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Readable Books in Natural Knowledge

ACHIEVEMENTS OF CHEMICAL SCIENCE



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ACHIEVEMENTS

OF

CHEMICAL SCIENCE

BY

JAMES C. PHILIP

M.A., D.Sc. (ABERDEEN), PH.D. (GÖTTINGEN)

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON

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PUBLISHERS' NOTE

So much attention is now given to the practical and systematic study of science in schools that the valuable influence of descriptive scientific literature is apt to be overlooked. An intimate knowledge of the simplest fact in Nature can be obtained only by personal observation or experiment in the open air or the laboratory, but broad views of scientific thought and progress are secured best from books in which the methods and results of investigation are stated in language which is simple without being childish.

Books intended to promote interest in science must differ completely from laboratory guides, text-books, or works of reference. They should aim at exalting the scientific spirit which leads men to devote their lives to the advancement of natural knowledge, and at showing how the human race eventually reaps the benefit of such research. Inspiration rather than information should be the keynote; and the execution should awaken in the

reader not only appreciation of the scientific method of study and spirit of self-sacrifice, but also a desire to emulate the lives of men whose labours have brought the knowledge of Nature to its present position.

These are the objects of the series of Readable Books in Natural Knowledge to which the present volume belongs. Each volume will endeavour to stimulate interest in the studies with which it is concerned, and to present natural phenomena and laws broadly and attractively. It is hoped that the books will provide the reading matter urgently required in connection with the science work in schools and will appeal also to a wide circle of other readers. The series should be of service in directing attention to the nobility of scientific ideals and the ultimate value of results obtained by careful and faithful work.

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AUTHOR'S NOTE

THE friendly comments of those who have found this little volume useful in school work suggest that its value would be enhanced by the addition of an index, and this appears accordingly as a new feature of the present issue. Its preparation was initiated by Miss C. M. Taylor, and cordial thanks are due for her readiness in putting the completed index at the disposal of the publishers.

J. C. P.

March 1920.

CHAPTER I

PIONEER WORK

ATTEMPTS to subdue new territory and to make it serve the purposes of civilisation are always interesting. The tale of the settler who presses forward into unexplored lands has a strange fascination for young and old alike; his patient labour and steady progress in the face of danger and privation win for him the admiration and gratitude of those who follow after.

So it is also with the pioneers who have shown the way into the vast and fruitful regions of experimental science. Their early labours on the virgin soil have not been in vain, and they themselves were the forerunners of an ever-increasing band of workers who have entered in and possessed the land in all its plenty. We of the twentieth century, who have abounding evidence of the extent to which human life has been enriched by

scientific discovery, do well to recall with gratitude the toilers of these early days.

The beginnings of chemistry lie in the distant past, but for centuries the results of the science were meagre in the extreme. Many substances now recognised as definite chemical compounds, such as sugar, soda, alum, acetic acid, and lime, had been discovered; many processes of an essentially chemical character, such as iron-smelting, dyeing, soap and glass manufacture, were in operation, but the discoveries were made in a haphazard fashion and the manufacturing processes were carried out by rule of thumb, not on any scientific plan. There were many chemical experimenters in the Middle Ages, but they were all possessed with the idea that the baser metals, such as lead, could be changed into gold, and their time was mostly wasted in unsuccessful attempts to bring about this wonderful transmutation.

It was not until the latter half of the eighteenth century that Europe saw a real attempt on the part of men of science to press forward into the region of chemical phenomena. This was not an organised effort: it only so happened that about this time a number of able philosophers were trying hard to discover what are the things that go to build up the material world around us. The question which every intelligent child is constantly putting to its

elders: "What is this made of?" is the very question which the chemist puts to Nature in all directions; and it is the fame of these pioneers of the eighteenth century that they wrestled successfully with the three problems—"What is Air?" "What is Water?" "What is Fire?"

It may seem strange that at this comparatively late period these fundamental questions had not yet received satisfactory answers. The truth is that the philosophers of earlier generations had settled them to their own satisfaction, and when once a wrong solution of a problem has been accepted as correct, it may be a long time before any one is original enough to discover the error, and having discovered it, bold enough to make it known. From ancient times down to the eighteenth century, the view was generally held that the ultimate constituents of the material world were four in number, viz. fire, air, earth, and water. It was supposed that by the combination in various proportions of these primitive substances, or elements, the most varied products could be obtained.

Aristotle, it is true, regarded fire, air, earth, and water, not as absolutely distinct substances, but rather as manifestations of different properties adhering to one primitive kind of matter. The fundamental qualities associated with this primordial matter were described by the four adjectives "warm,"

"cold," "dry," and "moist"; and it was supposed that fire was dry and warm, that air was warm and moist, that earth was cold and dry, and that water was cold and moist.

The experiments which finally disposed of these fantastic and erroneous notions and led up to what has been called "the chemical revolution," were made by a number of men in different European countries; but the prominent leaders in this matter were Priestley and Cavendish in England, and Lavoisier in France. These pioneers in the development of modern chemistry may not have fully recognised the importance of their work, but there is no doubt that their investigations prepared the way for the marvellous chemical discoveries of the nineteenth century.

What sort of men, then, were these, and what did they contribute to the sum of human knowledge? The two Englishmen were as the poles asunder in regard to their origin and personal character. Priestley was the son of a poor cloth-dresser; Cavendish was a wealthy aristocrat; Priestley was an open, warm-hearted man, fond of society and keen in controversy; Cavendish was a callous recluse, ill at ease in the company of his fellows and caring nothing about their affairs. They resembled each other in their zeal for science, but the general lines on which they worked were

quite different. Priestley occupied himself almost

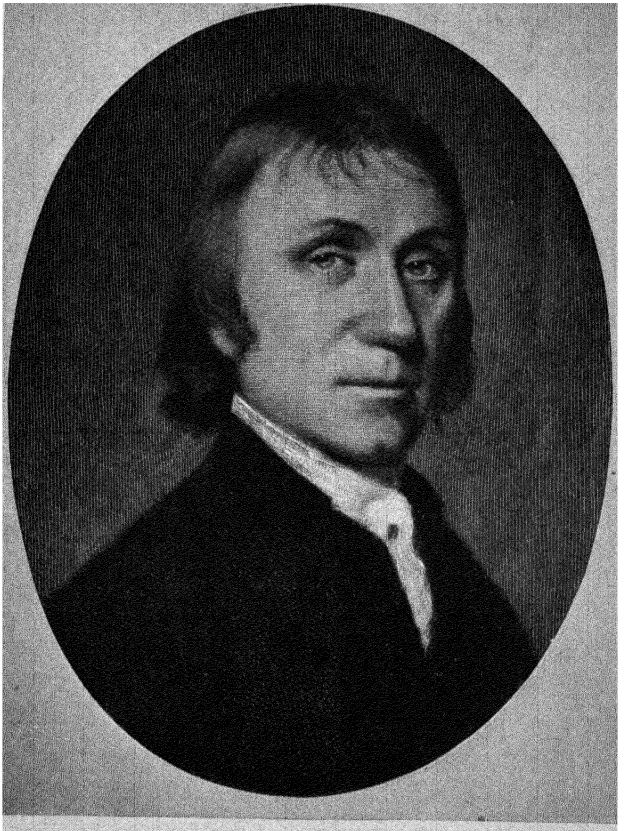


FIG. 1.—Joseph Priestley (1733-1804).

exclusively with *qualitative* experiments, trying to discover what kinds of matter entered into the

composition of various gases; Cavendish, on the other hand, spent his time mainly in *quantitative* investigations, that is, he was always counting, measuring, and weighing.

The first suggestion that atmospheric air was not the simple elementary substance which earlier philosophers supposed, had come from Dr. Black of Edinburgh, some twenty years or so before Priestley began his experiments. Dr. Black observed that lime-water (that is, the clear liquid obtained by shaking water with slaked lime and allowing the excess of the latter to settle to the bottom) became slightly turbid when exposed to the atmosphere, although no milkiness appeared when it was kept in a closed bottle. It was plain that there was something in the air which affected the lime-water, and, since the milkiness resulting from exposure was comparatively slight, Dr. Black felt justified in drawing a distinction between the greater part of the atmospheric air and that small part of it which acted on the lime-water. This small part he called "fixed air," and it is what we now term "carbon dioxide" or "carbonic acid gas."

The experiments and conclusions of the Edinburgh professor may seem trivial, but in reality they were epoch-making. The old view that air was an element, incapable of being resolved into any simpler constituents, had been successfully

challenged, and Priestley's experiments were to put the matter beyond all doubt. It is noteworthy that while in Leeds Priestley stayed next door to a brewery, and it was this circumstance which led him, at the outset of his scientific career, to make experiments with carbon dioxide, large quantities of this gas being produced in the process of brewing.

Closely connected with his work on "fixed air" were Priestley's experiments on the change produced in ordinary air by the burning of a candle. It was even then well known that when a candle is lighted in a closed space, say in a bell jar over water, the flame soon goes out, and the residual air, however long it is left to itself, remains incapable of supporting combustion. Priestley now made the very interesting discovery that such vitiated air could be restored through the agency of vegetation. He states that on the 17th of August 1771 he put a sprig of mint into a quantity of air in which a wax candle had burned out, and that on the 27th of the same month another candle burned perfectly well in it. This was a great surprise to Priestley; and further experiments were made which showed that the remarkable result obtained did not depend on anything peculiar to mint, but that balm, groundsel, or spinach were equally effective.

Just as the burning of a candle in air makes it incapable of supporting combustion, so

animals shut up in a closed space can live only a certain time. This fact was known to Priestley, and he was able to show that the air rendered noxious by respiration could be made fit for breathing again through the agency of vegetation. It was quite plain to him, then, that plants reverse the effects of animal respiration and tend to keep the atmosphere sweet and wholesome.

