not occur in Nature at all. We must, however, beware of pride. We must confess that, although we can produce organic compounds in the laboratory, we cannot turn out an organism. That is a different thing altogether, and there is no prospect that the breath of life will ever be evolved from any chemical mixture, however cunningly devised.

CHAPTER XXIII

THE ADULTERATION OF FOOD

THE chemist's imitation of Nature, as shown in the previous chapter, has led to results of marvellous interest and practical value, but in some cases, unfortunately, the imitation practised at the present time has an unworthy object. Just as there are some individuals who devote their chemical knowledge to the manufacture of bombs and infernal machines, so there are others who engage in the objectionable practice of adulterating food.

There have always been knaves ready to defraud the public, and the adulteration of food is no new thing. We have evidence on record that in past centuries bread, wine, butter, and drugs were all liable to adulteration. Things are bad enough now, but if one were to judge from a certain booklet published in the beginning of last century, the old days were even worse. This striking pamphlet has for part of its title—" Deadly Adulteration and Slow Poisoning, and Death in the Pot and the Bottle; in which the blood-empoisoning and life-destroying adulterations of wines, spirits, beers, bread, flour, tea, sugar, spices, cheesemongery, pastry, confectionery, medicines, &c., are laid open to the public," and the author expresses himself occasionally in the gloomiest terms regarding the state of matters in his day. " Bread," he says, " turns out to be a crutch to help us onward to

the grave, instead of being the staff of life. In porter there is no support, in cordials no consolation, in almost everything poison, and in scarcely any medicine cure."

The adulterations practised at that time, however, were comparatively crude, and with present-day methods and instruments they would be easily detected. As a result of the advance of chemical knowledge and practice, the adulterator has been forced to refine his nefarious methods, so that at the present time many of the alien substances introduced into our food can be detected only by the skilled analyst. "For ways that are dark, and tricks that are vain," the modern adulterator would indeed be hard to beat.

We must, of course, allow that if we call every foreign addition to our food an adulteration, there are cases where the offence is not very heinous. As examples of these less objectionable additions, we may take the colouring and flavouring of butter. Butter fat itself in the natural state has generally nothing like the yellow colour which we are accustomed to see in the commercial article, and the explanation is that in the great majority of cases an artificial colouring matter, quite harmless in itself, has been introduced. This is done, it is said, because the public prefers to have a highly coloured article. Again, the difference in flavour of various samples of butter is not natural; it is induced by the presence of certain micro-organisms which are cultivated for the purpose. These adulterations, although undesirable, are not harmful, and may be regarded as mildly fraudulent in comparison with others which are commonly practised.

Many common foods contain foreign materials introduced with the direct object of defrauding the public and securing a larger profit to the seller. Even the

ordinary food-stuffs of the breakfast-table are not always what they seem, with the exception, perhaps, of sugar, on the purity of which one can depend. The reader may be interested to hear a little about the ways in which these foods are adulterated, and about the methods by which the fraud can be detected.

In the case of milk the chief, and one might almost say the natural, adulterant is water. New milk contains as much as 87 per cent. of water, and the uninitiated might suppose that it would be very easy to add a little more without detection. Careful analysis, however, will always reveal any such manipulation, although it must be borne in mind that there may be a certain difference in the richness of milk from various cows.

One method which the chemist has at his disposal is the determination of the specific gravity—that is, he finds out how much heavier the milk is than an equal bulk of water. It is worth while remembering that the first recorded determination of the specific gravity of a substance was in connection with a question of fraud. Hiero, the King of Syracuse, had commissioned a goldsmith to make him a crown out of a certain quantity of gold. When the smith brought the finished crown, Hiero somehow suspected that there was an admixture of base metal, and asked Archimedes to find out for him whether this was so. The philosopher took a lump of pure gold equal in weight to the crown, and put each into a vessel full of water. He found that more water overflowed from the vessel into which the crown had been put than from the other, and concluded rightly that the crown must contain some lighter and baser metal. So the determination of specific gravity as a means of detecting fraud is a time-honoured practice.

If a bulk of water were taken which weighed exactly 100 ounces, an equal bulk of pure new milk would weigh about 103 ounces, a little less or a little more, according to its source. That is, the average specific gravity of milk may be taken as 1·03. If, then, a certain sample of milk had a specific gravity of only 1·02, we might be sure that it had been "watered." On the other hand, the fact that the specific gravity of a sample is 1·03, does not prove the milk to be satisfactory; for, curiously enough, it is possible, by a judicious combination of watering and skimming, to get a product which has the same specific gravity as the original milk.

The reader, of course, knows that the fat contained in the milk—in other words, the cream—rises slowly to the surface; but he may not have drawn the conclusion that this fat must therefore be lighter than the milk. What is left after removing the cream—that is, the skimmed milk—is actually heavier, bulk for bulk, than the fresh milk; its specific gravity is higher than 1·03. By adding water to this skimmed milk in the proper proportion, the specific gravity is brought down to the normal figure 1·03, and this "milk" is indistinguishable from fresh milk unless further tests are applied.

It will probably be suggested that a mere glance at this "milk" would show that it had been skimmed and watered. But our adulterator is not so easily caught; he perpetrates fraud upon fraud, exhibiting an ingenuity which is worthy of a better cause. A judicious admixture of a yellow dye to skimmed and watered milk is found to produce a rich, creamy appearance, and the public is delighted with its milk supply. So is the adulterator; he has sold his "milk" at the standard price, and he has still the cream to dispose of.

Since, then, the appearance of the milk and even the determination of its specific gravity may fail to give any proof of adulteration, further examination is necessary. The analyst must proceed to find also what is the amount of fat present in the milk. This is very quickly ascertained by treating a measured quantity in a centrifugal machine; the fat or cream under these circumstances separates almost immediately, and its bulk may be determined. If the amount of fat is less than 3 per cent., the milk has certainly been tampered with, since the normal product never contains a smaller percentage of fat than this. A thorough examination would include also the determination of the non-fatty solids, consisting chiefly of casein and milk-sugar; but a description of this would take us rather far.

Butter is another household article that is readily and frequently adulterated, although the recent Butter and Margarine Act should do something to protect the public. The usual frauds practised in the case of butter are (1) the sale of "renovated" or "process" butter as fresh butter, and (2) the substitution of a certain amount of cheap beef fat or lard for the true butter fat. Renovated butter is obtained from rancid butter by a process in which the objectionable matter is removed; the product is rendered sweet for the time being, and is sold as choice butter.

Artificial butter, on the other hand, or margarine, as it is commonly called, is prepared from beef fat or lard, which is worked up with ordinary butter and colouring matter so as to resemble the real article. Besides a certain difference in the taste of butter and margarine, there is one very simple method, known as the spoon test, by which they may be distinguished. If a

little genuine butter is melted in a large spoon over a small Bunsen flame, and the heating is continued, the butter ultimately boils quietly and foams up to the edge of the spoon. Margarine, treated in the same way, splutters about and crackles, but does not foam. The practice of selling margarine under the name of pure butter is probably dying out, but it is not so very long since a bold individual was prosecuted for actually advertising a process for the "scientific" blending of butter with beef fat or lard. Science, it would seem, covers a multitude of sins.

A food-stuff which is very frequently adulterated is chocolate. This substance is obtained by grinding cocoa nibs, which are the crushed kernels of cocoa beans. The nibs consist to about 45 per cent. of a fat, the so-called cocoa butter, and in this respect are quite different from the shells of the cocoa bean, which contain only 2 to 3 per cent. of the fat. Seeing that the price of cocoa nibs is about ten times that of cocoa shells, the common practice of adulterating chocolate with powdered cocoa shells is distinctly profitable. This fraud is best detected by the aid of the microscope, an instrument which is part of the necessary equipment of an analytical chemist's laboratory. To the practised eye the presence of the powdered shells is at once obvious.

There is another adulterant of chocolate or cocoa which is easily detected with the aid of the microscope, and that is starch. This substance is very widely distributed in the plant world, and occurs in all sorts of vegetables and cereals. The samples of starch obtained from these various sources, such as wheat, rice, potatoes, and maize, are chemically identical, but when they are examined under the microscope, the granules of which they consist

are found to be surprisingly different in shape and size. The granules of wheat starch are circular, those of potato starch are oval, while those of rice starch are many-sided ; the granules from maize starch, as found, for example, in cornflour, are also many-sided, but are uniformly much larger than rice-starch granules. It is therefore possible for a skilled analyst to determine with the microscope whether any starch, and, if so, what kind of starch, has been used in adulterating a given food-stuff. He can also discover at once whether a certain kind of starch is pure or is contaminated with another kind. Obviously there is a temptation for the adulterator to add a cheap starch to a more expensive one, say potato starch to arrowroot, keeping the price the same. The microscope, however, soon exposes such a fraud.

Substances which in some cases are to be regarded as regular adulterants are those used as preservatives. It is now generally agreed that a dairyman who knows his business does not require to add preservatives such as boric acid and formaldehyde, even in the hottest weather. Moreover, the passage of these substances into the digestive organs is not to edification. The amount of formaldehyde which must be added to milk in order to preserve it is certainly exceedingly small—1 part in 10,000 of milk will keep the latter sweet for five or six days—but it must be remembered that in the case of children who consume considerable quantities of milk, the total amount of preservative taken into the system becomes appreciable.

Similar objection may be taken to the employment of boric (or boracic) acid. This is used as a preservative of milk less frequently than formaldehyde, and it is generally mixed with borax, its sodium salt. Boric acid, by the
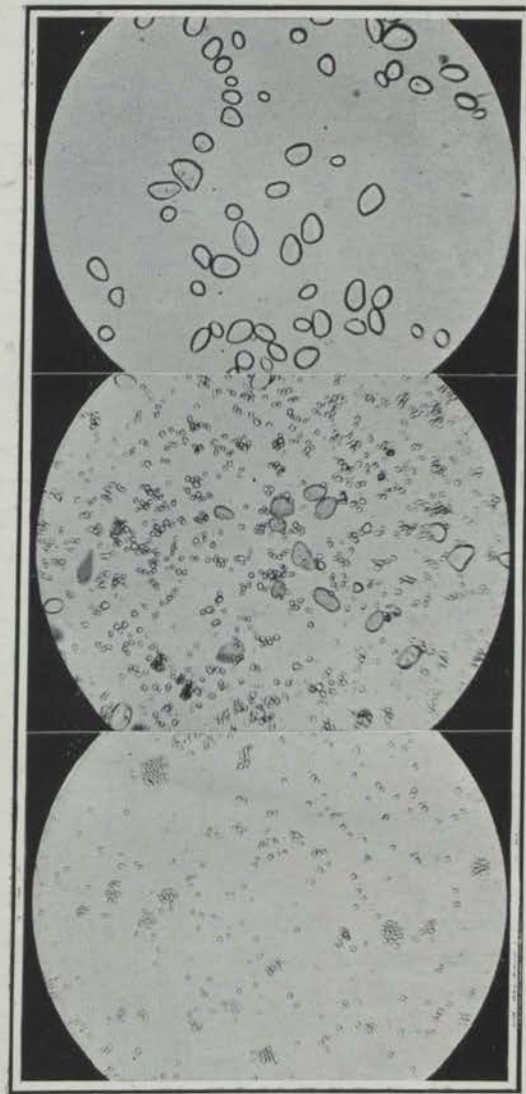
HOW THE MICROSCOPE REVEALS ADULTERATION

The granules shown in the left-hand section are those of rice starch; those in the right-hand section, magnified the same number of diameters, are from arrowroot. The middle section represents a mixture of starch granules from rice and arrowroot. It will be seen that any adulteration of arrowroot with rice starch can be detected easily.

Photos by Edward R. Bolton, Esq.

way, has an interesting natural origin. Practically all the acid we use for preservative and other purposes comes from Tuscany, where numbers of steam jets of volcanic origin — *soffioni*, as they are called — are to be found issuing from the ground. This steam contains small quantities of boric acid, and when a tank to hold water is built round the blowhole, the boric acid is condensed. It gradually accumulates in the water of the tank, and is then obtained by evaporation, the steam jets themselves being used to promote the process. Successful results have been obtained also from artificial *soffioni*, started by boring into the lower strata.

There are other chemicals which are often used as food preservatives, such as salt, sugar, and vinegar. These substances are themselves foods to some extent, and they are therefore much less objectionable than purely anti-septic preservatives like boric acid and formaldehyde. The use of common salt (sodium chloride) in preserving butter and meat is well known to every one, and it is not regarded as an adulterant. A curious effect is produced when the solution in which beef is salted contains some saltpetre (nitrate of potash) as well as sodium chloride. The saltpetre causes the meat to preserve its natural red colour, which would be destroyed, partially, at least, by the action of common salt alone.

Eggs are a form of food which is fortunately out of the reach of the adulterator. At least he cannot imitate the egg as a whole, and his turn comes only when the question of an egg substitute arises. In this line he has displayed his usual ingenuity, and brought out powders which are said to contain all the in-gredients of eggs, but which on examination are found to fall very far short of that standard. In one case

on record it was stated with a great show of authority that the composition of a certain egg substitute was "based on the scientific analysis of natural eggs," which, it should be noted, contain a fair proportion of nitrogenous matter. When tested, the product in question was found to be entirely innocent of nitrogen, and consisted of nearly pure tapioca starch with a little common salt and colouring matter added. This is another example of the way in which the name of science is taken in vain.

CHAPTER XXIV

THE VALUE OF THE BY-PRODUCT

IT is perhaps difficult for the outsider to realise that the manufacture of useful and valuable materials, which has been rendered possible only by the advance of chemical science, but which we now take so much as a matter of course, has meant at the same time the production of enormous quantities of rubbish. The raw material which Nature supplies may contain only a small proportion of the substance we wish to get from it; the rest is so much refuse, and, unless we can devise some way of using it, has to go on the dustheap. We extract the gold, and the dross is left.