These early experiments further made it clear that the physical life of an animal is in some respects very similar to the burning of a candle; our bodies are the scene of chemical changes which may fairly be described as combustion. The observation that animal respiration has the same effect on air as the burning of a candle suggested to Priestley a method of estimating the goodness of any sample of air. It was necessary only to insert a lighted candle: if it continued to burn, the air was fit for respiration; if the flame went out immediately, the air was noxious. This may seem a crude and old-fashioned way of finding out whether a given atmosphere is suitable for breathing or not, but the method is not so out of date as might be imagined. In certain mines at the present day the behaviour of a burning candle is taken as an indication of the condition of the air below ground.

One specially interesting illustration of this

is furnished by what took place after the disaster at the Snaefell lead mine, in the Isle of Man, in 1897. Owing, apparently, to the ignition of some wood, the lower parts of the mine became full of foul gas, and when the miners went down the main shaft to their work, they entered the noxious atmosphere and succumbed in a very short time. Altogether about twenty men lost their lives in this way. The work of the rescuing and exploring party was obviously very risky, and it was necessary to ascertain definitely how far down the shaft it was safe to proceed. One of the methods employed was to lower a candle from one stage to the next, and the Inspector of Mines has graphically told that the party got on all right as far as a certain platform about 130 fathoms from the surface, but that the flame of the candle went out when lowered to the bottom of the next ladder. The limit of safety was indicated very clearly in this way.

Priestley's method, then, of testing the goodness of air has still a practical value. But he not only observed the effects which respiration and combustion alike have on the condition of the atmosphere, he also discovered an "air," or a gas, as we should now call it, which was much better than ordinary air, both for breathing and for helping a candle to burn. This wonderful discovery, which will cause Priestley's

name to be remembered so long as there is a science of chemistry, was made in a very odd way, and shows what may come of an intelligent curiosity.

A large burning-glass, twelve inches in diameter, had come into Priestley's possession, and, like a boy with a new tool, he eagerly went round his laboratory, trying its effect on all sorts of substances. Amongst these was oxide of mercury, a red substance which is obtained by heating the metal quicksilver in air. The result of focussing the sun's rays on the mercury oxide by means of the lens was to make it give off a considerable quantity of a gas, which Priestley collected and examined. He made his candle test as usual, and found to his very great surprise that the combustion in this "air" was remarkably vigorous; further, a piece of glowing wood sparkled in it and was rapidly consumed.

Some time later Priestley conceived the idea of testing the goodness of this new "air" by putting a mouse into two ounce measures of it. The result was remarkable. Whereas the mouse could have lived only about a quarter of an hour in that quantity of common air, it lasted three times as long in the strange gas, so that there was no doubt about its superiority from the point of view of respiration. This was confirmed by the investigator himself breathing it, and he tells us that his breast "felt peculiarly light and easy for some time after-

wards." This experiment also has its modern counterpart, for in certain cases of serious illness and as a last resort pure oxygen gas, which is just the new "air" discovered by Priestley, is supplied to the patient, so that the flickering flame of life may be supported a little longer.

The occurrence of the "light and easy" feeling which Priestley experienced on breathing his new "air" has been confirmed by some very interesting experiments made recently. Tests were made on students who ran up and down stairs as fast as possible a given number of times, and had pure oxygen administered to them before and after their effort. It was found that by breathing oxygen the time of the run was shortened and the pulse frequency was lowered, while the feeling of distress and fatigue which follows such exertion was very much relieved.

Although Priestley's splendid pioneer work on carbon dioxide and oxygen overthrew the old notion that air is an elementary substance, there were many discoveries in this connection which were left for others to make. He actually failed to recognise nitrogen, the gas which, so far as bulk goes, is the main constituent of the atmosphere. We now know that air is a mixture chiefly of the two elementary gases, oxygen and nitrogen, the latter forming about four-fifths of the whole. This was

actually proved by an experiment which Priestley made and described in his papers without realising its great significance. He found that when a confined quantity of air is kept in contact with a moist mixture of iron filings and sulphur the volume of the air undergoes a diminution of about one-fifth. The oxygen, very ready as it always is to unite with other substances, had combined with the iron to form oxide, and the residual "air," had Priestley only realised it, was nitrogen. This gas is as much an elementary substance as oxygen, but is far less active in combining with other elements.

Even with the discovery of nitrogen as a definite element, made in 1772 by Rutherford, Professor of Botany in Edinburgh, the elucidation of the chemical nature of the atmosphere was not completed. In comparatively recent times has come the proof that common air contains quite a number of gases, most of them in very small quantity and all extremely reluctant to unite with any other kind of matter. It is owing, in fact, to this inertness that it has been so difficult to recognise and isolate these curious elements. The existence of argon, for instance, which forms about one per cent of common air, was discovered only by the observation that "atmospheric" nitrogen, obtained from air by removing the oxygen, the carbon dioxide, and the water vapour, is somewhat heavier, bulk

for bulk, than the nitrogen derived from various chemical compounds.

It is worth while to realise how small was the difference actually observed by Lord Rayleigh, who first investigated this matter. He found that the weight of the "atmospheric" nitrogen filling a certain glass globe was one-seventh of a grain greater than the weight ($35\frac{1}{2}$ grains) of the "chemical" nitrogen which occupied the same space. This may seem a very small difference, and many investigators would probably have attributed the discrepancy to some error in their experiments and would have thought no more about the matter. Lord Rayleigh, however, was able to show that the difference was a real one, not due to any experimental error; and ultimately, in co-operation with Sir William Ramsay, he succeeded in separating and examining the argon which is present in "atmospheric" nitrogen and renders it heavier than "chemical" nitrogen. A striking example this of the value that attaches to accurate observation of what is apparently trifling!

Great advances have indeed been made since Priestley's day in the study of the atmosphere and of the nature of gases generally, but his experiments formed the starting-point of all modern scientific progress in this direction. It was not only that he discovered certain fundamental facts about

common air, but he was the first to show how gases could be easily stored and handled. This in itself was a distinct achievement. It must be remembered that gases have many peculiar characteristics as contrasted with solids and liquids. They are generally invisible, and

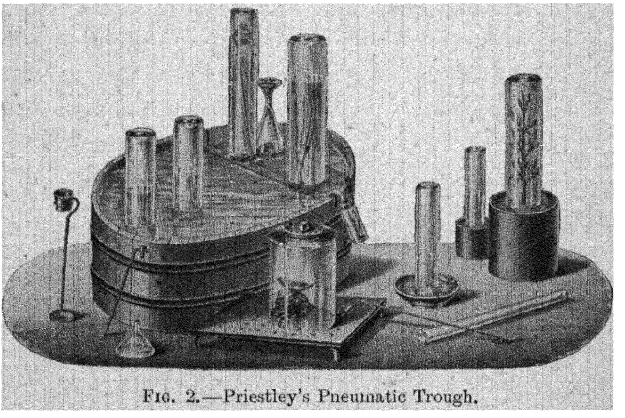


FIG. 2.—Priestley's Pneumatic Trough.

they cannot be handled like so much sand or water. Priestley showed how gases could be collected and stored over water, out of contact with the atmosphere, and the apparatus he devised for this purpose, his famous pneumatic trough, is in some form or other one of the indispensable articles in a chemical laboratory.

CHAPTER II

OLD IDEAS AND NEW FACTS ABOUT A COMMON SUBSTANCE

WE need not wonder that the philosophers of the ancient world regarded water as one of the elements, for it is everywhere in evidence, and life on this planet would be impossible without it. Water is indeed an absolute necessity of existence. Further, we are not familiar with any process taking place in nature whereby water is broken down into simpler things, or whereby other substances unite to form water and water only. The "man in the street," therefore, has really no reason to suppose that water is anything else than matter of the simplest kind. The investigations of the chemist, however, have revealed the wonderful fact that water is not an element at all, but contains two still simpler, more elementary, substances, namely hydrogen and oxygen. In the language of chemistry, water is a chemical compound of hydrogen and oxygen.

Now one of the standing marvels of chemistry is the extraordinary way in which the properties of two elements are altered when they form a compound, and the formation of water from hydrogen and

oxygen furnishes a most striking example of this fact. Hydrogen and oxygen resemble each other in being invisible gases, or "airs," as Priestley would have called them, but they are very different in other respects. Oxygen, as was shown in the last chapter, is that element in the atmosphere which supports combustion and is necessary for the continuance of life. Hydrogen, on the other hand, is a combustible gas, and in the early days was known as "inflammable air"; it is not an ordinary constituent of the air, and would not be suitable for breathing if it were.

One of the most remarkable properties of hydrogen gas is its extreme lightness. Every one knows that soap-bubbles blown with ordinary air gradually fall to the ground; those blown with hydrogen, however, are so light that they rise. This fact was discovered in 1782, and it was not long till some one made the suggestion that hydrogen might be used in filling balloons. The experiment was tried, and in 1783 two gentlemen in Paris made the first ascent in a balloon filled with hydrogen. About forty years later the plan of using coal gas instead of hydrogen for this purpose was adopted, and since that time most balloons have been inflated with coal gas.

By 1820 the streets of London and Paris were generally lighted with coal gas, and it was obtain-

able without much difficulty. Coal gas contains, as a rule, about 50 per cent of hydrogen, and this

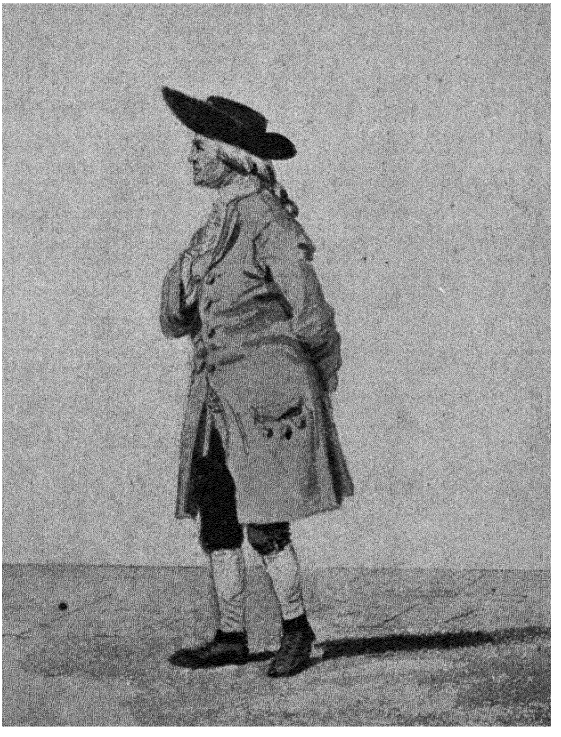


FIG. 3.—Cavendish, who established the true nature of hydrogen in 1766.

fact largely accounts for its being considerably lighter than ordinary air. Experiments have shown

that air is about fourteen times as heavy as hydrogen, bulk for bulk, and from two to two and a half times as heavy as coal gas.

The true nature of hydrogen was first established in 1766 by Cavendish, the English chemist to whom reference has been made in the previous chapter. To him, too, is due the discovery that water is not an element, but a compound of hydrogen and oxygen. It has been urged that other workers have claims to be regarded as the discoverer of the true nature of water, and the names of Watt, the inventor of the steam-engine, and of Lavoisier, the eminent French man of science, have been brought forward in this connection. It is quite true that these men were studying the problem of water at the time, but there is no doubt that Cavendish made the experiments which definitely settled the matter.

Priestley had noticed that when a mixture of air and hydrogen is exploded by an electric spark in a glass vessel, something like dew was deposited on the inside. Cavendish, in his characteristic way, made more accurate observations of this interesting phenomenon, and the results of his experiments may be described in his own words. "When inflammable air and common air," he says, "are exploded in a proper proportion, almost all the inflammable air and near one-fifth of the

common air lose their elasticity and are condensed into dew. And by this experiment it appears that this dew is plain water, and consequently that almost all the inflammable air and about one-fifth of the common air are turned into pure water." Cavendish then repeated the experiments, using pure oxygen instead of air, and found that when two parts by volume of hydrogen and one part by volume of oxygen are exploded by an electric spark, the whole is converted into water.

Thus the composition of water was established, and the old idea of it as an element was finally overthrown. What a striking instance, too, is furnished by this formation of water from hydrogen and oxygen of the extraordinary transformations that are brought about by chemical forces! Before the change is initiated by the heat of the electric spark we have a mixture of two gases, one of which is inflammable, and both of which are incapable of assuming the liquid state until they have been cooled two hundred degrees or more below zero; after the explosion nothing is left but a little harmless water, which exists in the liquid state at the ordinary temperature. It is one of the fundamental marvels of chemistry, and, could we but realise it, a far more wonderful occurrence than anything the magician or conjurer can produce.

Apart from these discoveries about its true

nature, water has an interest and a practical importance because it is able to dissolve other substances. Everybody knows that a little common salt, to take one example, disappears very quickly when put into water, especially if it is stirred or shaken. The water is said to dissolve the salt, and it has long been a question whether this effect is due to the action of chemical forces or whether the two substances are simply mixed together, like oxygen and hydrogen in a vessel before they are exploded by an electric spark. The fact that it is very easy to separate the water and the salt, by evaporating away the water, would seem to indicate that a salt solution is merely a mixture, and yet there are many other facts in favour of the view that when salt dissolves in water chemical forces are at work. The problem is rather a difficult one and cannot be discussed here.

As has just been stated, it is generally very easy to recover a substance from its solution in water, by the simple process of evaporation. Indeed the chemist in his laboratory makes frequent use of the process of solution, followed by evaporation, in order to purify substances. Suppose, for instance, that we had a sample of common salt containing chalk (that is, carbonate of lime), and that we wished to obtain the salt in a pure condition. This can be done by stirring or shaking the impure

salt with water and then "filtering," to use the chemical term. This means pouring the water into a piece of blotting-paper folded in the form of a cone and supported by a funnel, the liquid which runs through being caught in a dish below. Now chalk is not soluble in water; it therefore remains on the blotting-paper and is thus separated from the solution of pure salt in the dish. The water in the solution is then evaporated or boiled off and the pure salt is left behind.

Gunpowder might be treated in the same way. This material is a carefully prepared mixture of charcoal (or carbon), sulphur, and nitre—the first two being elements, the last mentioned a chemical compound. Of the three constituents only one, the nitre, is soluble in water, so that by boiling gunpowder with water, filtering, and evaporating, beautiful white crystals of this compound are obtained. It is indeed a common experience of the chemist, making use of these simple processes of solution, filtration, and evaporation, to extract beautiful crystalline products from the most unpromising material.

It is not only on the small scale of laboratory experiments, but also on the big scale of technical operations that solution in water and evaporation are useful to the chemist. An interesting illustration of this is furnished by the methods adopted

in Cheshire for getting salt from the extensive salt-beds which lie far below the surface in that district. The practice of mining the salt in the same way as coal is in vogue to some extent, but by far the greater part is raised by an entirely different method. A bore-hole is made through the overlying strata down to the salt-beds; water is run into the hole and in a short time dissolves a quantity of salt. The brine so formed is then pumped up to the surface and afterwards evaporated in shallow pans, till the salt separates out in crystals. Over one million tons of salt are raised every year in England in this way. The method is an imitation of Nature; for in many places we find brine springs where water, containing quantities of salt, comes to the surface of its own accord. Salt is obtained also from this natural brine, as well as by the evaporation of sea-water under the heat of the sun's rays.

The process of evaporation of water from a solution is sometimes so conducted that the vapour is condensed. When this is done, the operation is described as "distillation," and the boiler or "still" is closed except for a pipe which connects with a coiled or "worm" tube, cooled in a tank of cold water. As the solution is heated in the boiler, the condensed water trickles from the end of the worm tube and may be collected in any suitable vessel.

The dissolved substance, salt for instance, remains



Photo—Underwood & Underwood.

FIG. 4.—The evaporation of brine by the heat of the sun.

behind in the still, and the process of distillation,

therefore, affords a means of obtaining pure water from a solution. Ocean liners are regularly fitted with distilling apparatus, so that a good drinking-supply may be obtained from sea-water.

It is not only sea-water that contains dissolved substances. Even so-called "fresh" water, obtained from springs, rivers, or lakes, is found to hold in solution quite appreciable quantities of salts. The reader may be reminded here that the term "salts" covers a large number of substances, such as sodium chloride (common salt), calcium carbonate (chalk), magnesium sulphate (Epsom salts), and potassium nitrate (nitre or saltpetre). They are all produced by the interaction of an acid (*e.g.* hydrochloric acid, carbonic acid, sulphuric acid, or nitric acid) with a substance of an opposite character, known as a "base," *e.g.* soda, lime, magnesia, potash, or ammonia.

The salts present in fresh water are derived from the soil or the rocks through which the water has percolated, or over which it has flowed. For the rain which falls on the earth is practically free from dissolved substances, as may very easily be shown by collecting some in a glass dish and evaporating away the water. This is only what we should expect, since rain-water is the result of natural distillation. It has accumulated in the clouds by the evaporation of water from the surface

of the globe, more particularly of the oceans, and such evaporation, or distillation, as we have seen already, is a means of obtaining pure water from a solution.

The actual amount of salts dissolved in spring or river water depends, of course, on the nature of the soil or the rocks with which it has been in contact. One of the commonest substances present in ordinary fresh water is chalk, or calcium carbonate, to give it the systematic chemical name. This statement may seem to the reader inconsistent with what was said above about the insolubility of chalk in water. The explanation is that although chalk will not dissolve in ordinary water, it will do so in water which is charged with carbon dioxide. This may be verified by continuing an experiment to which reference was made in the first chapter. It was there stated that when the gas carbon dioxide is bubbled through lime-water (obtained by shaking up slaked lime with water and pouring off the clear portion) a cloudiness, due to the formation of chalk, is produced. Curiously enough, however, if we continue to pass carbon dioxide through the turbid lime-water, the cloudiness disappears; the chalk becomes soluble when the water is charged with carbon dioxide.

Now falling rain picks up some of the carbon dioxide from the atmosphere, and when it reaches

the ground it is to some extent charged with that gas. Should it then come in contact with chalk or limestone, some is dissolved and the properties of the water, from the point of view of domestic or technical purposes, are altered. A water which contains a good deal of chalk or other salts in solution is described as "hard"; a relatively large quantity of soap is needed to produce a lather in such a case, for the first portions of the soap are used up in converting the chalk, etc., into curd. Waters, on the other hand, which contain very small quantities of such dissolved substances or none at all,—rain-water, for instance,—are termed "soft"; a very little soap is sufficient in this case to make a lather.