Now rubbish-heaps there will be as long as the world lasts, but provided that they are not a public nuisance, and that they are kept out of our sight, we accept them as a necessary evil. It will be readily admitted, however, that a rubbish-heap which as late as 1888 covered 450 acres of ground, and was then receiving a trifling daily addition of 1000 tons, is no ordinary affair. This heap of alkali waste, about which we shall have more to say later on, was at the same time a public nuisance; the neighbourhood was, and still is, pervaded by a most objectionable odour.

There are many other cases in which the waste products of a chemical industry, although less obnoxious than alkali waste, accumulate at an altogether un-

manageable rate, and it is no wonder that manufacturers and their chemists have made heroic attempts to deal with this rubbish problem. Indeed, the story of the way in which the attacking forces have slowly advanced, at great expenditure of energy, patience, and fortune, reads like a romance.

The reader, however, will readily understand that besides the mere wish to avoid the awkward accumulation of rubbish, the desire to make something out of it has helped in the solution of the problem. The manufacturer is only too pleased if the chemist can tell him how waste material can be converted into a useful by-product. Indeed, history shows that the discovery of methods for utilising the waste products of a chemical industry has frequently saved it from going down in the face of fierce competition. Economy demands some utilisation of the waste material, and this has been effected with much profit to the manufacturer even in industries where there is no particular difficulty in getting rid of it.

An instance of the production of much waste material is to be found in the brewing industry. The main object of brewing is, of course, to get beer, but during the process of manufacture a very large quantity of carbon dioxide is produced. The alcohol in the beer is obtained by the fermentation of sugar, in which process sugar is changed into alcohol + carbon dioxide. The quantity by weight of the carbon dioxide formed during the fermentation is almost equal to that of the alcohol, and the process is generally carried on in open vessels, so that the gas simply escapes into the air, and is lost. Carbon dioxide, that is to say, is a waste product of the brewing industry.

It is quite easy to carry out the fermentation in closed vessels provided only with an outlet for the carbon dioxide, and by this method the gas could be collected and condensed to the liquid form in steel bottles; in this shape carbon dioxide is a marketable commodity. Such a conversion of the chief waste product of the brewing industry into a useful by-product has actually been carried out, and the carbon dioxide so obtained has found application in refrigeration and in the preparation of aerated waters. Nowadays, however, the attempt to recover the carbon dioxide as a by-product is very seldom made, because, from the commercial point of view, it is not worth while.

A waste product which is more tangible but less easy to deal with than carbon dioxide is blast-furnace slag. From what was said in a previous chapter, the reader will understand that iron-smelting consists essentially in heating together crude iron oxide, carbon in the form of coke, and a flux, such as lime, to remove the earthy material from the ore in a fluid form. At the end of the operation two things are obtained, namely, pig-iron and slag, the latter being simply the flux + the earthy material from the iron ore. It is run out of the blast furnace in a molten condition and is a sort of cross between glass and cinders. This unpromising material is turned out in Great Britain at the rate of nearly twenty million tons annually, and the mere removal of this refuse from the foundry involves the smelters in very considerable expense. In some cases it is taken out and shot into the maw of the all-devouring sea. In other cases, as in the Black Country, it is allowed to accumulate in huge, unsightly mounds —veritable rubbish-heaps of modern civilisation.

It is perhaps too much to hope that such an enormous mass of waste material will ever be entirely devoted to useful ends instead of disfiguring the landscape and covering up the fertile soil, but recent work has undoubtedly led to encouraging results in the utilisation of slag. Much of it is employed in road-making and in reclaiming waste land, but in addition there is now made a very large quantity of slag cement, for which purpose the finely powdered slag is mixed with lime. Another purpose to which considerable quantities of slag are devoted is the making of "slag wool." This curious product is somewhat similar to "glass wool," the name in each case indicating a resemblance to cotton wool. When a jet of steam is directed against molten slag, little globules of the liquid material are blown off, each with a long, thin tail or filament. By mechanical means the filaments are separated from the globules, and slag wool consists simply of masses of the filaments. It is a non-conducting, non-inflammable material, and as such is usefully employed in covering steam-pipes and boilers. In virtue also of its non-conducting properties, it is used to coat refrigerating plant.

It is very curious that while there has been such difficulty in utilising blast-furnace slag, there is another kind of slag, turned out from steelworks, which has found a ready application. If the reader considers for a moment how this basic slag, as it is called, is obtained, he will understand why it is a more valuable by-product than blast-furnace slag.

Steel is obtained by blowing air into molten pig-iron; the impurities in the latter are thereby oxidised, and the purified metal is then supplied with the requisite quantity of carbon to convert it into steel. It is par-

ticularly important to get all the phosphorus removed from the metal, and this is best secured by adding quicklime to the molten pig. Any phosphorus which is present in the latter is oxidised by the blast of air, and is then in a condition to combine with the lime. The slag, therefore, which is obtained at the end of the operation, contains phosphate of lime, and it is just the presence of this phosphate which makes basic slag valuable as a fertiliser. The greater part, say 1,500,000 tons, of the basic slag which is turned out of the steelworks of Europe is sold for this purpose. The only thing necessary in order that its fertilising power should be available is that it be finely ground. This is quite a straightforward operation, so that we have here an excellent example of the way in which the waste material of an industry is converted very simply into a valuable by-product.

More striking than any of the cases yet quoted is the tale of the soda industry in Great Britain. Not once, but twice during its history, a waste product of the most disagreeable description has become a valuable source of income to the manufacturer. Refuse has been converted into riches, and one of the by-products has actually become the most important part of the output.

Carbonate of soda is found in nature to a limited extent, but it is the artificial production which alone is of any importance. This goes back to about the time of the French Revolution, when a certain Frenchman, Leblanc by name, first showed how to turn common salt into carbonate of soda. Any one who seeks to produce soda on a large scale is bound to start with salt, for it is the compound of sodium of which there is the most plentiful supply in Nature. The process

which Leblanc devised laid the foundation of an enormous industry, and has given us cheap soap and cheap glass; but he himself, poor man, did not have much joy out of his invention. The unsettled nature of his time prevented his getting any profits; he did not even receive the reward promised by his own Government, and at length, in disappointment and despair, he put an end to his own life.

Leblanc's process for the manufacture of soda has been worked in England for about ninety years, and in order to appreciate its strange and chequered history, we must understand what the process is. The first stage is the conversion of common salt (chloride of soda) into sulphate of soda, or "salt cake," as it is called, by heating with sulphuric acid. This operation results, not only in the formation of salt cake, but also in the evolution of torrents of hydrochloric acid gas. While the industry was in its infancy the hydrochloric acid had little or no value, and was allowed to go up the chimneys and pollute the air. The results of this were remarkable; the vegetation in the neighbourhood of the alkali works was devastated; the smell pervading the atmosphere was noxious, and articles made of iron, such as locks, gutters, and tools, were rapidly corroded. No wonder that the alkali works were unpopular institutions.

The manufacturers thought that by building very high chimneys, up to 500 feet, the acid gas would get dissipated in the upper layers of the atmosphere, but this plan did not work out in practice, for the fumes descended like a pall on still wider areas, and the vegetation vanished. A striking commentary on the anxiety there was about 1840 to get rid of this public nuisance is furnished by the patent which was taken out for a sort of floating

salt cake furnace. Weather permitting, the furnace was to be towed out to sea, and there allowed to do its worst, so far as pollution of the atmosphere was concerned.

Gradually, as time went on, another method of dealing with the waste hydrochloric acid came into vogue. This gas is very easily soluble in water, so that by making it pass through a chimney or tower packed with coke over which water was constantly running, it was possible to absorb the greater part of the acid fumes. This was undoubtedly the right direction in which to go to work, but the absorption of the acid was never complete, and as the number of alkali works increased very rapidly, the public nuisance caused by the uncondensed acid vapours was as great as ever. It is estimated that even as late as 1860 the English alkali works were pouring out about a thousand tons of this corrosive hydrochloric acid gas every week. Besides, those manufacturers who went in for absorbing it were left with enormous quantities of the acid liquor on their hands. There was not much demand for this; it had little value, and the bulk of it was accordingly tipped into the nearest stream. Here the acid did fresh damage, for it killed all the fish; the people immediately concerned with the stream objected to its pollution, and complaints were very numerous.

Altogether rather an awkward situation for the alkali manufacturers! Yet within the space of a few years the whole aspect of affairs was altered. The hydrochloric acid, which had been such an unmitigated nuisance to everybody since the start of the alkali industry, was discovered to be a valuable product. The alkali manufacturer became very careful to keep and use every particle of the substance which a few years before he

would have given anything to be rid of. In fact, the utilisation of the hydrochloric acid rapidly became the most profitable part of the manufacture of soda by Leblanc's method.

What was responsible for this sudden transformation, for this striking conversion of waste into wealth? One of the chief factors was undoubtedly the removal of the duty on paper in 1861, as the reader will agree when the connection between these apparently unconnected events is explained.

The removal of the restricting duty gave an immense stimulus to the demand for paper materials. Cotton and linen rags, which had previously served for the manufacture of paper, were no longer adequate to supply the demand. Other raw materials, straw, wood, and esparto grass, were therefore requisitioned, but these substances had to undergo very drastic treatment before they appeared in the form of paper. Among other things, they required much bleaching, and *the* source of bleaching materials is hydrochloric acid. Chlorine, prepared from hydrochloric acid, is used for the purpose, either directly or after conversion into bleaching powder. The connection between the paper duty and the fortunes of the soda industry is therefore pretty obvious.

The discovery of this valuable outlet for their hydrochloric acid, and the passing of the Alkali Act in 1863, stimulated the manufacturers to devise improved methods of absorbing the acid; and so efficient is the absorption now that the escaping gases contain less than 0·2 grain of hydrochloric acid per cubic foot. Any one who allows a larger proportion of the acid to escape is liable to a fine.

Having seen the good fortune which at length attended the efforts of the alkali trade to get rid of waste product,

we might suppose that there would be contentment all round, among the public as well as among the manufacturers. But this was not so, and the cause of trouble was the second stage of the Leblanc soda process.

We have been so occupied in following up the history of the waste hydrochloric acid that we have yet to learn the fate of the salt cake which is produced at the same time. In the second stage of the Leblanc process the salt cake is mixed with limestone and coal dust, and heated in a furnace. The chemical changes which take place in this furnace are somewhat complicated, but the net result is a product known as "black ash," consisting chiefly of carbonate of soda and sulphide of lime. With the help of water, the soda is extracted from the black ash, the portion which is insoluble being termed "alkali waste." This objectionable refuse contains both the calcium from the limestone and the sulphur originally used in the manufacture of the sulphuric acid for the first stage. Of these, the sulphur is especially valuable, but for many long years no satisfactory method could be devised for recovering it from the waste, which was simply thrown away.

The accumulation of this waste material in the neighbourhood of alkali works led to much unpleasantness. Even when it was stamped down and covered over with a layer of cinders, moisture and air gradually got at the waste, with the result that sulphuretted hydrogen gas was given off into the atmosphere. Apart from the abominable odour, such accumulations are themselves an eyesore, and their magnitude is such that one can appreciate the importance of the soda industry from a mere glance at these rubbish-heaps. Those in the neighbourhood of Widnes alone, to which reference was made in

the beginning of the chapter, are estimated to contain 8,000,000 tons of material.

To the trouble which this waste brought upon the manufacturers of soda by Leblanc's method there was added the menace of serious competition. The ammonia-soda process, as it is called, has during the last thirty years become a formidable rival of the Leblanc process, and at the present day considerably more than half the world's production of soda is made by the newer method. Curiously enough, while the Leblanc process was a French patent which has been worked mostly in England, the ammonia-soda process was an English patent which commended itself first and foremost to the Germans. This later method of manufacturing soda has many advantages, and although we cannot go into details, we may mention that brine pumped directly from the salt beds is converted into soda in such a way that the product is a purer one than that yielded by the Leblanc method, and that there are no disagreeable waste products.

The reader might suppose that the ammonia-soda process, with all these advantages, would speedily displace the older Leblanc process. But the latter has offered a stubborn resistance, a fact attributable to the once despised and obnoxious hydrochloric acid. The value of this by-product has kept the Leblanc process going. At the same time everybody concerned realised that, with this serious competition to face, all must be done to effect economies, and, if possible, recover that lost sulphur from the alkali waste. As one of the leading chemical manufacturers in this country said in 1881: "The recovery of sulphur from alkali waste, as a means of cheapening the cost of production by Leblanc's process, has become of vital importance."
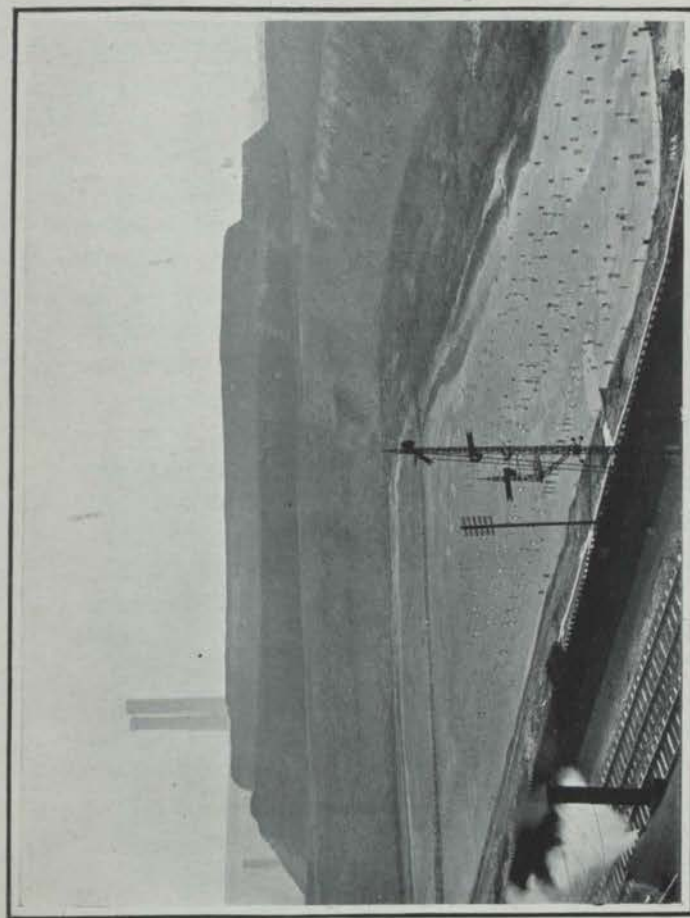
By permission of THE RUBBISH HEAP OF A CHEMICAL INDUSTRY The United Alkali Co. Ltd.