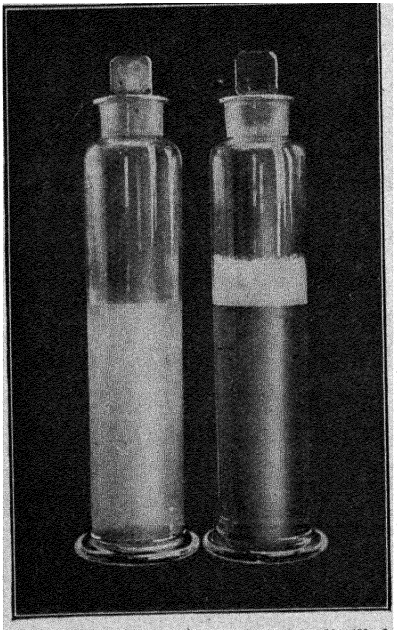


FIG. 5.—London tap water and distilled water, to which equal quantities of soap solution have been added.

So far as the hardness of a water is due to the presence of carbonate of lime (or carbonate of magnesia, which behaves similarly), it may be removed by the simple process of boiling. The effect of this is to boil off the extra carbon dioxide, by virtue of which alone the chalk was capable of dissolving; the chalk itself is consequently thrown out of solution and is deposited on the inside of the vessel in which the water is boiled. A glance inside any kettle which is constantly being used to boil hard water will reveal the presence of the chalky deposit or "fur," as it is sometimes termed. Water, consequently, which has been boiled requires less soap to form a lather than some of the same water which has not been boiled.

The furring of a kettle is in reality very closely related to the formation of "stalactites" and "stalagmites" in limestone caves. When rain-water charged with carbon dioxide percolates through the rocks situated above such a cavern, it dissolves a considerable quantity of calcium carbonate, which is carried with the water to the roof of the cavern. Here, as the drops slowly form and ultimately fall to the ground, some of the carbon dioxide in the water has time to escape; and in proportion as the gas gets away the water loses its power of holding calcium carbonate in solution.

Some of this substance, therefore, is deposited from each drop at the point where it falls; and in the course of years and centuries the quantity may have so accumulated as to produce a conical, icicle-

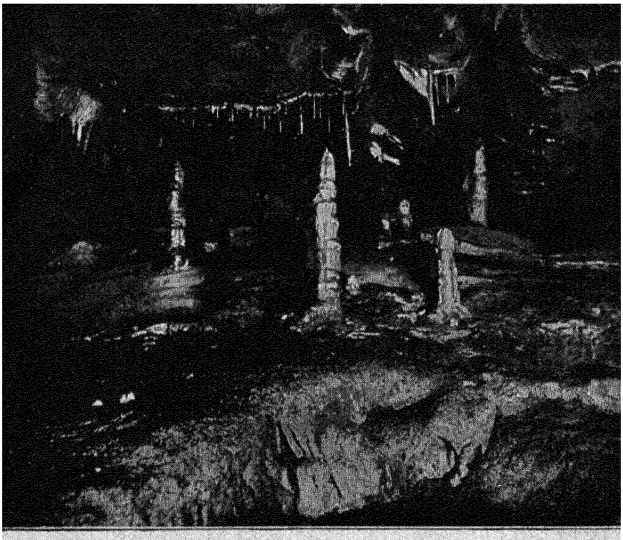


FIG. 6.—Stalactites and stalagmites.

like mass of calcium carbonate hanging from the roof of the cavern. This mass is described as a "stalactite."

A further loss of carbon dioxide, and consequently a further deposition of calcium carbonate, occurs as the drops of water are falling and after they have reached the ground. Hence there is

gradually built up on the floor of the cavern a mound of calcium carbonate, known as a "stalagmite," which rises to meet the corresponding stalactite. If the process has continued long enough, the stalactite and stalagmite may have met, so that a complete column of calcium carbonate is formed.

Chalk is the commonest of the substances which natural waters, apart from sea-water, hold in solution, but there are many others frequently found along with calcium carbonate. There is, for instance, the carbonate of magnesia, as well as the sulphates and chlorides both of lime and magnesia. Sometimes the water from a spring contains such a large quantity of a particular salt that it is quite exceptional, and it is then spoken of as a "mineral" water. The bitter springs at Epsom, for instance, yield a water with a comparatively large quantity of sulphate of magnesia, and this compound is accordingly known as Epsom salts. Other waters, again, such as those at Marienbad, contain large quantities of sulphate of soda. Some springs are characterised by *gases* with which their waters are charged. The well-known Seltzer and Apollinaris waters are good examples of this; they are rich in carbon dioxide, and contain in addition small quantities of the carbonate and chloride of soda. Sulphur springs, such as those at Aix-la-Chapelle

and Harrogate, yield the unpleasant smelling gas known as sulphuretted hydrogen.

When ordinary substances, sugar and salt for instance, are put into water and dissolved, nothing very striking happens. There is none of the evident production of heat which so often accompanies chemical action, and perhaps leads so many people to think that explosions are a normal and regular kind of chemical change. But in certain circumstances even water, with all its sober and cooling qualities, may develop a good deal of heat when brought into contact with other substances. A simple example of this is furnished by the result of pouring sulphuric acid, sometimes known as vitriol, into a vessel of water. A large amount of heat is produced, and the vessel may become too hot to hold.

More familiar, perhaps, to most people is the chemical change known as the slaking of lime. This is a process which is carried out on a large scale in the preparation of building mortar. Pieces of "quick" lime, obtained by strongly heating limestone so that the carbon dioxide in this material is driven off, are moistened with water, and presently it is seen that quantities of steam are being produced, and that the hard lumps of the quicklime are swelling and cracking in every direction, ultimately falling down into a soft powdery substance.

These effects are the result of chemical action; quicklime, which is a compound of the metal calcium with oxygen, enters readily into chemical combination with water, forming another substance, known commonly as slaked lime.

One usually regards water as by its very nature

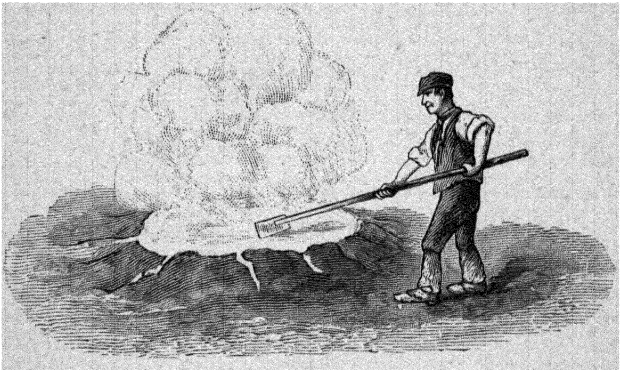


FIG. 7.—Slaking lime.

opposed to fire, and yet it takes part in one or two interesting chemical changes which result in the production of inflammable gases. There is the very important case of acetylene, the gas produced by the action of water on calcium carbide. This latter substance is prepared on the large scale by heating a mixture of limestone and coke in the electric furnace. Calcium carbide is a solid material, and by itself is quite harmless with regard to fire; the addition of water to it, however, immediately causes the evolu-

tion of acetylene, which is very readily inflammable, and is characterised by its high illuminating power. By regulating the addition of water to calcium carbide the rate of production of the acetylene varies accordingly, and this principle is extensively made use of in the construction of cycle and motor lamps.

Another substance which is in some respects similar to calcium carbide in its response to water is calcium phosphide. This material is utilised in producing signal fires at sea, and for this purpose has only to be thrown into the water; the phosphide is acted on chemically by the water and gives rise to a gas which is spontaneously inflammable. If it is intended that the signal shall last for some time, the phosphide may be put in a canister, supported on a wooden float, and provided with a hole at each end. When this is thrown overboard, the water enters at the lower hole, and the flame issues at the upper one.

CHAPTER III

THE PROBLEM OF COMBUSTION

THE latter half of the eighteenth century was a great epoch in the history of chemical science. It was in these days that chemists found out the true

nature of air and water, discoveries that paved the way for the wonderful achievements of later years. Another problem which was much in the minds of men of science about that time, and the solution of which was closely connected with the newly acquired knowledge of air and water, was furnished by the phenomena of combustion. The burning of a combustible substance and the production of flame had from the earliest times been objects of interest, even of veneration, and the making of fire was one of the notable achievements of primitive man. In spite, however, of this prolonged familiarity with the phenomena of combustion, there was not until comparatively recent times any clear understanding as to what actually takes place when a substance burns.

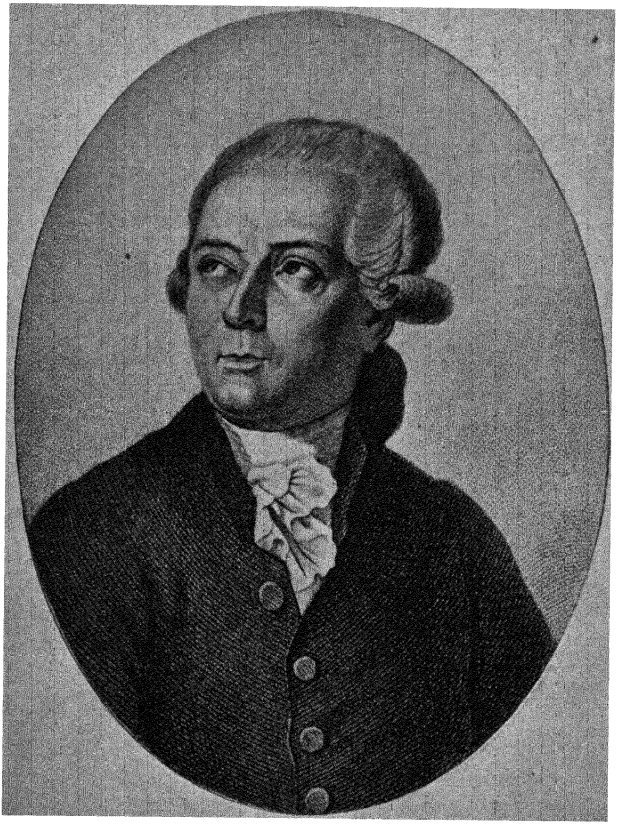
During the greater part of the eighteenth century the idea was commonly held among chemists that combustible material contained an elusive substance termed "phlogiston." They believed that, in the process of burning, the combustible substance and the phlogiston parted company, and that the escaping phlogiston was responsible for the phenomena of fire and flame. Everybody knows that the burning, say of a candle or a piece of wood, is accompanied by the disappearance of visible matter, and the mere appearance of a flame rather suggests that some elusive ethereal substance is escaping from its

material prison. The phlogiston theory, therefore, has something plausible about it.

The credit of showing that a burning substance, so far from parting with anything, actually combines with a constituent of the air, is due to the famous French chemist Lavoisier. The discovery of oxygen by Priestley, and the proof of the compound nature of water, brought forward by Cavendish, contributed largely to the overthrow of phlogiston; but it was the Frenchman who actually cleared away the fantastic ideas which had gathered round the phenomenon of combustion. Lavoisier, it is sad to relate, was one of the victims of the French Revolution. Neither his public services nor his brilliance as a man of science availed him in these dark and bloody days. It was he who showed that combustion is the chemical combination of the combustible substance with the oxygen of the air. If this view is correct, then we ought to find that the substances produced by the combustion, taken all together, weigh more than the combustible substance which gave rise to them. This is evidently a crucial experiment as between the phlogiston theory and Lavoisier's account of combustion; for, according to the former, the combustible substance, being relieved of phlogiston, should become lighter in the process of burning.

In order to apply the test, say with a candle,

it is necessary to know, first of all, what are the



invisible products into which the candle is converted on burning. Some candles consist of compounds of

carbon and hydrogen only, while others consist of compounds of carbon, hydrogen, and oxygen. In both cases, however, the result of combustion is the same—carbonic acid gas (carbon dioxide) and water vapour are produced.

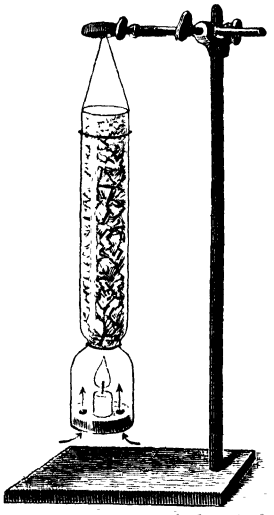


Fig. 9.—Substances produced by combustion weigh more than the combustible substance which gives rise to them.

Now it is fairly easy to burn a candle in such a way as to permit the capture and retention of these products. A small candle end is fixed on a perforated cork, which fits into the lower end of a lamp glass. The upper part of the glass is filled with pieces of caustic soda, a substance which absorbs both water and carbon dioxide with great readiness. As a support for the caustic soda, a piece of wire gauze is placed at the constriction of the lamp glass. When this little apparatus is ready, it is suspended on one side of a balance, and then the other side is slightly

over-weighted by the addition of, say, shot pellets, so that the end of the beam which carries the lamp glass is in the air. The candle is then removed for a moment, lighted, and replaced. The side of the balance carrying the candle descends in a very short time, and we have thus clear proof of the fact that the substances produced by the combustion weigh more than the combustible substance which gives rise to them.

This experiment illustrates the very valuable service which the balance renders in the investigation of chemical problems. Since the days of Lavoisier this instrument has enabled the chemist to learn a great deal about the wonderful laws which regulate chemical changes of all sorts. An instance of the value of the balance has already been quoted in the first chapter, where it was pointed out that a small difference in weight convinced Lord Rayleigh that there must be in atmospheric air a gaseous element similar to nitrogen, but somewhat heavier bulk for bulk. One may, indeed, safely say that the modern advance of chemical knowledge dates fairly definitely from the time when the balance came to be recognised as a regular part of the equipment of a laboratory, and when it was regarded as necessary to find out not only *what sort* of substances were taking part in a chemical change, but also *how much* of each.

Since the days when the question "What is fire?" received a satisfactory answer, the problem of combustion has been continually cropping up in ever so many different forms, and the chemist has been led gradually to see that a very large number of chemical changes belong to this class. It is, of course, part of the business of the man of science to detect similarity in things which appear quite different, and to put side by side phenomena which to the outsider seem quite unrelated, but are really closely connected.

The rusting of iron, for instance, is in many respects similar to combustion. The burning of a candle in a closed space, say in a bell-jar over water, ultimately renders the air in that space unfit for breathing, and unable to support combustion. Now the effect of allowing iron to rust in the air of a bell-jar over water is exactly the same; the air left behind when the formation of rust has ceased will not permit a candle to burn, and is unfit for respiration. It is clear, therefore, that when iron rusts it removes from the air the same constituent as is necessary for the combustion of a candle. In both cases—burning and rusting—it is the oxygen of the air which is concerned in the process, and we might describe the chemical change in each instance as "oxidation." The difference between burning and rusting lies in the fact that

one change is rapid and the other slow, and this somewhat obscures the real similarity of the two processes. A burning candle will consume the greater part of the oxygen in the air of a bell-jar in a minute or two, whereas moist iron will require hours for the same purpose. The result is that, although the combination of iron and oxygen is accompanied by the production of a considerable amount of heat, the slowness of the change allows all this heat to get scattered, and the observer sees nothing in the rusting of iron to suggest the heat and light generally associated with combustion. There is no doubt, however, that heat is produced during the rusting of iron, and we are therefore justified in describing this change as a "slow combustion."

Other facts, observed by chemists, encourage one to accept this extension of the idea of combustion. Iron, which in rusting combines slowly with the oxygen of the air, may be made also to undergo rapid combustion. For this purpose iron must be prepared in a very finely divided condition, so that a large surface is exposed. Iron powder in such a state will oxidise spontaneously and suddenly when thrown into the air, and the combustion is rapid enough in this case to give the phenomena of heat and light.

On the other hand, it is possible to burn even

an inflammable gas such as hydrogen at ordinary temperatures, so slowly that the production of heat and light is not apparent. This can be done with the help of what is known as "colloidal platinum," a brownish liquid consisting only of water and exceedingly fine, suspended particles of the metal platinum. If a small quantity of this liquid is shaken in a bottle with a mixture of hydrogen and oxygen—a mixture which, if a match were put to it, would go off with a violent explosion and probably burst the bottle—the hydrogen combines slowly with the oxygen and water is formed. The heat produced when a given quantity of hydrogen undergoes this slow combustion has time to scatter, but in reality is quite as great as when the hydrogen is mixed with oxygen and burned in a moment with bang and flash.

The wider idea of combustion which these and other facts lead us to adopt has proved very useful in connection with various practical problems which the chemist has had to solve from time to time. Chemistry, after all, is not an affair of laboratory experiments only. Many natural processes are really chemical changes; many devices of civilised man, both in the home and in the factory, depend on the operation of subtle chemical forces, and the chemist, therefore, has very often to deal with problems which arise in the course of ordinary life.

Some of these problems which are interesting in the present connection have been suggested by the frequent occurrence of what is known as "spontaneous combustion." Various materials have been observed in certain conditions to ignite of their own accord—at least without any very obvious cause. There is, for instance, the spontaneous firing of haystacks, which has been known for a long time, and against which the farmer must be on his guard. If the hay is stacked before it has been sufficiently dried, chemical changes begin and continue inside the stack, leading ultimately to the loss of the hay. There seems to be little doubt that minute living organisms or bacteria are responsible for these chemical changes to begin with, and that fermentation is set up by their subtle agency. For this process moisture is necessary, and hence it is that firing is so much more likely to occur when the hay is imperfectly dried.

To some extent fermentation resembles combustion, for one of its chief results is the conversion of complex carbon compounds, such as are present in hay, into carbon dioxide; further, the process of fermentation is accompanied by the production of heat. The amount of heat produced in this way is not very great, it is true, and if the fermentation were taking place in a small heap of hay exposed to the winds of heaven, nothing would result.

But the conditions are quite different in the inside of a stack. There the hay which is undergoing a slow fermentation is cut off from the outside by great masses of the same material, and since hay is a very bad heat conductor, the heat produced at any spot where fermentation is taking place cannot escape very easily. It therefore accumulates, and the temperature rises wherever the hay is fermenting.

Now the bacteria become more active as the temperature rises, and consequently the fermentation and production of heat take place more quickly. It is plain, therefore, that the accumulation of heat becomes rapidly greater, like a sum of money at compound interest. How the chemical action started by the bacteria is continued at high temperatures is not exactly understood, but there is no doubt as to its vigour, or as to the enormous production of heat. Cases are on record where the interior of a stack was found to be charred completely, and the carbon to which the hay had been reduced burst into flame at once when spread out in the air.

Another interesting practical problem connected with spontaneous combustion is the cause of the self-ignition of coal on board ship. The losses incurred in this way some forty years ago were so great that a Royal Commission was appointed to consider the matter. The evidence collected by this Commission showed that in 1874 actually

more than fifty British coal-carrying ships were destroyed by fire owing to the self-ignition of their cargo.

Enquiry into the circumstances of these disasters showed that the bigger the cargo of coal and the longer the voyage, the more likely was spontaneous ignition to occur. A study of the problem by chemists proved that finely-divided coal might undergo slow oxidation, especially in the presence of moisture. Now the mere tipping of coal into a ship's hold reduces much of it to dust, and the constant rolling of the vessel during a long and stormy voyage acts in the same direction.

If, then, as may easily happen, the coal has been somewhat wet when taken on board, the conditions are fulfilled in which slow oxidation occurs. Should this take place in the middle of a big cargo of coal, the heat produced by the oxidation has much difficulty in escaping, as in the case of the haystack, and the temperature rises. But the hotter the coal, the more rapid is the oxidation; the temperature rises more and more quickly, and the combustion, which was slow in the beginning, becomes impetuous and leads finally to ignition.