One of the huge unsightly mounds of alkali waste which are to be seen at St. Rollox, Glasgow.

THE VALUE OF THE BY-PRODUCT

At length, after a series of abortive attempts, success was attained. By a process patented in England in 1888, 90 per cent. of the sulphur in alkali waste is recovered, and can be sold as pure sulphur. Even in 1893, only five years after the patent was taken out, 35,000 tons of sulphur were recovered by this method in England alone.

From the public point of view also, this utilisation of alkali waste is welcome, for sulphur was the constituent of the waste which was responsible for its objectionable properties. Once the sulphur is removed, as is done nowadays, the residue is innocuous and unobjectionable, so that the nose of the community is no longer offended. Not always have private profit- and public interest been served together as in this utilisation of alkali waste.

With the economy thus effected, the Leblanc process has entered on a new lease of life. At the same time it is interesting to note that some manufacturers who use the Leblanc process turn out no carbonate of soda at all, but caustic soda, bleaching powder, and pure sulphur. It is in respect of these secondary products that the Leblanc process has an advantage over its rival.

The story of the soda industry is interesting because of its varying fortune, and because of the illustration it furnishes of the value of the by-product. Even yet it is not quite certain that the industry is at the end of its vicissitudes, for the manufacture of alkali and bleach by electrolytic methods is being rapidly developed, and bids fair to be a formidable competitor. Time only can show whether these new methods will be able to overthrow the older processes of soda manufacture.

CHAPTER XXV

VALUABLE SUBSTANCES FROM UNLIKELY SOURCES

THE last chapter will have shown the reader how waste products, sometimes merely embarrassing in their character, sometimes definitely obnoxious, can be brought to play their part in our industrial economy. We are encouraged to believe that everything has its place, could we but find it out, and that the waste material of our industries is frequently wealth in disguise. Perhaps in no case has the disguise been more complete than in the by-products of gas manufacture. Some reference has already been made to these in chapter xiii., but the lessons of the alkali trade may be suitably enforced by a study of the marvellous story of coal tar, and other equally unsavoury products of the gasworks. Here also science has shown how useful and beautiful substances can be obtained from the most unpromising material, and how so-called waste products can be made to contribute largely to revenue.

The reader may remember that in the dry distillation of coal four products are primarily obtained, namely, coke, ammoniacal liquor, tar, and coal gas. Little more need be said about the coke and the gas except to point out again that even the sulphuretted hydrogen in the latter, which must be removed on account of its harmful character, is made to pay part of the cost of production. The

amount of sulphur in coal is very small, only 1 to 2 per cent., equivalent to an average of about 35 lbs. per ton. Only about one-third of this amount reaches the gas purifiers as sulphuretted hydrogen, and yet so large is the quantity of coal which is treated in the gasworks of Great Britain that in the aggregate the recovered sulphur amounts to thousands of tons per annum. In some gasworks this recovered sulphur is used in the preparation of sulphuric acid, which in its turn is employed in fixing ammonia and forming ammonium sulphate.

Besides the sulphuretted hydrogen, there is another impurity in crude coal gas which has to be removed, and which at the same time is made to contribute to the cost of production. This is the poisonous compound of hydrogen, carbon, and nitrogen known as hydrocyanic acid. By suitable chemical methods it is extracted from the crude gas and converted into potassium ferrocyanide, a substance which is perhaps better known as yellow prussiate of potash. From this product it is easy to prepare either Prussian blue, for the manufacture of printing-ink, or potassium cyanide. This latter compound is extensively employed in gold extraction and in electro-plating. Thus it is that the objectionable impurity present in the crude coal gas to the extent of less than 1 part in 1000 is converted into useful products.

Another valuable by-product of gas manufacture is sulphate of ammonia, obtained from the ammoniacal liquor. The amount of nitrogen in coal is 1 to 2 per cent., but only a part of this is obtained in the form of ammonia. Roughly speaking, we may say that for every ton of coal put into the gas retorts 25 to 30 lbs. of ammonium sulphate are recovered from the liquor. In Great Britain the annual output of ammonia from

the gasworks alone in the form of ammonium sulphate is enormous—about 160,000 tons. It is valued as a nitrogenous manure, and large quantities of it are exported to Germany and other countries for this purpose.

The remaining primary by-product of coal-gas manufacture is tar, the unlovely qualities of which need no exposition. Yet out of this dirty, sticky substance the chemist has been able to evolve all manner of useful and wonderful things, as we shall see presently. To begin with, we may note that the tar helps to pay the cost of producing coal gas, as is shown by the following table. This gives approximately the amounts of the various charges incurred in manufacturing 1000 cubic feet of coal gas, as well as the prices which the by-products or residuals will fetch.

Cost of 1000 Cubic Feet of Gas

	s.	d.
2 cwts. coal at 11s. 6d. per ton . .	1	1¾
Purification	0	0½
Salaries	0	0½
Wages	0	2¼
Maintenance	0	3½
Total	1	8½

Returns from Residuals of 2 cwts. Coal

	s.	d.
Coke	0	6
Tar, 1 gallon	0	1¼
Ammonia products	0	2¼
Total	0	9½

The net cost, therefore, of making 1000 cubic feet of gas in the holder is about 11d.

The share borne by the residuals in defraying the cost of making coal gas has an important bearing on the question of gas *versus* electricity for lighting purposes. No doubt electricity has replaced gas to a considerable extent, but apart from the fact that gas is now largely employed for heating, the constant discovery of new uses for the by-products of gas manufacture tends to cheapen the cost of production.

For long after the introduction of coal gas the tar was a nuisance, a disagreeable by-product the removal of which involved the manufacturer in considerable expense. The demand for it was exceedingly small and far short of the quantity which was turned out of the gasworks. Two men who carried on the distillation of tar in these early days have left it on record that the gas company gave them the tar on condition that they removed it at their own expense. The volatile spirit or "naphtha," which these two workers got by distilling tar, was employed by Mr. Mackintosh of Glasgow in dissolving indiarubber for the manufacture of the waterproof material which bears his name.

In 1838 a patent was taken out for impregnating or "pickling" wood with heavy oil from coal tar, and this proved an important outlet for the gas manufacturer's refuse. Wood that has to be exposed to the action of water or to a moist soil will last much longer if it is steeped in this creosote oil; and for the treatment of railway sleepers, telegraph poles, and wooden beams for harbour works, &c., it is extensively used even at the present day.

For the naphtha, however, which was distilled out of the tar before it was used for pickling timber there was a very limited outlet. Some was used for dissolving

indiarubber or making varnish, and some was employed for illuminating purposes. A patent flare lamp for the combustion of this naphtha was invented sixty years ago, and is still part of the regular equipment of a coster's barrow.

The thorough utilisation of coal tar was not possible until chemists had made a complete study of its constituents. This was carried out to a large extent by the middle of last century, and one result of these investigations was to demonstrate the presence in coal tar of the following important compounds :—benzene, toluene, phenol or carbolic acid, naphthalene, and anthracene. All of these, except phenol, are compounds of carbon and hydrogen, that is, hydrocarbons, and their importance arises from the fact that they are the starting-points for the manufacture of the aniline dyes and other synthetic products of that kind. The actual proportion of these five compounds in coal tar is not great—as a rule, perhaps less than 12 per cent., but they are the constituents which chiefly concern us here.

They are extracted from coal tar by the process of distillation. Some are much more volatile than others, and when the tar is boiled these distil over first, are condensed, and so are separated from the less volatile constituents. The temperature of the tar in the boiler is continuously raised, and the process of separating a more volatile from a less volatile part is repeated.

In this way the tar distiller obtains a number of portions or " fractions," and has finally left in his boiler a quantity of pitch, amounting to about 60 per cent. of the original tar. The various fractions in which the distillate is collected are known as " first runnings," " light oil," " carbolic oil," " creosote oil," and " anthra-

cene oil." When each of these is further subjected to fractional distillation, the important compounds already mentioned are obtained in a state of comparative purity.

All this clever sifting out of the constituents of coal tar was very interesting from the purely scientific point of view, and though that alone would never have made coal tar the highly important commercial product that it is to-day, still we must admit that the present realised value of coal tar goes back ultimately to those purely scientific researches carried on about the middle of last century. It is well to realise how much of our modern comfort and luxury is traceable to such researches, for there is sometimes a disposition on the part of the commercial world to scoff at anything which cannot be shown to have an immediate use. This is a narrow view of the acquisition of knowledge. The history of the last half-century teaches us most emphatically that the advance of a chemical industry is secured not by the employment of practical men only, but by the co-operation of these with the skilled chemist. The apparently unpractical researches of the latter are, with the aid of the engineer, converted into practical manufacturing processes. We in Great Britain have been slow to appreciate the value of the trained chemist and the research laboratory ; the result is that we have suffered in certain industries where these factors are essential to success.

Yet it was an Englishman who made the discovery on which the whole coal-tar industry is founded. In 1856, the late Sir William Perkin, while still a lad of eighteen, discovered that when aniline was oxidised by dichromate of potash, a beautiful purple colouring matter, which we now speak of as mauve, was produced. A

demand soon arose for this, the first artificial dye, and Perkin, with the assistance of his father and brother, started a small factory for its production at Greenford, near London.

The importance of Perkin's discovery in relation to the utilisation of tar lies in this, that although aniline, the raw material for the manufacture of mauve and other dyes, occurs only in traces in coal tar, it is very easily produced from benzene, which, as we have seen, is one of the regular constituents. For this purpose benzene is first treated with nitric acid, which converts it into nitro-benzene—a substance which in smell closely resembles oil of bitter almonds, and which is used in scenting soaps. Nitro-benzene, when treated with iron filings and hydrochloric acid, is converted into aniline. This liquid is a basic substance, which contains the elements carbon, hydrogen, and nitrogen, and unites readily with acids to form salts. Perkin's discovery, therefore, that aniline was the parent substance of artificial colouring matters meant that there was a new outlet for the benzene from coal tar.

Mauve was only the first of a long series of artificial dyes which chemists have succeeded in building up out of the constituents of coal tar. Some of these, such as alizarin and indigo, have competed successfully with the naturally occurring dye, while others, so far as we know, do not occur in Nature at all, but are of purely laboratory origin, such as magenta and Bismarck brown.

The phenomenal growth of the artificial colour industry can best be realised by contrasting the modest works at Greenford, where Perkin began the manufacture of mauve, with the extensive dye-works of Germany at the present time. The manufacture of artificial colouring

matters has there attained the rank of a distinctively national industry, and the annual value of the dyes exported to other countries is about £8,000,000. It is a somewhat bitter reflection that the foundation of this huge industry was laid in England, and that it flourished here for about twenty years after its start, only to dwindle subsequently to unworthy proportions. The truth is that the German manufacturers recognised the value of the scientifically trained man, in this industry above all others; they spent large sums on laboratory investigations, in the confidence that these would ultimately bear fruit, and their faith has had its reward. Would that our English manufacturers had had a little more of this virtue!

The importance of the coal tar products in the modern world was lately emphasised by the celebration of the Coal Tar Jubilee in 1906. After the lapse of fifty years, chemists, manufacturers, and dyers from all parts of the world met in London to honour Sir William Perkin, the founder of the industry. The chief meeting was held in the Royal Institution, where in 1825 another English chemist, Faraday, discovered benzene, the hydrocarbon which, one might say, has been at the bottom of the whole business. On the table at which distinguished men of science and industry offered their congratulations to Sir William Perkin stood a small bottle of benzene, the identical specimen which Faraday had prepared eighty years before.

The whole story of how the aniline and other dyes have been produced from such an uninviting mess as coal tar is really marvellous; it is truly, as some one has said, a "romance of dirt." We must remember, too, that coal tar has been made to yield many other valuable products

besides colouring matters. Even *Punch* at one time felt moved to wonder at the host of things that have their origin in coal tar, and delivered himself of the following lines :—

> " There's hardly a thing that a man can name
> Of use or beauty in life's small game
> But you can extract in alembic or jar
> From the ' physical basis ' of black coal tar.
> Oil and ointment, and wax and wine,
> And the lovely colours called aniline ;
> You can make anything from a salve to a star,
> If you only know how, from black coal tar."

" Anything from a salve to a star " is rather a big order, but the variety of purposes to which the derivatives of coal tar are applied is certainly very remarkable. In photographic developers, in the colour of microscopic sections, in patent fuel, in the colour of our butter, in artificial perfumes, in the surgeon's antiseptics, in the latest shade of tie, and in the explosive lyddite, we may detect the trail of the tar.

Some readers may be interested to know that among the drugs to which the study of benzene and its derivatives have led are the well-known antipyrine and phenacetine, as well as a host of others which would not be so familiar. Whoever wants a local anæsthetic, a hypnotic, or an antiseptic can have his requirements met by something which has been derived from coal tar.