Another difficulty of the same kind arises in connection with the storage of greasy rags and the use of oils to lubricate wool before spinning. Heaps of cotton waste impregnated with oil or

grease have been known to ignite spontaneously, and it is therefore extremely dangerous to have such accumulations about a factory. It may seem strange that greasy rags should give rise to fire, but the chemist is able to supply an intelligible explanation of this fact. In order to appreciate this we must bear in mind the curious property of absorbing oxygen possessed by many oils. Linseed oil, for instance, obtained from the seeds of the flax plant, if left simply exposed to the air, will take up a considerable quantity of oxygen, as is shown by the fact that it gains in weight to the extent perhaps of 20 per cent. It is then no longer a liquid, but a solid substance; the oil is said to have "dried." On account of its behaviour in this respect linseed oil is largely used in the preparation of paints and varnishes.

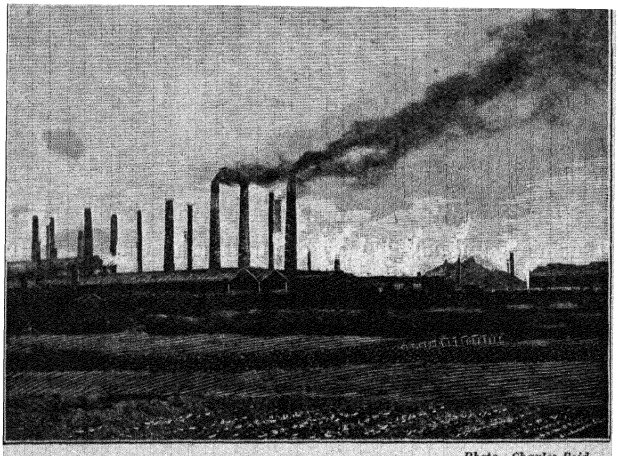
This absorption of oxygen by linseed and other "drying" oils is a chemical action, and, like other cases of oxidation, is accompanied by the production of heat. This, of course, could not be observed if the oil were simply spread out on a plate to dry; the heat would be dissipated too easily. But in a heap, say of oily cotton waste, the conditions are very favourable both for a rapid oxidation and for accumulation of the heat produced by the oxidation. The spontaneous ignition of coal, as was pointed out above, is promoted by fine division of the material,

and it is well known that any chemical action in which a solid substance takes part is immensely accelerated by increasing the extent of its surface. Now cotton waste and rags present a very large surface to the air, so that any oil which they have taken up is in a condition specially favourable for rapid oxidation. Material like cotton waste or rags is also a bad heat conductor, and it is therefore not surprising that the heat which results from oxidation of the oil accumulates rapidly and may lead to actual ignition.

The variety of circumstances in which spontaneous combustion may occur illustrates very well the great extent of the field of chemical action. Even when the question of combustion alone is considered, we see that the chemist may be called in by the farmer, by the coal exporter, or by the cloth manufacturer to deal with difficulties arising incidentally in the course of these callings. And these problems can be solved only when the real nature of combustion has been made clear by accurate scientific investigation, and when it is recognised that combustion is not always an affair of great light and heat, but that it may be, in its early stages at least, a comparatively slow process.

There are, after all, comparatively few people who are directly interested in the firing of haystacks and in the self-ignition of coal or cotton waste, but

there is one form of combustion in which everybody is concerned, and that is the burning of coal in the domestic fire. This practice may be a very delightful one, but it is exceedingly wasteful, and gives rise to much trouble in the shape of smoke,



Photo—Charles Reid.

FIG. 10.—The fouling of the air by smoky chimneys.

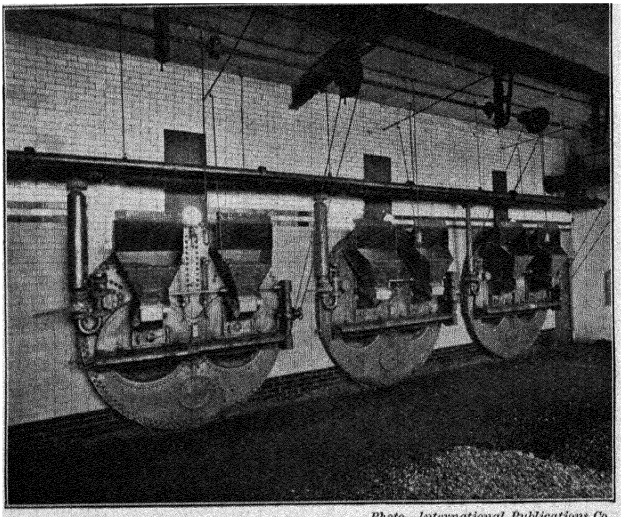
smuts, and fog. In Britain it is the almost universal custom to employ open fireplaces, and the coal which is burned in these is of the "bituminous" variety, that is, it is comparatively soft, and yields much gas and tarry matter when heated. This coal cannot be burned in the ordinary open grate without the production of smoke, which means so much loss of combustible material as well as pollu-

tion of the atmosphere. It would be difficult to say exactly how much soot is produced in England every year, but there is no doubt that the quantity is to be reckoned in tens of thousands of tons.

We have every right, therefore, on grounds both of economy and public health, to speak of "the smoke problem" and even of "the smoke nuisance." The difficulty is not a new one, for when bituminous coal was first employed in England about the year 1300, the smoke was pronounced such an annoyance that its use was for a time prohibited by law. Indeed it is said that a certain citizen of London was executed for burning this fuel!

What, then, has the chemist to say about this smoke nuisance, for it is obviously a problem in combustion? Since it is impossible to secure perfect combustion of bituminous coal in open grates, it is plain that in order to improve matters either the character of our fireplaces must be altered, or some other fuel must be employed. The way in which the coal is burned is of great importance, as all those will admit who have tried holding a newspaper in front of a dimly burning fire. The effect of thus closing the upper part of the grate front is to make more oxygen pass through the fuel and so facilitate the combustion. Much has already been done in lessening the smoke from factory furnaces by regulating the air-supply

and feeding in the fuel by so-called "mechanical stokers." The alteration of the domestic fireplace so as to secure the proper smokeless combustion of soft coal is quite possible, but is expensive, and has not been carried out to any large extent.



Photo—International Publications Co.

FIG. 11.—Furnaces with mechanical stokers.

As regards the possibility of replacing bituminous coal by another fuel, chemical investigation has made it plain that the chief objection to the former is the large quantity of tarry matter which it yields on heating. This being so, one might suggest the use of anthracite, a hard coal which contains little volatile matter, or of coke, which is

coal artificially deprived of its gas and tar. The objection, however, to anthracite coal and coke is that they are very difficult to ignite and, when they have been ignited, burn without that bright flame which is part of the charm of the open fireplace. What is required is a carbonaceous fuel which contains enough gas to ignite easily and yet gives no tarry matter when it is heated.

These conditions are fulfilled to a very large extent by a product known as "coalite," which may be described as half-coked coal. The process by which it is prepared is similar to that adopted in getting coke; that is, soft coal is heated in retorts and the gas and tar which come off are collected separately. If the retorts are heated to a very high temperature, all the gas is driven out of the coal and the residue is ordinary coke. When, however, the retorts are heated to a lower temperature, the tar and only part of the gas are expelled; the residue (coalite), containing as it does some inflammable gas but no tar, ignites readily and burns with a smokeless flame.

The general use of such a fuel would get rid of the smoke difficulty, and we may regard the problem as solved so far as the chemist is concerned. But the public, unfortunately, is not very ready to listen to the advice of science, and the custom of burning dirty, smoky coal will probably die hard. From the commercial point of view also there are

difficulties in the way of introducing this smokeless fuel.

Another way of avoiding the production of smoke is to give up solid fuel altogether and burn gas. Where provision is made for first mixing it with air, as in burners of the Bunsen type, coal gas gives a smokeless flame and can be used to heat asbestos or some other solid, non-combustible material. Such gas fires have been introduced to a considerable extent, but they are much less fascinating than the smoky coal fire; they cannot be poked and nothing can be thrown into them, hence they are regarded with disfavour by many people. However this may be, it is fairly certain, from the purely chemical point of view, that the smoke problem will be solved in the future by the extended use of gas or a half-coked coal.

CHAPTER IV

SOURCES OF POWER

SINCE the earliest times man has constantly been endeavouring to get somebody or something else to do his hard work for him. With the object of saving labour and increasing the efficiency of manual work, implements of all sorts have been devised,

from the simple axe or bow of the primitive savage to the most cunning hand tool or machine of the present day. Even so much labour as is involved in the handling of a tool could be avoided by making somebody else do it, and so slavery arose. But a substitute was to be found not only among one's fellowmen, but among the lower animals, and from very early times the ox and the horse especially have been trained by man to plough his fields and bear his burdens.

The forces of inanimate nature also have been invoked by man for similar purposes. The wind has been harnessed and its power has been utilised in the grinding of corn, the pumping of water, and the propelling of ships. In our streams and rivers, too, we have an obvious source of power, one which has been much used in the past and is exceedingly valuable to-day. By the intermediate agency of water-wheels or turbines the fall of water from a higher level to a lower may be employed to drive a saw-mill, a threshing-mill, or an electric dynamo. From a dynamo electric current is obtained, so that it is possible to convert water power into electricity, which in its turn may be employed to light the streets, to work a lift, or drive a train. A crowning example of the utilisation of water power for electrical purposes is found at Niagara. The value of the total energy available there is to be reckoned

in millions of pounds sterling; but only a small fraction of the energy is utilised as yet.

From the chemist's point of view water power is valuable because it is a cheap source of electricity; and with the help of the electric current he can bring about some very wonderful chemical changes. An interesting example of what is done in this way is furnished by the aluminium works in the Scottish Highlands, at Foyers in Inverness-shire and at Kinlochleven in Argyllshire. The industry carried on at these places is the preparation of aluminium from the mineral known as "bauxite," which consists chiefly of the oxide of the metal. We need not discuss here the details of the operation by which the metal is obtained; the interesting point is that an electric current is used, and that water power serves for the production of the current. So far as this country is concerned, the conditions for securing a big store of water power are best realised in the remote Highlands, for there the rainfall is heavy, and the mountainous nature of the country permits the storage of the water at a great height above the machinery which is to be driven. At Kinlochleven the water is led from the reservoir into pipes at a height of 900 feet above the factory, and from that point the pipes, which are more than three feet in diameter, run down the hillsides for a mile and a quarter.

Norway is a country in which, owing to the

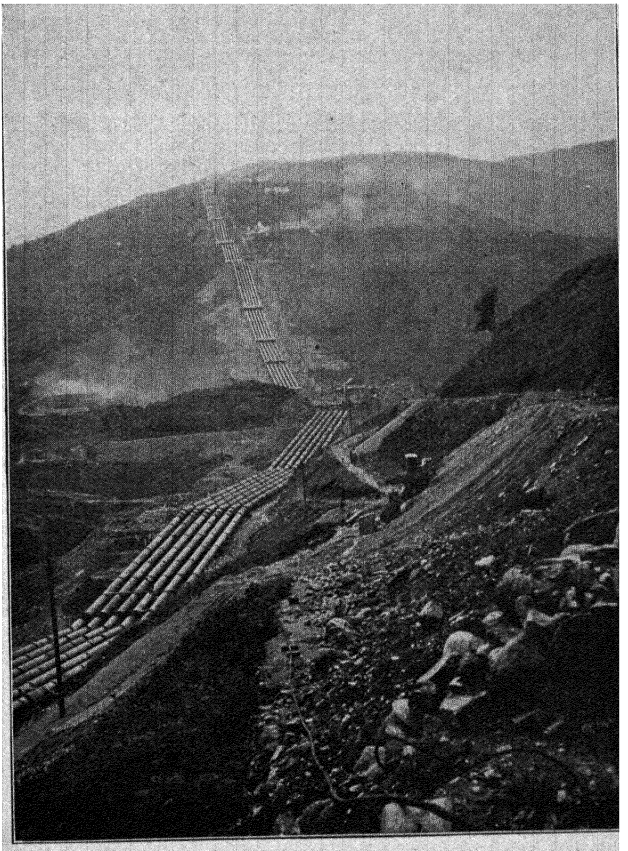


FIG. 12.—Water power at Kinlochleven.
(By permission of the British Aluminium Co., Ltd.)

numerous falls, water power is much more abundant

than in Britain. Hence electricity is cheap there, and chemical industries which require the electric current can be carried on under favourable conditions. The production of nitric acid from the nitrogen of the atmosphere is a case in point. As already stated, the chief constituents of the air are oxygen and nitrogen, mixed with each other but not combined chemically. It is rather difficult to persuade oxygen and nitrogen to form a chemical compound, but the union does take place to some extent when a discharge of lightning occurs. The compound of oxygen and nitrogen so produced yields, in the presence of water, the substance known as nitric acid, which contains the elements hydrogen, nitrogen, and oxygen. In the form of its salts, nitric acid is valuable as a manure, and it is therefore very desirable to make it from the atmosphere. This is done on a large scale in Norway, by a process which practically consists in producing artificial lightning. The electric current required for this purpose is obtained by the utilisation of water power.

The bulk of the energy, however, which is available at the present time for all the varied objects of human enterprise is derived not from wind or water, but from the combustion of fuel. It is this chemical change which makes possible the extraordinary engineering and industrial developments of these

later days, and the nineteenth century will always be remembered as the epoch in which men found out what wonderful things could be done with the help of steam. The steam, clearly, is only an intermediate agent; the real source of power is the fuel employed to make the steam. We may regard a ton of coal, therefore, not only as so much material, but also as a store of energy, and the steam engine as simply a contrivance for converting the chemical energy of the coal into mechanical work. This being so, the reader who knows the part played by the steam-engine in modern civilised life will admit at once that there is more reason than ever for regarding combustion as the fundamental chemical change.

It may be suggested, however, that steam is being displaced by electricity, that electric trains are taking the place of steam trains, and that electrically driven machinery is to be found in almost every factory nowadays. That is quite true; but a little consideration will show that combustion is still the real source of power. What happens is that the mechanical energy into which the chemical energy of the fuel is converted is put first into a dynamo, from which in turn electrical energy is obtained. Now electricity is a very convenient form of energy, because it can be transmitted by means of wires, or cables, to any desired

point, and there reconverted into mechanical energy by means of an electric motor.

Except, then, in the comparatively few places where water power can be used in driving dynamos, combustion is still the only available practical source of energy. It is true that the steam-engine has been displaced to a considerable extent by oil and gas engines, but in these also, although the nature of the fuel and the manner of its burning are different, it is combustion from which the power comes. One does indeed see less of the burning of the fuel in these days, of which fact our electrified railways supply an interesting example. In the old times each train had its engine, and on each engine power was produced by the combustion of coal. Nowadays the combustion is carried on out of sight at some central station, and the electricity generated there is distributed along the railway line. This centralisation of the combustion process has led naturally to a great improvement in the atmosphere of those underground railways which have been electrified, for they are now free from smoke.

Combustion, then, is at the root of the remarkable engineering and industrial developments which the past hundred years have witnessed, not excluding the introduction of motors and aeroplanes. Nature's stores of fuel are in fact a huge reservoir of energy, and the questions which interest the

chemist chiefly concern the kind of fuel which is available and the best and most economical way of using it. For it must be borne in mind that the combustible material stored up in the earth, although it is very large in quantity, is yet not inexhaustible; and in the interests of the generations to come it is only right that we should avoid waste as far as possible.

What sort of fuel, then, is it which Nature supplies, and what are the various ways in which the energy there stored up is utilised for industrial purposes? All natural fuel, it should be remembered, is carbonaceous; that is, it consists mainly of carbon or of compounds of carbon and hydrogen. In the process of burning, the carbon and hydrogen combine with the oxygen of the air and yield respectively carbon dioxide and water, and these final products of combustion remain the same whether the original fuel is solid, liquid, or gaseous.

The chief solid fuels obtained directly from Nature are wood, peat, and coal. The first of these, however, cannot be seriously reckoned as a fuel. It is true that a great deal of wood is burned in those countries where forests are abundant, but it is scarcely utilised at all for manufacturing and industrial objects. Indeed, it would be madness to use wood in this way, for our supplies of timber would be rapidly exhausted. As it is, the forests

of Europe and North America are disappearing at an alarming rate; trees take a long time to grow, and vegetation, as we have seen, is the necessary counterpart of animal life. Besides, vast quantities of timber are required in the construction and fittings of buildings of every kind, as well as in the manufacture of paper.

The forests of the distant past are now no more, but we find their remains below the surface of the ground. Since the vegetation of those far-off ages died or was submerged, the material of which it consisted has undergone a series of chemical changes, and we dig it up to-day in the form of peat or coal. Woody matter, apart from the water with which it is charged, consists, to a large extent, of cellulose, a chemical compound of carbon, hydrogen, and oxygen. In the course of ages, however, the cellulose from the fallen forests and jungles of the past has lost a great part of its oxygen and some of its hydrogen, and has been converted more or less completely into carbon. These changes have not proceeded so far in the case of peat as in the case of coal; the latter material, therefore, contains a much higher proportion of carbon than peat, and it is also more compact, since it has been subjected to greater pressure.

The amount of energy stored up in the peat bogs of the world must be enormous. The area

covered by these is above 1,000,000 acres in Ireland alone, and about 100,000,000 acres in Russia, and it has been estimated that an acre of bog, having a depth of 8 feet, would yield about 1250 tons of dried peat. Here, then, is a huge store of a fuel which, unlike wood, cannot be used for any other purpose than combustion, and one is perhaps inclined to wonder why peat is scarcely ever employed except quite locally, in the immediate neighbourhood of the bogs. A little consideration, however, gives an intelligible explanation of this fact.

Everybody knows that peat, when freshly dug, contains a very large quantity of water. As a matter of fact, the proportion is sometimes as high as 80 or 90 per cent of the total weight, and it is no easy matter to remove all this water in a short time, and get the peat in a condition fit for burning. The old-fashioned way of letting the peat dry in the air is a slow process, unsuited to the demands of these hustling modern days, and the fuel, even when dried, is very bulky for transport. In recent years, however, various devices have been adopted, which to some extent get rid of the difficulties in the utilisation of peat. The water is squeezed out mechanically, and the dried material is compressed so as to produce a more compact fuel. We may therefore look forward to the peat bog

being more effectively used in the service of man than it has been up to the present.