As a last example of the unexpected things that have cropped up during the study of coal tar products we may take saccharine. This substance is prepared from the hydrocarbon toluene, and therefore indirectly from coal tar. Its most remarkable property is its sweetening power,

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which is said to be three hundred times as great as that of sugar. This being so, it might be looked on as a formidable competitor of sugar, but doubts have arisen as to its suitability as a food, and its sale is now restricted by law in every European country ; it can be purchased at the druggist's shop, but not at the grocer's. It is valuable to people who suffer from diabetes, and who have therefore to avoid the use of sugar.

Enough has been said in this chapter to convince the reader that very valuable substances can be obtained from the most unlikely sources. If he is an optimist, these facts will help to confirm him in his view of life. If he is a pessimist, prone to see the unlovely side of things, he does well to realise that there is beauty even in coal tar.

CHAPTER XXVI

CHEMISTRY AND ELECTRICITY

IF the reader has had the patience to accompany us thus far, he will have learned that chemistry, so far from being an isolated system of facts, is intimately related to many other departments of scientific activity. The chemist has something to tell us about agriculture, about the composition of the stars, about the relation of animals and plants to the atmosphere, about the physiology of nutrition, and other diverse matters. Especially when one considers the modern applications of science to industry and manufactures, does the all-pervading influence of chemistry become apparent, for in the most unexpected quarters chemical changes are utilised and made to contribute to the requirements and comforts of life.

It is not surprising to find that the bearing of chemistry on other branches of science has led to the development of special study on the borderland of chemistry. Hence it comes that there is nowadays such specialisation as is indicated by the names "Agricultural Chemistry," "Physical Chemistry," and "Biochemistry." Another lateral branch of the science with a double-barrelled name is "Electrochemistry," a subject which is of vast importance at the present time, not only from the point of view of the pure scientist, but also from that of the man who is mainly interested in applied science.

The relation between chemistry and electricity is one

of mutual indebtedness. It is a long time now since Volta first showed how chemical forces might be utilised in the production of an electric current—how chemical energy might be converted into electrical energy. The chemical cell which Volta constructed consisted merely of a plate of copper (C) and a plate of zinc (Z) immersed in water to which a little sulphuric acid had been added. Volta found that if the two plates were joined by a wire outside the liquid, then an electric current passed through the wire.

The electric current obtained from such a cell is not manufactured out of nothing: there is a *quid pro quo*. While the cell is running and producing current, chemical changes are going on which mean a lowering of the store of energy in the cell. As has been pointed out by the

FIG. 12.—Volta's Cell.

author of "The Romance of Modern Electricity," this is exactly analogous to what happens in the case of a "grandfather's clock." The store of energy in the clock-weights at any time depends on the height to which they have been wound by muscular force, and the driving of the clockwork for any given time is possible only at the cost of so much of the energy residing in the weights; they will be lower down at the end of the period than they were at the beginning.

Similarly we can get a current out of a chemical cell only in so far as chemical changes go on which lower the amount of available energy in the cell. The nature of the changes which may thus be utilised in the pro-

duction of an electric current are very well illustrated by reference to the Daniell cell, which is only slightly different from Volta's original one. The metals in the Daniell cell are the same as those in Volta's cell, zinc and copper, but instead of being immersed in acidulated water, the zinc plate dips in a solution of sulphate of zinc, and the copper plate in a solution of sulphate of copper. The two solutions are prevented from mixing by a partition of porous earthenware, generally in the form of a cylindrical pot, inside which is the zinc sulphate and the zinc pole of the cell, and round which is the sulphate of copper solution with the copper pole. In the form of Daniell cell represented in the diagram the copper pole is replaced by a copper pot which holds the copper sulphate solution.
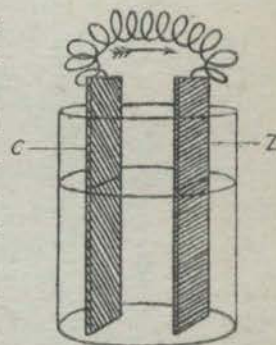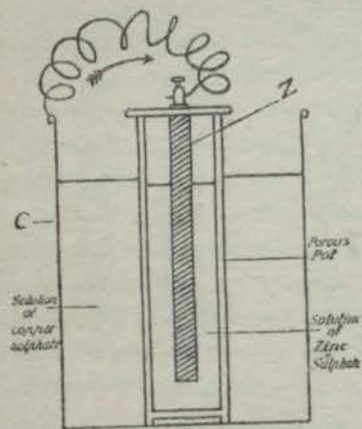
FIG. 13.—Daniell Cell.

If, now, the zinc pole is connected with the copper pole by means of a wire, an electric current runs through this wire from the copper to the zinc. The passing of a current is evidence that work is being done by the cell, and the question therefore arises—What is the source of the energy?

In the grandfather's clock the equivalent for the driving of the works is found in the gradual fall of the weights —a fairly obvious phenomenon; but a cursory inspection of the Daniell cell does not reveal any marked change

which might be regarded as responsible for the electric current. Closer examination, however, shows that the current has been obtained only at the expense of certain alterations in the cell. If, before allowing the cell to run, say for an hour, we were to weigh the two poles, then, on weighing them again afterwards, we should find that the zinc pole had become lighter, and the copper pole heavier. Further, we should find that the solution round the zinc pole contained more sulphate of zinc than at the start, and that the solution in contact with the copper pole had lost some of its copper sulphate. The changes, then, which occur during the production of the current are (1) the disappearance of some of the zinc to form zinc sulphate, and (2) the deposition of copper on the other pole from the copper sulphate. All this might be represented very simply in the following way: zinc+copper sulphate→copper +zinc sulphate, the arrow indicating that the substances on the left are replaced by the substances named on the right.

This may strike the reader as something quite novel, but as a matter of fact a chemical change of exactly the same kind has already been considered in earlier chapters. One thing which, as was pointed out, served to support the alchemists' belief in the transmutation of metals was the observation than when a clean steel knife-blade has been dipped into a solution of copper sulphate it looks as if it had been converted into copper. Things, however, are not always what they seem, and careful investigation has shown (1) that the formation of copper is only superficial, and (2) that in exchange for the copper which has spontaneously settled on the blade, a certain quantity of iron has passed into solution as sulphate of iron. The

change might in fact be represented as follows : iron + copper sulphate → copper + iron sulphate.

Now something exactly similar happens when a piece of zinc is employed instead of the knife-blade. If we were to put a few bits of zinc foil in a solution of copper sulphate, and leave them for some time, we should find that they had entirely disappeared, and that in their place a spongy mass of metallic copper lay at the bottom of the solution. This simple little experiment shows that the change zinc + copper sulphate → copper + zinc sulphate is one which takes place *spontaneously*.

A little reflection will convince the reader that the forces which bring about any spontaneous natural change can, if properly harnessed, be made to do work of various kinds. The force of gravitation, under the influence of which an unsupported body falls to the ground, is harnessed for the service of man in innumerable ways, as, for instance, in the grandfather's clock. The conversion of quicklime + water into slaked lime is a change which takes place spontaneously, and, as we have seen in an earlier chapter, is accompanied by a considerable increase in bulk. The force of this expansion has occasionally been utilised in blasting coal, by the simple device of packing quicklime into a hole in the coal and moistening it with water. The chemical forces set to work immediately, and the mechanical force of the expansion which accompanies the reaction suffices to split the coal apart.

The Daniell cell is another illustration of this same general principle. It is simply a device whereby the spontaneous chemical change zinc + copper sulphate → copper + zinc sulphate is harnessed and made to do work. The chemical energy of the cell is con-

verted into electrical energy, as evidenced by the production of an electric current.

Besides the reaction which has just been discussed, there are many others which have been similarly harnessed. Among the better known electrical cells, which, like the Daniell cell, are devices for transforming the energy of a chemical reaction into electrical energy, are the Grove cell, the bichromate cell, and the Leclanché cell.

Another very common form in which chemical energy is stored, ready for conversion into electrical energy, is the secondary cell or accumulator, sometimes called a storage cell. This is a sort of artificial chemical cell, and when complete consists of two lead plates immersed in dilute sulphuric acid, one of the plates, however, being specially prepared and coated with peroxide of lead. In this condition the cell is a store of chemical energy, and when the plates or poles are connected by a wire, a current passes through the latter from the peroxide plate to the lead plate. If much current is taken out of the secondary cell, it gets run down, like the weights in the grandfather's clock, but like these it can be " wound up " again. This is done by passing through the cell, say from a dynamo, a current of electricity in the opposite direction to that of the current which the cell itself yields. The result of this is to put into the cell a fresh supply of electrical energy, which is there stored as chemical energy ready for immediate use.

From what has been said, it will be plain that chemistry has made some very important contributions to the development and application of electricity. This debt, however, has been amply repaid, and any one who studies the modern development of chemistry will be much struck with the part which electricity now

plays in the chemical world. As was said at the beginning of the chapter, the relationship between chemistry and electricity is one of mutual indebtedness.

We have seen how chemical changes have been utilised in the production of electrical energy ; suppose we glance now at one or two of the ways in which electricity has contributed to the advance of chemical knowledge and practice. It will be found that some of the most recent achievements of industrial chemistry have been rendered possible only by the co-operation of the chemist and the electrical engineer.

It must be remembered that in some cases the electric current has been used only indirectly in order to bring about chemical changes. It is a familiar fact, illustrated by the common electric glow lamp, that the passage of a current through any body produces heat. The greater the opposition offered by the body to the passage of the electricity, the more intense is the heat generated by a given current. If, therefore, we employ very powerful currents, and pass them through bodies which offer a stout resistance, an enormous amount of heat is generated, and a very high temperature is reached, much higher, in fact, than is attainable by any ordinary methods. Many substances which are usually quite indifferent to each other, react readily at such high temperatures, so that the electric current, merely by its heating action, has been extremely useful in extending the chemist's field of knowledge. Some of the interesting facts which have thus been discovered at the high temperature of the electric furnace have already been described in chapter xvii.

It is, however, not only by virtue of its heating effect that the electric current has been of service to the

chemical discoverer and manufacturer. It has a remarkable power of splitting up compounds into simpler parts, provided it is applied to these compounds while they are either in the dissolved or the molten condition. The value of the electric current for this purpose was demonstrated by the famous English chemist, Sir Humphry Davy, who succeeded in showing that potash and soda, which up to the time of his experiments had been regarded as elements, were really compounds. It was by passing an electric current through fused caustic potash that Davy first obtained potassium, a metal which is so ready to interact with air and moisture that it can be preserved only under naphtha. Potassium has the consistency of hard butter, and it may easily be cut with a knife; the clean, fresh surface of the metal obtained by cutting is quite shiny, but it rapidly tarnishes, owing to the action of air and moisture. When a small piece of potassium is thrown into water, hydrogen gas and caustic potash are immediately generated, and the heat of the reaction is so intense that the hydrogen catches fire. The pouring on of water, therefore, a process which is usually associated with the extinction of fire, may in some cases actually lead to the production of flame. Sodium, the metal which Sir Humphry Davy first isolated from caustic soda by the action of the electric current, is very similar to potassium, but rather less active.

The decomposing action of the electric current is known as " electrolysis," and soon after Davy's time another famous English investigator, Michael Faraday, discovered the laws which govern this phenomenon. He showed that when two wires connected with the poles of a battery were immersed in the solution of a salt or in

the fused salt itself, decomposition took place, with the result that the metallic part of the salt was liberated at one wire (the cathode), and the acidic part of the salt at the other wire (the anode). Investigation, indeed, has shown that the passage of an electric current through a salt solution consists in a general movement of the metallic part towards the cathode, and a general movement of the acidic part in the opposite direction; but most obvious to the onlooker is what happens at the wires or electrodes.

What the observer sees taking place at the electrodes is sometimes only the secondary, not the direct, result of electrolysis. For instance, if we were to pass a current through a solution of common salt, or sodium chloride, to give it the systematical chemical name, the metallic part of the salt, the sodium, would be liberated primarily at the cathode. Any particle of sodium, however, which was thus liberated, would immediately be set upon by the surrounding water molecules; hydrogen gas would be evolved, and caustic soda would be formed in solution round the cathode. The action of water on sodium prevents our obtaining this metal by the electrolysis of an *aqueous* solution of any sodium salt.

Sometimes the wire or plate which forms the anode is attacked and dissolved by the acidic part of the salt which is being electrolysed. An interesting example of this is furnished by the electrolysis of a solution of copper sulphate between copper electrodes. During this process the metallic part of the salt, the copper, is deposited on the cathode, which therefore becomes gradually heavier. The sulphate, or acidic part of the salt, instead of being liberated at the copper anode, attacks it, forming copper sulphate, which dissolves in the water. So the net

result of the electrolysis is that copper is transferred from the anode to the cathode, the latter increasing in weight exactly as fast as the former becomes lighter.

This simple operation is really of very great technical importance, for the greater part of the world's supply of copper is refined on the same principle. Plates of the impure copper which comes from the smelter are used as anodes in baths of acidified copper sulphate, while sheets of pure copper act as the cathodes. When a current is passed through such a bath, the anode is gradually dissolved, as already described, and pure copper is deposited on the cathode. The impurities in the anode either pass into the solution and remain there, or else settle down to the bottom of the bath as a sort of sludge. The small quantities of gold and silver which are present in crude copper are thus deposited in the sludge, which is worked up for the sake of these valuable metals after the electrolysis is over.

It is estimated that in the United States alone about 250,000 tons of copper are refined every year by this electrolytic process, 27,000,000 ounces of silver, and 346,000 ounces of gold being obtained as by-products from the sludge.

Electrolysis, however, is applied, not only in the purification of metals which have been produced by smelting, but in obtaining the metals themselves from their compounds. Aluminium furnishes the best example of this operation, for nowadays it is obtained exclusively by the electrolysis of alumina, the oxide of the metal. This material is found in various forms and in great abundance on the surface of the earth, but if it is to be employed in the electrolytic production of aluminium, it must first be purified and separated from the dross which

accompanies it in the natural state. The mineral which is used in this country as a source of alumina is "bauxite," obtainable in large quantities in the south-east of France.

When pure alumina has been prepared from bauxite it is dissolved in a bath of molten cryolite—a Greenland mineral—and subjected to the decomposing action of an electric current. Electrolysis takes place quietly at a temperature of about 1500° Fahrenheit, with the result that the aluminium from the alumina is separated at the cathode, and the oxygen goes to the anode. The latter is made of carbon, and at the comparatively high temperature which prevails, it combines with the oxygen from the alumina, and passes away as gaseous carbon monoxide. The metal, on the other hand, collects at the bottom of the bath in the molten condition, and is run off from time to time.

There are some very interesting points about the production of aluminium in this country. As already stated, the raw materials of the industry, the bauxite and the cryolite, are obtained from France and Greenland respectively; the bauxite is purified in Ireland (where also, by the way, this mineral is to be found), while the actual production of the metal is carried on in some of the most outlying parts of Great Britain. We usually associate metallurgical processes, such as tin- and iron-smelting, with busy centres of population, and it may seem strange that in order to find aluminium works we must go to the remote Scottish Highlands. For this curious circumstance, however, there is a very sufficient explanation.

Even the non-technical reader will perceive that in order to produce aluminium cheaply, it is absolutely necessary to have inexpensive power for the dynamos
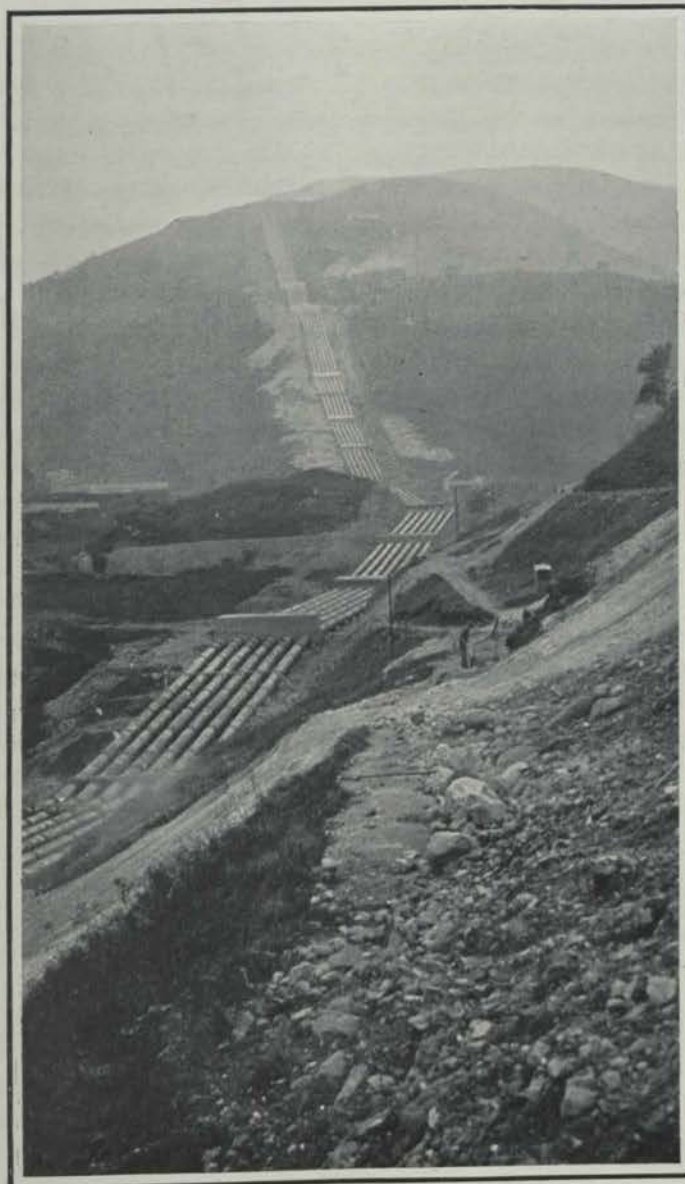
By permission of   the British Aluminium Co.

A STRIKING FEATURE OF MODERN ALUMINIUM WORKS

For the production of aluminium water power is required. Water is stored at a high level and is then brought down to the factory in pipes. The illustration shows the pipe track recently laid down for this purpose at Kinlochleven in Argyleshire. The six pipes, each of which is thirty-nine inches in diameter, run down the hillsides for one mile and a quarter.

CHAPTER XXVII

SOME INTERESTING FACTS ABOUT SOLUTIONS

IF the reader were to glance at the titles of the papers published in any modern chemical journal, he would probably be struck by a number of the most unpronounceable and incomprehensible names. It is perhaps a little difficult for him to realise how any one can profitably spend time working at "The Reduction of Hydroxylaminohydroumbelluloneoxime" or "The Preparation of Ethyl-α-cyano-γ-keto-γ-phenyl-butyrate," but science is now so specialised that many of the advance workers are necessarily engaged in fields which seem very remote from everyday concerns. Not only, however, is new and strange ground constantly being broken; the old problems, which earlier workers thought they had settled, are regularly coming up for review; new facts are daily discovered which bear on these problems, and which, if they do not clear up difficulties entirely, at least contribute to their settlement.

So it has been in recent years with the problem of solutions; the last two decades have witnessed an extraordinary activity on the part of chemists anxious to throw light on such questions as: What happens to sugar and common salt when they are dissolved in water? How is the behaviour of the water affected by their presence?

These may at first sight appear to be questions of

purely academic interest, but they really have a direct bearing on many practical problems. To take one instance: a knowledge of the properties of solutions is essential to any one who attempts to understand either plant or animal life, for the vital processes are invariably associated with solutions. The ultimate unit in the plant is the cell, and the cell sap is the seat of its life; fresh food, too, is brought from outside always in dissolved form. In the animal, again, solutions are everywhere in evidence—to wit, the blood, the digestive fluids, the urine, the lymph. From the biological point of view, in fact, the study of solutions is to be regarded as of the utmost importance.

One feature about solutions which is very characteristic, and at the same time fairly easily detected, is the property of diffusion. It must not be supposed that when we dissolve cane sugar in water and set the solution on one side, the sugar molecules remain absolutely at rest. On the contrary, we have every ground for believing that each sugar molecule, surrounded, it may be, by a retinue of water molecules, is constantly moving about through the solution, ever and anon coming into collision with other molecules. We must picture a sugar solution, therefore, as a scene of bustling activity, and the molecules as on the move in every direction, limited only by the boundaries of the liquid; for they cannot travel except where there is a water-way.

In virtue of this molecular movement, it follows that when a strong sugar solution is put in contact with pure water the sugar molecules will gradually distribute themselves throughout the water. In fact, the process of distribution—"diffusion," as it is called—continues until the strength of the sugar solution is everywhere the same.

This may be shown by a very simple experiment, in which some concentrated sugar solution is put at the bottom of a tall glass jar, the upper part being then carefully filled with water. If left to themselves, the sugar molecules gradually penetrate the water which occupies the upper part of the jar, until there are as many of them at the top as at the bottom. This interesting phenomenon of diffusion is not peculiar to sugar in water; it is characteristic of all dissolved substances. The rate of diffusion, however, differs markedly from one case to another; for example, sodium chloride (common salt) diffuses three to four times as rapidly as cane sugar.

The idea of diffusion is not new to the reader, for at an earlier stage we have adopted the view that the molecules of a gas are in constant motion, by virtue of which they also are ready to diffuse, to expand, and occupy fully any space which is put at their disposal. The magnitude of this diffusive and expansive force—the pressure, in other words—can be ascertained by interposing some surface in the path of the expanding gas, and thus stopping its further diffusion.

Similarly, in the case of dissolved cane sugar, we may ascertain the magnitude of its diffusive force by interposing between the sugar solution and the water into which it naturally diffuses some diaphragm which shall allow only the water to pass, and which, like a sieve, shall stop the diffusion of the sugar molecules. Such diaphragms have been discovered, and are known as "semi-permeable membranes," the name having reference to the fact that the membrane is permeable for water, but not for the dissolved substance. The interposition of such a diaphragm between a strong sugar solution and water prevents the sugar molecules doing what they would

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naturally do—that is, diffusing into the water. As the water and the sugar solution are bound to come into equilibrium somehow or other, and as the usual way of reaching equilibrium is barred, the principle of Mahomet and the mountain comes into play. Instead of the sugar molecules diffusing into the water, the latter percolates through the membrane into the sugar solution, and the membrane, if unsupported, would soon be ruptured. The diffusive force of the sugar thus assumes the guise of a water-attracting force.

This force is known as the "osmotic pressure" of the sugar solution, and although it is rather a difficult quantity to measure, several successful attempts have recently been made in this direction. The semi-permeable membrane used in these interesting experiments consisted of copper ferrocyanide, deposited on and supported by the walls of a porous pot or tube. The necessity of giving the membrane some such support will be obvious when it is stated that the osmotic pressure of a 12 per cent. sugar solution is 142 pounds per square inch. A weaker solution has a smaller osmotic pressure; and, in fact, it has been found that this quantity is proportional to the concentration of the solution.

Semi-permeable membranes are not only produced by the chemist in his laboratory; they occur frequently in the plant and animal worlds. A red blood corpuscle, for instance, consists of a delicate, flexible, semi-permeable skin, inside which is a solution of the colouring matter of the blood, the hæmoglobin. While the latter is unable to pass out through the enclosing membrane, water can pass in and out freely. The corpuscle is, therefore, exactly comparable with a drop of a sugar solution surrounded by a semi-permeable membrane.

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Suppose, now, we put some blood corpuscles in pure water; what result may be expected? Obviously, if the contents of the corpuscle were able to penetrate their skin, they would diffuse out into the surrounding water. Owing, however, to the semi-permeable nature of the enclosing membrane, this is impossible. What really happens is that the water passes in through the skin, which accordingly expands as the contents increase in bulk. The membrane enclosing a blood corpuscle is, however, very delicate; a slight increase in the volume of the contents is sufficient to burst it, so that the hæmoglobin escapes and imparts its colour to the water; the corpuscles are said to be "laked."

If, now, instead of using pure water we put blood corpuscles in each of several solutions of common salt of gradually increasing strength, we should obtain a very interesting result. In all solutions of less than 0·5 per cent. strength the corpuscles behave as in pure water, bursting and colouring the liquid. In all solutions containing more than 0·5 per cent. of salt, the corpuscles sink to the bottom, and leave a colourless liquid above.

The explanation of this latter behaviour will be readily understood if we consider what would be the result of putting a drop of sugar solution, surrounded by a semi-permeable membrane, in a still stronger solution. There is a natural tendency, constantly at work, to equalise the osmotic pressures on the two sides of such a membrane, so that water will always pass from the solution with the smaller osmotic pressure (that is, from the weaker solution) to the one with the greater osmotic pressure (that is, the stronger solution). In the case suggested, therefore, water will pass from the inside of the drop to the outside, so that the sugar solution within becomes

stronger. A blood corpuscle is affected in exactly the same way when it is put in a strong solution of salt; water actually passes out through the skin, the corpuscle shrinks in size, becomes more dense, and sinks to the bottom of the salt solution.

If we were to test a number of sugar solutions of gradually increasing strength in the same way as has been suggested for salt, we should find that the blood corpuscles were burst in all sugar solutions up to 5 per cent. strength, but sank to the bottom in solutions of greater concentration. For both sugar and salt, therefore, we can, with the help of the corpuscles as indicators, pick out solutions which have the same osmotic effect. From this point of view, a 5 per cent. solution of cane sugar must be regarded as equivalent to a 0·5 per cent. solution of common salt, even although the amounts of dissolved matter are so different in the two cases. This may seem rather strange, but investigations which we cannot consider here have shown that the magnitude of the osmotic pressure is determined, not by the *weight* of a substance which is dissolved in a given volume of solution, but by the *number of molecules* present in that volume. Now the sugar molecule is a very heavy one, so that proportionately more of this substance must be taken in order to get a definite number of molecules.

There are other interesting properties of solutions which are in reality closely connected with osmotic pressure. There is, for instance, the fact, perhaps already known to some readers, that a solution freezes at a lower temperature than water, and boils at a higher temperature. More than that, the extent to which the freezing-point of a solution is below 32° Fahrenheit, and its boiling-point above 212°, is proportional to the *number of*

molecules of the dissolved substance in a given volume. So that the chemist can compare the number of molecules present in solutions of salt and sugar by finding out the temperatures at which these solutions freeze or boil. Working on the same principle, one could get a very fair idea of the amount of solid dissolved in sea water by comparing its freezing-point with those of a number of common salt solutions of known strengths. The sea water must contain about as much dissolved solid as that particular salt solution which has the same freezing-point.

The topic of the freezing and boiling of solutions is in reality closely related to the interesting question how the water can be separated from the dissolved substance—how, for example, pure fresh water can be obtained from sea water. The problem is not quite so simple as was thought by the examination candidate who suggested that in order to procure fresh from salt water it was only necessary to set aside and skim off the salt after standing. This method certainly works in the case of milk, but then milk is not simply a solution ; the particles of fat which separate from milk on standing are not dissolved—they are only suspended, and gradually come to the top because they are lighter than water.

One way, however, of getting pure water from a solution of salt is to freeze it ; when that takes place the solution does not freeze as a whole ; the solid crystals which separate consist of ice alone—that is, they are pure water. In virtue of this fact, an iceberg formed in sea water would, if melted, be found to yield approximately fresh water. Any salt which it still contained must have been merely imprisoned or entangled among the freezing particles of water.

The separation of pure water from a salt solution, however, can be carried out not only by freezing, but by boiling. The latter process, indeed, is more easily effected, and gives a more perfect separation ; it is, therefore, used on a large scale for the production of fresh water from sea water. The whole operation of heating the sea water and condensing the steam which comes off is known as distillation, and the plant necessary for carrying this out is part of the regular equipment of an ocean liner.

It will be obvious to the reader that one result of boiling a solution, and thus getting rid of some of the water, will be to increase the strength of the solution, provided, of course, that the dissolved substance itself has no tendency to volatilise. Now, as already stated, the greater the concentration, the higher is the boiling-point. If, therefore, a thermometer is put in a solution, say, of sugar, which is boiling in an open vessel, the readings of the thermometer will get higher and higher. Any one who has made fondant for confectionery purposes will have observed this. In this operation sugar and water are mixed in certain proportions in a pan and heated ; the temperature rises rapidly to the point at which the mixture begins to boil, and then slowly thereafter as the water is boiled off and the sugar solution concentrates. The subsequent behaviour of the sugar solution when cold varies with the extent to which this concentration has been allowed to proceed ; it depends on the temperature at which the boiling has been stopped.

In the endeavour to bring home to the reader the curious properties exhibited by solutions, the writer has taken sugar or salt as the dissolved substance. These compounds have the advantage of being perfectly well

known to every one, but at the same time they represent two quite distinct classes. So far, no reference has been made to this distinction between sugar and salt, but it is one which has led to much controversy and practical work on the part of modern chemists, and as such deserves our attention.

There are various good grounds for believing that the molecule of cane sugar is nearly six times as heavy as the molecule of sodium chloride (common salt). If, then, we took equal weights of the two substances, we should have six times as many molecules of salt as of sugar. Since, as already stated, the extent to which the freezing-point is lowered—the "depression," as we may call it—is proportional to the *number* of molecules or dissolved units, it follows that salt ought to produce a depression six times as great as that caused by an equal weight of sugar, provided that each is dissolved in the same quantity of water. Expectations, however, are not realised in this case, and the salt gives a depression about *eleven* times as great as that due to the sugar. The salt, in the process of solution, seems to have yielded nearly twice as many dissolved units as we should expect. What interpretation can be given of this extraordinary behaviour?

Before any explanation is attempted, attention must be directed to another point of distinction between salt and sugar. If two wires connected with an electric battery were immersed in pure water, only an infinitesimally small current would pass; the water offers an enormous resistance to the passage of the current, and may be described as practically a non-conductor. The moment, however, a pinch of salt is dissolved in the water, all this is changed, and the current experiences

a comparatively small resistance. The addition of salt confers on water the power to conduct the electric current, and the salt solution may be electrolysed as described in the previous chapter.

The case of sugar is quite different. The resistance offered by water to the passage of a current is not diminished by the addition of sugar, nor can a solution of sugar be electrolysed. Such differences in behaviour as those exhibited by salt and sugar are shown by hosts of other substances. Of the chemical compounds which can be dissolved in water, many, comprising acids, bases, and salts, behave like sodium chloride, and are accordingly called "electrolytes"; the others, which, like sugar, do not increase the conducting power of water, are known as "non-electrolytes."

Now the curious thing is that it is just those substances which make water a conductor—that is, the electrolytes—which have an unexpectedly big effect on the freezing-point of water. This coincidence was emphasised some twenty-five years ago by the well-known Swedish chemist Arrhenius, who also suggested an ingenious explanation.

According to this, the molecule of an electrolyte, when dissolved in water, is liable to "dissociate," or split up into two parts or "ions," one of which carries a positive electric charge and the other a negative charge. When, for instance, sodium chloride is added to water, the atom of sodium and the atom of chlorine which have combined to form the molecule of that substance, are instantly seized with a desire for divorce, and they separate, so far, at least, as the most of the molecules are concerned, giving rise to a positively charged sodium ion and a negatively charged chlorine ion.

At first this theory seems rather fantastic; there

appears to be no sufficient reason why mere contact with water should induce sodium chloride and other electrolytes to commit "molecular suicide," as one critic has put it. The question of a motive for this "suicide" has been a difficulty, but recent work indicates that the ions have a greater affection for water than they have for each other, and hence arises their apparent readiness to part company. Whether this be the correct explanation or not, it is certain that the Arrhenius hypothesis of ionic dissociation gives an excellent interpretation of many properties of solutions, and has provided a basis for much valuable work.

How, then, does it explain the fact that salt has an abnormally big influence on the freezing-point of water? Simply in this way, that such a dissociation of sodium chloride as has been suggested would mean an exceptionally large number of dissolved units, and since the depression of the freezing-point is proportional to the number of dissolved units, the effect of the salt on the freezing-point is unexpectedly great.

Then, again, the fact that sodium chloride makes water a conductor of the electric current becomes intelligible on the basis of Arrhenius' hypothesis. For if the salt solution contains a large number of positively and negatively charged particles, the mere immersion of two battery wires will cause a streaming of the +ions to the negative wire, and of the −ions in the opposite direction. Such a procession of ions carrying electric charges is nothing else than a transport of electricity, and is therefore equivalent to the passage of a current through the solution. The presence of the salt, that is, has changed the water from a non-conductor to a conductor.

It may sound rather fanciful to talk of a procession of ions, but ocular demonstration can be given of the fact that during electrolysis the positive or metallic part of a salt actually moves towards one electrode, while the negative or acidic part is at the same time travelling towards the other. For such a demonstration some coloured salt—permanganate of potash, for instance—must be employed. Sometime, perhaps, the reader may have the opportunity of seeing this very interesting experiment.

CHAPTER XXVIII

FROM SOLUTIONS TO CRYSTALS

IN the foregoing chapter reference was made to the curious ways in which common substances affect the properties of water, and to the methods of getting pure water from a solution. It was there suggested that by cooling a salt solution until it began to freeze a separation of water from the dissolved substance could be affected, since it is pure ice which crystallises first. Strictly speaking, this method would not work with a strong solution, for cooling in this case might result in the separation of the salt itself in the crystalline form before the freezing-point was reached.

This phenomenon of salt crystallisation depends on the fact that substances as a rule are more soluble in hot than in cold water. Thus, for example, a saturated solution of saltpetre (potassium nitrate)—that is, a solution which cannot dissolve any more nitrate—contains 24 per cent. of the salt at 68° Fahrenheit, 48 per cent. at 130°, and 71 per cent. at 212°. Hence if a saturated solution of saltpetre were prepared at 130° Fahrenheit, and was then cooled down, ultimately to 68°, it would give up as crystals all the salt which it contained over and above 24 per cent. In such a case the saltpetre is said to have "crystallised out" from the solution.

Crystallisation is a common laboratory operation, and is an efficient means of purifying salts and other substances. This depends on the fact that when an impure material is dissolved in water and crystallisation is allowed to take place, the separated crystals are comparatively free from impurities. These are found to have accumulated in the liquid which is alongside the crystals—the "mother liquor," as it is called. If the crystals are redissolved, and the process of crystallisation repeated, a still purer product is obtained. Sometimes it is necessary to carry out a recrystallisation repeatedly in order to get absolutely pure material, and cases are on record in which the operation has been performed twenty to thirty times. The reader will perceive, therefore, that patience is an essential part of the chemist's equipment.

If a strong salt solution always behaved as it ought, and as we might reasonably expect it to behave, then when cooled to the temperature at which it is saturated, it would begin to deposit crystals. But just as there are not a few individuals who have a great reluctance to get out of bed when they ought to be up, so there are some salts which exhibit a curious hesitancy to leave the dissolved condition; their solutions deposit no crystals even when cooled far below the saturation-point. In these circumstances we have what is known as a "supersaturated" solution.

We do not require to go very far afield to find a salt which exhibits this curious inertia. Sodium thiosulphate, better known, perhaps, as the "hypo" of the photographer, is a very good case in point. A strong solution of this substance may be made by nearly filling a flask with the crystals of the salt, adding a little

water, and then immersing the flask in hot water. This treatment renders the contents of the flask fluid, and they remain in this condition even when cooled to the ordinary temperature. The solution is then supersaturated, and will deposit crystals only when it is irritated in some manner. This may be done by vigorous shaking or stirring, but most certainly by dropping in a crystal of sodium thiosulphate itself. This operation is described as "inoculation" or "sowing," and it is certainly a sowing which produces an immediate harvest.

The presence of an already formed crystal acts as a stimulus to the molecules which have sluggishly lingered in the dissolved condition, and they hasten to arrange themselves in the regular manner which is characteristic of the crystalline state. One result of this is that the contents of the flask, formerly fluid, appear to have become nearly solid, and another obvious fact is a considerable rise in temperature.

This evolution of heat which accompanies the crystallisation of a supersaturated solution is not to be wondered at; it is simply the repayment of a loan. For most salts absorb heat when they pass from the solid to the dissolved condition—a fact which any one can realise by putting a quantity of saltpetre in water and observing that the vessel containing the water becomes sensibly colder. This heat which the salt abstracts from the water and the containing vessel when it passes into solution, is duly returned by it when it comes out of solution; hence the remarkable evolution of heat when a supersaturated solution is suddenly stimulated into crystallisation.

Another substance which resembles sodium thiosulphate in readily forming supersaturated solutions is acetate of

soda. Indeed its behaviour in this respect has been turned to practical account in railway foot-warmers. When these are filled with a hot, strong solution of sodium acetate instead of hot water, the store of available heat is about four times as great.

Reluctance to pass into the crystallised state is exhibited not only by dissolved substances, but also by many fused compounds. It is possible in the latter case to cool the molten substance below its freezing-point without crystallisation setting in; the substance is said to be "supercooled." As with supersaturated solutions, mere contact with a crystal is sufficient to induce crystallisation.

There is, however, a remarkable difference in the rates at which different supercooled substances respond to this stimulus. This is very well shown by filling a long, narrow tube with the supercooled liquid and touching one end of the column with a crystal of the solid material. Crystallisation starts immediately at the point of contact, and is propagated through the tube at a rate which is perfectly regular, but differs from one case to another. For instance, yellow phosphorus and benzophenone (a substance well known to the student of organic chemistry) can both be obtained in the supercooled condition, but the rates of solidification in narrow tubes are very different in the two cases. The crystallisation of the phosphorus proceeds at the very great speed of 39 inches a second; in the case of benzophenone, the rate is only $\frac{1}{75}$th of an inch per second.

The most effective way of inducing crystallisation in a supersaturated solution or in a supercooled substance is, as already indicated, the addition of a crystal of the solid. But suppose no solid is available! what then? This is the position in which a chemist frequently finds himself

when he is on the track of a new compound. He may have actually got it before him in a solution or in the form of an impure oil which will not crystallise. In such a case, seeing none of the already formed solid is available, the only thing to do is to try mechanical methods of inducing crystallisation. If the reader has ever gone into a research laboratory for organic chemistry, he may have seen some one eagerly stirring and scratching at an oily-looking substance on a watch-glass. This is all with the object of persuading the substance to crystallise, and it is wonderful how frequently this method is effective.

An excellent illustration of the way in which scratching promotes crystallisation is furnished by the behaviour of potassium bitartrate. This substance is found in grape juice, and is more familiar, especially to housewives, under the name of "cream of tartar"; it is only sparingly soluble in water. If a saturated solution is made at 90° or 100° Fahrenheit, and is then cooled, it will be super-saturated at the ordinary temperature. If the solution, as soon as it has cooled, is poured on a glass plate, and the plate is scratched with a glass rod in such a way that the latter writes invisible letters on the plate, the writing soon becomes visible, because specially rapid crystallisation is induced along the lines where the glass rod and plate were in contact. The letters are traced out by the deposited crystals.

When a salt crystallises out from its solution in water it frequently happens that it carries water along with it. In the act of crystallisation each molecule of the salt hooks on to itself one or more molecules of water. This is not a mere mechanical adherence, for the crystals may be removed from the solution, and pressed between blotting-paper until they are absolutely dry, without

detaching any of these water molecules. They are, as a matter of fact, chemically combined with the salt to form a composite molecule, and they will not be drawn by methods which suffice to dry up ordinary moisture. Water which is held by a salt in this way is described as "water of crystallisation."

Although blotting-paper fails to effect the separation of a salt and its water of crystallisation, the bond of union is really not very strong, and it may be said that the love between the two grows cold as the temperature rises. So that by merely warming a salt which contains water of crystallisation, the water is driven off as vapour, and finally the salt alone—the "anhydrous" salt, as it is called—is left.

Water molecules, however, are not all alike in the tenacity with which they cling to the salt molecule. Some can be detached only by the application of a higher temperature than is required for others. Of this graded affection blue vitriol—or copper sulphate, to give it its chemical name—furnishes an interesting example. The ordinary crystals of this substance are blue in colour, and contain 36 per cent. of their weight of water; each molecule of the salt carries with it five molecules of water of crystallisation. If the crystals are exposed for some time to the temperature of 212° Fahrenheit, say in a steam oven, four out of the five molecules go off, and the residue is pale blue. The last molecule is more faithful, but a rise of temperature to 400° compels even this one to take its departure, and a white powder is left as the anhydrous salt.

In some cases the molecules of water in a crystallised salt begin to evaporate of their own accord even at the ordinary temperature. A domestic example of this

curious behaviour is available, for washing-soda, which normally contains ten molecules of water of crystallisation to each molecule of sodium carbonate, loses some of them on mere exposure to the air. This process is revealed to the observer by the fact that the crystals of washing-soda, originally clear and transparent, become gradually opaque, as if a white powder had been deposited on them. This is due simply to the partial removal of water from the surface layer of the crystals, which therefore exhibit signs of disintegration.

In blue vitriol an instance has already been cited of the way in which the colour of a given salt varies according to the number of molecules of water of crystallisation which it contains. An even more striking example of this phenomenon is furnished by a substance known to chemists as magnesium platinocyanide. This salt can be obtained with seven, six, or two molecules of water, as well as in the anhydrous state, and these various products are respectively scarlet, lemon-yellow, colourless, and orange-yellow.

The extraordinary influence which water thus has in altering the colour of a salt explains the action of the so-called " sympathetic " or " invisible " inks. One of these is a solution of cobalt chloride, a salt which crystallises with six molecules of water in the form of dark red crystals ; the anhydrous salt, on the other hand, is deep blue in colour. The water solution of cobalt chloride is merely pink, and if this is used to write on paper instead of ordinary ink, the impression left is so slight as to be scarcely noticeable, even when it has dried. The application of heat to the paper, however, makes the writing immediately visible, for the cobalt chloride is thereby converted into the blue anhydrous salt. Curiously

enough, if left to itself, the writing fades away, for the blue salt gradually absorbs moisture from the air, regenerating the pink salt, which is almost invisible.

On the same lines the reader will himself be able to explain the behaviour of certain artificial flowers which are said to be made in Paris. Their petals are tinted with cobalt chloride, with the result that while the flowers are usually of a rose colour, they turn blue in a very dry atmosphere.

Nothing has as yet been said about the strikingly regular and beautiful forms in which dissolved substances crystallise out from their solutions. These must be seen to be appreciated. As a rule, each dissolved salt separates in a definite shape, peculiar to itself, and it is, in fact, this regularity of form which is the main distinguishing feature of the crystalline state. If the separate crystals are large, it is easy not only to see distinctly the various shiny faces, but also to count them, and when the chemist has become familiar with the crystalline habits of a particular substance, he can afterwards identify it, even amongst many others, merely by its appearance.

The process of crystallisation consists in an ordered fitting and packing together of the molecules of the solid. This regularity of arrangement is evident not only from a study of large, well-formed crystals, but also from the appearance under the microscope of minute quantities of crystallised solutions. If, for instance, a drop of ammonium chloride solution is crystallised under a microscope slide, the crystals are seen on close examination to have assumed a regular fern-like shape (see Fig. 14).

The reader must not suppose that it is only from solutions in water and other similar liquids that crystals are formed. Fused substances, as already indicated,

solidify to crystalline masses, but, in addition, we must be prepared to think of crystallisation as having taken place from solvents which are solid at the ordinary temperature. A fused alloy, for instance, containing a
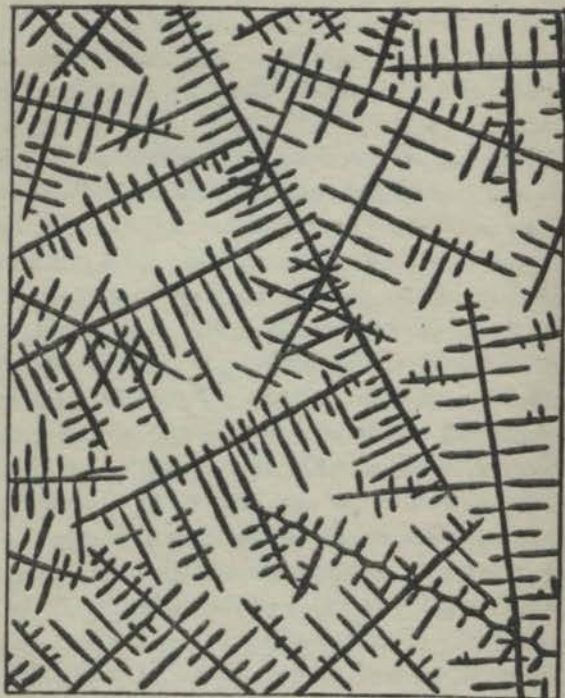
FIG. 14.—Crystals of sal ammoniac which have separated out from solution in water ; as seen under the microscope.

little of one metal dissolved in another, is quite analogous to a solution of a salt in water, although the alloy must be kept at a very much higher temperature, if it is to remain in the liquid condition. Now just as the salt crystallises out from its water solution, so the one metal

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crystallises out from the fused alloy. The difference is that in the alloy we cannot see the crystals which were formed first, because the alloy as a whole has subsequently solidified. In fact, an alloy which has crystallised and has then been cooled down to the ordinary temperature is similar to what a salt solution would become if it were cooled a long way below the freezing-point of water. In the latter circumstances we should not be able to see the salt crystals because of the masses of ice with which they were surrounded.

In spite of this difficulty, there are ways and means of finding what sort and shape of crystals have primarily separated from an alloy. In a few cases the Röntgen rays are serviceable, by virtue of the fact that metals differ in their permeability to these rays ; some metals are transparent to the rays, others are opaque.

Suppose, for instance, we had a small quantity of gold, which is opaque, dissolved in a large quantity of sodium, a metal which is comparatively transparent to the Röntgen rays. Such an alloy if fused would be comparable with a dilute solution of a salt in water. In this latter case, since the solution is dilute, the primary crystallisation on cooling would consist of ice ; similarly, the fused alloy, if cooled, would deposit sodium. That is, the first crystals to separate from the alloy would consist of the metal which is transparent to the Röntgen rays, while the spaces between these crystals would ultimately contain the gold, which crystallises last. The slower the cooling, the better will be the opportunity for the primary crystals to grow large.

If, now, a thin section of the cold alloy is placed on the top of a light-tight envelope containing a sensitive plate, and exposed to the Röntgen rays, these are able to pass

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through the primary sodium crystals and act on the plate, but are blocked to a large extent by the opaque gold in the spaces between the crystals. The impression, therefore, obtained on the plate differentiates between the primary crystals and the rest of the alloy.

FIG. 15.—Crystals which have separated from a fused alloy of copper and tin ; as seen under the microscope.

This extremely interesting method of studying the crystalline condition of alloys can obviously be employed only when there is a fairly well-marked difference between the two metals in relation to the Röntgen rays ; the scope of its application is therefore somewhat limited.

Another way of revealing the crystalline condition of an alloy is to cut a section, polish one of the surfaces, and treat it with an acid. This treatment brings out the details of the crystalline structure, and with the help of microscope and camera a photomicrograph is obtained, the surface of the alloy being illuminated by either oblique or reflected light. This method is not restricted in its scope like the previous one, and it is largely applied at the present time, notably in the investigation of the character of iron and steel which have been exposed to different conditions (compare Fig. 15).

Working on these lines, the modern chemist can do really marvellous things in the way of deciphering the life-history of an alloy. The tale is on the face of it, if he has but the key to the language, and the necessary patience. As aids he requires chiefly two instruments which in countless directions are invaluable to the scientific worker. It is indeed difficult to realise how much poorer natural science would be to-day had we no microscope and no camera.

CHAPTER XXIX

GREAT EFFECTS FROM SMALL CAUSES

IT is a commonplace to say that incidents or persons may have an influence quite out of proportion to their apparent value. This is what every one learns sooner or later, but it is worth while noting here how very remarkably this principle is enforced by many facts with which the chemist is familiar. Nature herself, in various striking cases, reminds us that what is apparently insignificant is frequently of the utmost importance. Take the case of carbon dioxide; this gas is present in the atmosphere to the trifling extent of 3 parts in 10,000, and yet it is on this that the whole vegetable life of our globe depends. As was pointed out in a previous chapter, it was not until the existence and significance of this $\frac{3}{100}$ths of 1 per cent. of carbon dioxide were appreciated, that the miracle of vegetable growth could be rightly interpreted.

Modern chemistry furnishes many remarkable instances of the way in which the history of a chemical change or the behaviour of a particular substance is profoundly modified by the presence of small quantities of foreign material. It is not necessary to go far afield in search of such cases, for water, one of the commonest chemical compounds, has recently been shown to have an extraordinary influence in promoting chemical action between other substances.

The reader is probably familiar with the experiment in which a lighted taper is brought to the mouth of a soda-water bottle containing a mixture of hydrogen and oxygen. A vigorous action, marked by a violent explosion, takes place between the gases, and water is produced. The striking liberation of energy which accompanies the chemical action between hydrogen and oxygen is evidence of the extreme eagerness of the two elements to "go for" each other. Yet, if care is taken to remove all traces of moisture from the original gases, 'this lust of battle has apparently gone. A tube containing a mixture of perfectly dry hydrogen and perfectly dry oxygen may be strongly heated without the contents exploding—a really astounding result.

It has been put on record that in twelve successive experiments on pairs of tubes, one of each pair containing perfectly dried hydrogen and oxygen, the other containing the imperfectly dried gases, the result of heating the tubes to redness in a Bunsen burner was invariably the same; there was an explosion in the tube containing the imperfectly dried gases, but no explosion in the other. It is true that in order to secure this result the gases in the latter tube had been very carefully dried for ten days, but this does not detract from the striking character of the experiments.

"Dried for ten days!" the reader may exclaim; "how is that done?" He must, of course, dismiss from his mind the idea of using any ordinary methods of drying wet objects. A gas can be dried only by letting it come in contact with some material which has an intense fondness for water, and which will readily absorb it whenever it gets the chance. Such substances are quicklime, strong sulphuric acid, and phosphoric oxide.

In the experiments just described the condition of perfect dryness was attained by putting some phosphoric oxide in the tube along with the hydrogen and the oxygen. The oxide in these circumstances acts like so much bird-lime, and any water molecules that are flying about are gradually caught. In the absence of water molecules—the mischief-makers, we may term them, or shall we say match-makers?—the hydrogen and the oxygen are quite callous to each other. So soon, however, as the merest trace of moisture is admitted into the tube, the contents will explode when heated. A few water molecules, in fact, are responsible for all the difference between peace and war, or between the single and wedded states—according to the way in which the reader prefers to picture the interaction of hydrogen and oxygen.

This extraordinary influence of water on chemical change is so remarkable that it is worth while to refer to another interesting experiment that has been made. As the reader is aware, ammonia is a colourless alkaline gas, whereas hydrogen chloride is a colourless acid gas. Like alkalies and acids in general, these two gases interact, forming a salt—ammonium chloride or sal ammoniac—the characteristic and curious feature of the process being the production of this white solid substance from two colourless, invisible gases. It turns out now that this combination between ammonia and hydrogen chloride, which takes place so readily under ordinary circumstances, is not observed when the gases have first been completely freed from all stray water molecules.

The ordinary incandescent mantle is an excellent example of the value which may attach to small quantities of foreign material. The mantle consists to the extent of 99 per cent. of thoria, which is the oxide of the metal thorium,

and is obtained chiefly from monazite sand, found in Brazil and in the United States. The remaining 1 per cent. of the mantle is ceria, the oxide of the rare metal cerium, and, in spite of its small proportion, it is on this admixture that the virtue of the mantle wholly depends. Mantles composed of pure thoria alone would be of no use, for when put in a Bunsen flame they give out only a dull light. On the other hand, if more than 1 per cent. of ceria is added to the thoria a less brilliant effect is obtained; it is, in fact, possible to have too much of a good thing.

Not only has this paltry 1 per cent. of ceria made the incandescent mantle a brilliant success; it has indirectly been the salvation of the gas industry. In competition with electricity, gas would have been badly beaten as a source of light had it not been for the discovery of the incandescent mantle. By its agency the illuminating power of a cubic foot of coal gas is enormously increased.

Another interesting fact in connection with the incandescent mantle deserving of passing notice is the extraordinary effect which the rapidly increasing use of thorium nitrate had on the price of that article. Early in 1894, an ounce of thorium nitrate sold for 55s.; by January 1895, on account of competition and improved methods of production, the price had fallen to 25s., by July 1895 to 14s., by November of the same year to 8s. In another six months the price was again halved, while at the present time it has fallen to about 1s. Seldom indeed has any chemical product undergone such a rapid change in price.

Another interesting illustration of the extraordinary influence exerted by small quantities of foreign matter is furnished by the behaviour of certain phosphorescent substances. Among them are the sulphides of the metals

barium, strontium, and calcium, and, as the name "phosphorescent" implies, these sulphides are luminous in a dark room after they have been brought out of the light. Luminous paints or luminous compositions generally are dependent for their characteristic behaviour on the presence of such a phosphorescent substance. Curiously enough, however, the pure materials do not appear to be phosphorescent; it is only when minute traces of other matter are present that they are stimulated to luminous activity.

Incandescent mantles and phosphorescent substances illustrate very well the striking modifications of properties which are attributable to small quantities of foreign material. But it is not only the properties of particular compounds which are affected by impurities; as we have seen in the case of imperfectly dried hydrogen and oxygen, the speed at which a chemical change takes place may be remarkably modified by the presence of some alien substance, which keeps, so to speak, in the background, and does not itself suffer any apparent alteration. Such an acceleration of chemical change by an alien substance is known as "catalysis," and the alien substance itself is spoken of as a "catalytic agent."

Chemical changes which take place under the influence of a catalytic agent are not merely laboratory curiosities—they are of the utmost importance in the technical world. The most modern method of manufacturing sulphuric acid, for instance, depends on just such a change, and if the reader tries to realise the fact that about 3000 tons of sulphuric acid are made in England every day, he may appreciate the bearing of catalysis on chemical industry. The main thing to be done in making this important product is to persuade sulphur dioxide—the

suffocating gas which is produced when sulphur is burned —to combine with more oxygen. This will not occur spontaneously when the gases are merely mixed, even at a high temperature. They must be brought into contact with some third substance which plays the same part as water does in the combination of hydrogen and oxygen.

In the case of sulphur dioxide and oxygen the third party, which acts in some subtle way as mediator between the other two, is platinum in a finely divided condition. This metal has quite a reputation for accelerating chemical actions in which it is not directly involved; it is a sort of chemical busybody. There is a well-known experiment which illustrates this characteristic of platinum very clearly indeed. A roll of platinum foil is suspended in the flame of a Bunsen burner until it is red hot; the gas is then turned off, and immediately turned on again, but not lighted. The observer sees that the foil, which had begun to cool down whenever the gas was turned off, begins to glow afresh, although there is no visible flame; it remains in this condition so long as the mixture of air and gas from the burner is allowed to flow over it. What has happened is that the platinum induces the slow combustion of the gas, and it is the heat given out in this process which keeps the metal visibly hot. The platinum itself is not affected, so that we have here an excellent example of catalytic action.

A similar part is played by the finely divided platinum in the modern method of making sulphuric acid—the "contact" process, as it is appropriately called. Under the persuasive influence of the catalytic agent at a temperature of about 500° Fahrenheit, sulphur dioxide and oxygen readily unite to form another compound named

sulphur trioxide, which need only be dissolved in water to produce sulphuric acid.

This sounds all very simple, and, in fact, this way of making sulphuric acid was discovered long ago. It could not, however, be employed on the manufacturing scale, as the platinum turned out to be very sensitive to impurities in the sulphur dioxide, and gradually became ineffective. Ways and means, however, have now been discovered for thoroughly removing the impurities and keeping the platinum in good condition, so that what for long was merely a laboratory experiment has now become the basis of a very important manufacturing operation. The "contact" process is rapidly coming to the front, and bids fair to oust the old and cumbrous method of manufacture, the prominent feature of which is the use of huge leaden chambers.

In recent years platinum has been prepared in another condition in which it exhibits remarkable catalytic activity, namely in solution in water. It may seem to the reader rather absurd to speak of dissolving a metal in water, as if it were so much sugar or salt, but it is indeed a fact that, by the help of the electric current, platinum has been got into water in such a state that it closely resembles a dissolved substance. If two pieces of stout platinum wire are immersed in water so that their points are very close together, and an electric discharge is passed across the intervening space, the water gradually assumes a deep brown colour, and is found then to contain platinum in solution. At least it seems to be in solution, for the liquid may be filtered through a piece of blotting-paper without leaving any particles behind, and it may be kept for a long time without depositing any sediment. On grounds, however, into which we cannot go here, the

view is adopted that this platinum solution is really a suspension of exceedingly minute particles, so tiny that they can find their way through the pores of filtering-paper.

However that may be, there is no doubt that platinum in this condition is intensely active from the catalytic point of view, as shown, for instance, by its effect in upsetting the equilibrium of hydrogen peroxide. This is a substance which, in water solution, is applied as a bleaching agent for hair, ivory, and old pictures. Chemically, it is a very interesting substance, being closely related to water; its molecule, in fact, is a molecule of water, to which an extra atom of oxygen has been tacked on. The attachment, however, is not very secure, and the result is that hydrogen peroxide is readily decomposed into water and oxygen. This chemical action, this decomposition, is accelerated in quite a remarkable manner by the addition of a little platinum solution to the hydrogen peroxide. Thus if we were to take dilute hydrogen peroxide and add to it so much platinum solution that a pint of the mixture contained $\frac{1}{100000}$th of an ounce of platinum, the decomposition of the hydrogen peroxide would be complete in about two hours; if no platinum solution were added the hydrogen peroxide would lose practically none of its oxygen in that time.

Perhaps a still more convincing proof of the catalytic power of this platinum solution is obtained by shaking some of it in a flask with a mixture of hydrogen and oxygen. In ordinary circumstances these two gases require to be strongly heated before they will combine to form water, but under the persuasive influence of the platinum solution they unite *at the temperature of the room*, slowly but steadily and without any fuss. The

extraordinary thing is that a minute quantity of platinum is able to bring about the combination of very large quantities of hydrogen and oxygen. One experiment has been recorded in which, under the influence of the $\frac{1}{10000}$th of an ounce of platinum, over two gallons of a mixture of hydrogen and oxygen disappeared in seventeen days. And the platinum was as active at the end of this period as at the beginning!

There are numerous catalytic agents in addition to those which are used in the laboratory or the factory. Our bodies are the scene of many chemical changes which are promoted and accelerated by the influence of certain agents called enzymes, the exact nature of which is not yet known. These substances play an important part as catalytic agents, notably in the processes of digestion, but an excursion into this interesting field would take us too far. Perhaps enough has been said to convince the reader that in chemistry, at least, much that is apparently insignificant is of the greatest value and importance.

CHAPTER XXX

HOW TRIFLING OBSERVATIONS LEAD TO GREAT DISCOVERIES

THE scientist who is advancing into the unknown generally sets out with the object of searching for something which his theories lead him to believe is to be found in the unexplored region just ahead. It frequently happens, however, that as he steadily plods forward he discovers something by the way which is of much greater importance than the ultimate object of his search. The story of the ways in which some such unexpected discoveries have been made is interesting, if not romantic, and the rehearsal of one or two of these will show the reader how much depends sometimes on a casual occurrence, and on the observer's readiness to note what happens and to take advantage of it.

The discovery of oxygen, the important element which forms one-fifth by volume of the air, was made in a very casual sort of fashion about 140 years ago. Priestley, we are told, was very proud of a burning-glass which had come into his possession, and was going round his laboratory one day concentrating the sun's rays with this lens, and focussing them on all sorts of substances. Among the materials which he thus happened to expose to the heat of the concentrated solar rays was oxide of mercury, which, as we now know, is very readily split up

by heating into its constituent elements, mercury and oxygen.

Priestley observed that a gas was given off from the mercury oxide, and when he had collected some of the gas he was able to show that a candle burned in it with a remarkably vigorous flame. To Priestley this was something quite new and fascinating; as he says himself, "This surprised me more than I can well express; I was utterly at a loss how to account for it." Further experiments showed him that the gas "possessed all the properties of common air, only in much greater perfection." He had, in fact, discovered oxygen, and all as the result of curiosity about the powers of his newly acquired lens. He was, it is true, on the look-out for new gases at that time, but, after all, the concentration of the sun's rays by a lens is a most unusual way of producing heat, and would not naturally be chosen for that purpose.

If, however, the investigator's mind is occupied with a definite subject, it is wonderful how the most trifling occurrences are seen by him to have a bearing on the problem and are made to contribute to its solution. So it was with Priestley, and so it has been in many other cases which might be quoted.

One of those which has been put on record occurred in connection with the discovery of blasting gelatine by Nobel. As has been stated in a previous chapter, the dangerously explosive substance nitro-glycerine cannot by itself be safely handled and transported. The difficulty may be got over by soaking up the liquid nitro-glycerine into *kieselguhr*, and so converting it into the product known as dynamite. It was obvious to Nobel that this operation involved a reduction of the explosive force of

nitro-glycerine, for the absorbent *kieselguhr* is a neutral, harmless, non-explosive material. So, although it can take up as much as three times its quantity of nitro-glycerine, the explosive power of the latter is lowered by one-fourth. Nobel was therefore anxious to find as a substitute for *kieselguhr* some substance which would convert nitro-glycerine into a form suitable for safe handling and transport, and which at the same time, being itself explosive, would not diminish the effectiveness of the nitro-glycerine.

The discovery of a material with the desired properties came quite by accident. Nobel cut his finger one day in the laboratory, and procured some collodion to paint over the cut and so form an artificial protective skin. Collodion, it should be stated, is a solution of a substance resembling gun-cotton in a mixture of alcohol and ether; as these two liquids are very volatile, a film of collodion exposed to the air soon dries up and forms a skin.

After Nobel had used a little of the collodion to paint over the wound, it occurred to him to pour what was left into a vessel containing nitro-glycerine. He did this, and observed that the collodion mixed with the nitro-glycerine and formed a jelly-like mass. This little observation was enough to show him the way in which the problem of the replacement of *kieselguhr* by a more active substance could be solved. Experiments were carried out on a large scale, and these led to the manufacture of the explosive known as blasting gelatine, which is a mixture of nine parts of nitro-glycerine and one part of soluble gun-cotton. Pure blasting gelatine is so violent in its action that it cannot be used except for the hardest rocks; it was employed, for instance, in parts of the

St. Gotthard tunnel. For ordinary practical purposes, however, the explosive power of blasting gelatine is modified by introducing a certain amount of non-explosive absorbent material.

Some discoveries have actually been made through an accident happening to the apparatus with which experiments were being carried out. This was the case with one important series of investigations into the behaviour of gases; and the famous chemist Graham has explained what it was that led him to make his wonderful experiments on gaseous diffusion. It appears that an earlier worker, Döbereiner, had occasion to prepare large quantities of hydrogen, and one day accidentally used as gas-holder a glass jar which had a tiny crack in it.

Now it is a well-known fact that if an undamaged glass jar or tumbler containing hydrogen or air is inverted in a dish of water, so that the level of the water outside and inside the jar or tumbler is the same, then no appreciable change will take place in the position of the water-level, even after a considerable time. But Döbereiner, to his great surprise, found that with his cracked jar inverted in water and containing hydrogen, the water gradually *rose* inside, $1\frac{1}{2}$ inches in 12 hours, $2\frac{3}{8}$ inches in 24 hours.

It was left to Graham to give the correct interpretation of this very striking observation. He showed that hydrogen, as the lightest known gas, can get through minute apertures more rapidly than any other gas, so that what occurred in Döbereiner's cracked glass jar was an escape of hydrogen from the inside to the outside, accompanied by a slower entrance of air through the crack. As the hydrogen escaped more rapidly than the air got in, the pressure of the gas inside the jar was

lowered and the level of the water rose. Thus it was that the use of a cracked vessel instead of a sound one led on to Graham's famous investigations on the diffusion of gases.

A more recent and equally striking instance of a breakage leading directly to a valuable discovery has been recorded in connection with the manufacture of artificial indigo—a manufacture which, as we have already seen, furnishes a conspicuous case of the chemist's successful attempt to build up natural products, and to compete with Nature herself.

One of the most important steps in the manufacturing process is the production of phthalic acid from naphthalene—the chief raw material of synthetic indigo. This change can be effected by the action of hot sulphuric acid upon naphthalene, but only slowly. In the course, however, of experiments carried out with the object of improving the method of converting naphthalene into phthalic acid, the bulb of a thermometer was accidentally broken, and the mercury ran out into the heated mixture. It was at once noticed that in presence of mercury the conversion of naphthalene into phthalic acid was much accelerated, and this chance observation led at once to the desired improvement of the process. The use of mercury at this stage of indigo manufacture is now an established custom.

The reader must, of course, remember that without adequate knowledge on the part of the investigator and without keenness of observation these chance occurrences would have been of no account. The observer, even supposing he has the necessary equipment, must always be on the look-out for what is strange and unexpected, always eager to see Nature in unfamiliar garb.

The difficulty is that people sometimes make a valuable observation without attaching importance to it. It may be difficult to bring their new discovery into harmony with what they already know, and so they come to the conclusion that their observation must have been wrong, and that their senses must have deceived them; or else, by some forced explanation, they seek to fit the newly observed facts into some of the mental pigeon-holes which are already available. When such difficulties crop up, the remedy is to have recourse to fresh observation and to collect more facts.

In this connection there is an interesting story of Liebig, whose fame as a chemist rests on many other things than extract of meat. On one occasion he prepared a liquid which in many of its properties resembled chloride of iodine, although in other respects quite different. He was struck by the differences, but, without making any further experiments, devised an explanation which satisfied him at the time. He was at least sufficiently satisfied to label the bottle of liquid " chloride of iodine." The reader can imagine Liebig's disappointment and chagrin a few months later when he heard of the discovery by a Frenchman of the new element "bromine," and realised that it was this element which he had had before his eyes all the time and had labelled "chloride of iodine." Liebig tells the story himself, and quotes it as showing the result of adopting explanations not founded on experiment.

As an example of the persistent and successful following up of puzzling observations by further experiments, nothing better can be quoted than the work which led to the discovery that there was in atmospheric air a gas, the presence of which had not previously been

suspected. That argon, as this gas is now called, should have so long remained undiscovered, is due to the fact that it is extremely similar to nitrogen; it is, therefore, difficult to find any way of distinguishing and separating the two gases when they are mixed together, as in ordinary air. As a matter of fact, argon is rather heavier, bulk for bulk, than nitrogen, and it was this slight difference which Lord Rayleigh observed and followed up.

Suppose the reader tries to realise how very small was the difference in weight actually observed. The globe which Lord Rayleigh used in weighing gases was filled, firstly, with nitrogen—"atmospheric" nitrogen—obtained from air by removal of oxygen, moisture, and carbon dioxide; secondly, with nitrogen prepared from various chemical compounds. Although these two samples would naturally be expected to exhibit the same behaviour, the weight of the "atmospheric" nitrogen filling the globe was one-seventh of a grain heavier than the weight ($35\frac{1}{2}$ grains) of the "chemical" nitrogen filling the same globe. This is obviously quite a small difference, and probably many investigators would have attributed the discrepancy to some error in their experiments, and thought no more about it. Not so Lord Rayleigh; after showing that numerous possible sources of error were excluded, he succeeded, in co-operation with Professor Ramsay, in separating and examining the argon which is responsible for the greater weight of "atmospheric" nitrogen as compared with "chemical" nitrogen.

From all this the reader will see what a high value attaches to close and trustworthy observation even of trifling occurrences. Elaborate apparatus and costly materials are all very well, but what is primarily essential

for the true investigator is the learning and observing attitude towards Nature. Any one, indeed, who cultivates the habit of careful and patient observation rediscovers many things for himself, and may hope to add his contribution to the romance of science.

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