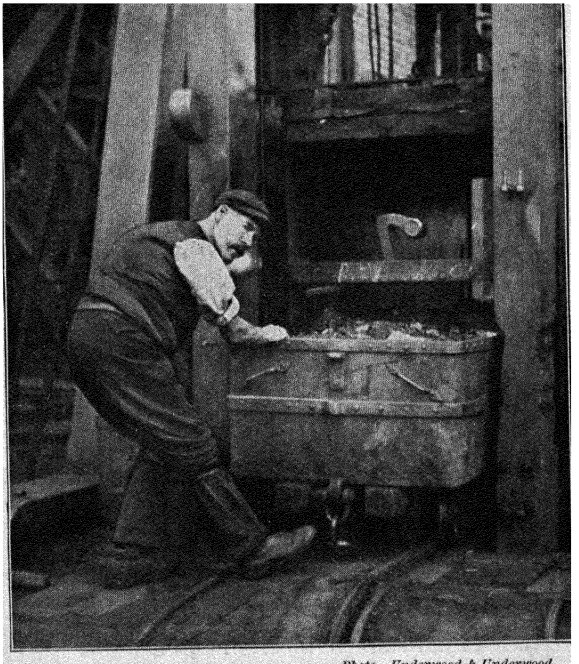
Even if this is the case, coal will remain, as it has been in the past, the chief fuel which Nature supplies. The quantity mined in Britain every



FIG. 13.—Coal-hewing.

year is above 200,000,000 tons; and since the people who know best estimate that our coal-supply will last at least several hundred years, the reader will see what a vast amount of energy lies below the surface of this little island. Of the coal which is burned in Britain about one-fourth is used for domestic purposes, while the remainder is consumed

in manufacturing and technical operations. Altogether, our dependence on coal is so complete that if the supplies failed suddenly our modern life, on



Photo—Underwood & Underwood.

FIG. 14.—Coal at the pit-head.

both its social and industrial sides, would soon be completely paralysed.

Fortunately, there is no likelihood of our coal running short for some centuries to come; but we

ought to remember all the same that the supply is not inexhaustible, and that the modern world is, in this matter of fuel consumption, living on its capital. It is therefore the duty of men of science of the present generation to see that the methods of consuming coal are as little wasteful as possible. That there is room for improvement is clear from the evidence given before a recent Royal Commission. One witness, indeed, estimated that if all steam-engines were thoroughly efficient, 50 per cent of the coal now used in them might be saved.

It is true that coal is not the only natural fuel which is available to-day on the large scale. In certain quarters of the globe, notably North America and Russia, there are large numbers of oil-wells, which yield liquid fuel in the same way as an ordinary spring gives water. The occurrence of petroleum in some parts of the earth's surface has long been known, but the existence of enormous underground reservoirs is a discovery of comparatively recent times. It is not so very long ago since an American engineer, making a boring into the upper rock strata, "struck oil," as the saying is. He observed that when he had made a hole thirty or forty feet deep, oil came welling up of its own accord. This discovery naturally led to further investigations of the same kind, and during the last fifty years or so whole districts in the South of

Russia as well as in the United States have been tapped and are now devoted to "oil-bearing."

The depth at which the oil-yielding strata occur varies much, and may be very considerable. In some cases bore-holes have been sunk to a depth of

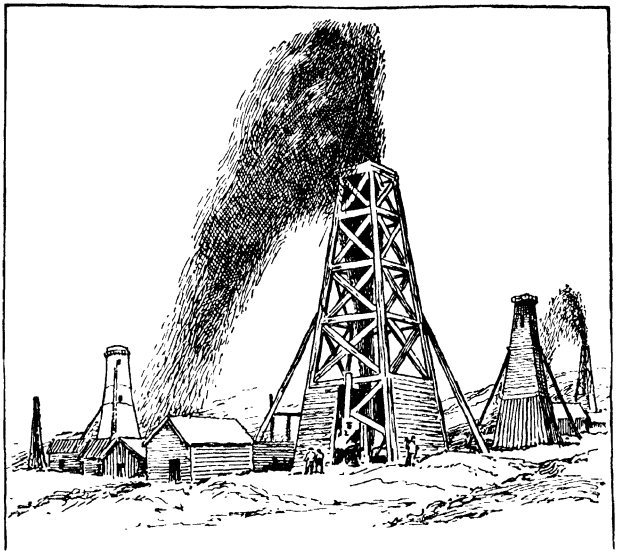


FIG. 15.—A gushing oil-well.

nearly half a mile before an oil reservoir was tapped. While it is necessary sometimes to pump the oil up to the surface, there are many wells in which there is a spontaneous flow. Indeed it is often found, especially when a new spot has been tapped, that the oil is under very great pressure, and the

difficulty in such cases is to avoid loss of valuable fuel.

Numerous instances of such spouting or gushing wells are on record. Baku, the district in South Russia where petroleum is chiefly found, has been the scene of many such outbursts. In 1886, for instance, a certain well gushed to such purpose that the whole neighbourhood was deluged, and many thousand tons of valuable oil were lost before it was found possible to control the outflow. Another well in the same quarter burst out into a fountain 350 feet in height, and in this case also there was a great loss of material, so much so that a large petroleum lake was formed, which overflowed into the Caspian Sea.

The material which is thus obtained from the bowels of the earth is described as "mineral" oil, in contrast to the animal or vegetable oils, such as cod liver or olive oil, which are closely related to fats. Mineral oil, or petroleum, is a mixture of hydrocarbons (that is, compounds of carbon and hydrogen), and an extraordinary variety of valuable products can be extracted from it by suitable treatment. Some of the constituents are much more volatile than others, and so a process of distillation is employed to separate the crude petroleum into different "fractions," as they are called. Some of the first products obtained in this way, that is the

most volatile portions of the oil, are naphtha and petrol.

That part of the petroleum which distils at a rather higher temperature than the naphtha and the petrol is used for illuminating purposes, and in America is known as "kerosene." Lubricating oil, vaseline, and paraffin wax are other products which are obtained from the portions of the petroleum which are still less volatile than kerosene. Naphtha, petrol, kerosene, lubricating oil, vaseline, and paraffin wax are materials which are all serviceable to man in different ways, so that scientific treatment enables us to utilise fully the various valuable properties of the natural product.

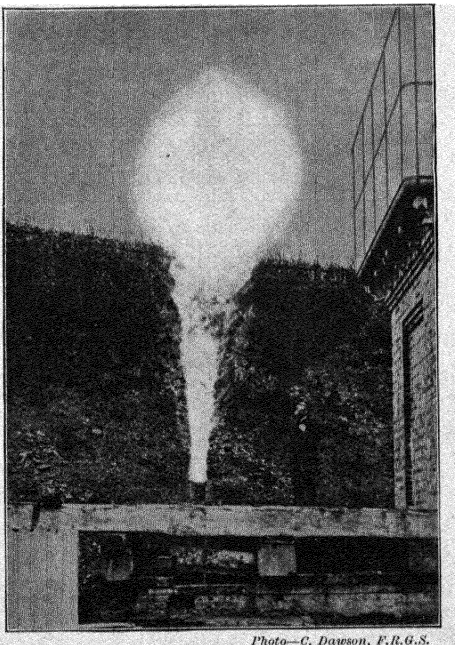
From the point of view of the present chapter, petroleum is chiefly interesting because it yields liquid fuel, utilised in motors and oil engines. The question how long this natural source of power will last is very difficult to answer. While it is possible to make an estimate of the duration of our coal-supply, by inspecting the depth and extent of all the known coal-seams, there is no means of discovering the magnitude of the subterranean petroleum reservoirs. They are beyond human inspection, and this part of our fuel capital is therefore a very uncertain quantity. It is quite possible that the oil-bearing strata will be exhausted at no very distant date, for the old wells are

continually running out and new wells have to be opened in order to keep up the supply.

In the districts where petroleum occurs large quantities of inflammable natural gas make their appearance, generally in close association with the petroleum. Indeed, natural gas is very similar in character to this product, for it also consists of hydrocarbons. The difference is that the hydrocarbons which constitute natural gas are more volatile than the bulk of those found in petroleum, so much so that they are not liquid under ordinary conditions. Natural gas, being inflammable, can be used as a fuel, and as such it is a source of power. In districts where it occurs in large quantities, Pennsylvania for instance, it is extensively used to produce both heat and light, and in some parts the manufacture of coal gas for these purposes is superfluous.

England, while in no sense an oil-bearing country like Russia or the United States, can furnish an instance of a natural gas well. At Heathfield, in Sussex, there is a supply which, although of small dimensions compared with the Pennsylvania wells, has proved wonderfully steady. The gas was discovered first in 1893, in the course of boring operations carried out with the object of obtaining water, and it has been regularly used in the neighbourhood, chiefly for lighting the railway

station. The gas-supply was tapped at a depth of 200-300 feet, and the pressure behind it must have been considerable, for ignition of the gas gave a flame 16 feet high!



Photo—C. Dawson, F.R.G.S.

FIG. 16.—Burning natural gas at Heathfield, Sussex.

It is perhaps premature to trouble our minds with a problem which is really one for the men of science of the distant future, but it is at least interesting to enquire what could be done

supposing the supplies of natural fuel—coal, peat, petroleum, natural gas—were to run out. How could these sources of power be replaced? So far as we can see at present, the most promising course would be to produce large quantities of alcohol. Experience has shown that this substance can be used instead of petrol in driving an engine, and it can be obtained with comparative ease from the starch and sugar constituents of potatoes, wheat, beetroot, rice, and similar substances. By growing these common products of the soil, therefore, it is possible to obtain a substitute for the natural fuels. At the present time, however, the natural fuels are both abundant and cheap, and the use of alcohol as a source of power is excluded by its price.

CHAPTER V

SECONDARY FUELS

MAN has not been content to use the natural fuels just as he gets them from Mother Earth. He subjects them to various processes in order to convert them into forms more convenient for his different purposes. In the last chapter we have seen that crude petroleum is separated into a number of portions before it comes on the market, and some-

thing of the same sort is done with coal. The chief motives for this further treatment of the natural product are convenience and economy, and it is interesting to note how these have stimulated the invention and manufacture of artificial forms of fuel.

One of the oldest and most important of these secondary fuels is coal gas. This was originally used for purposes of illumination only, but at the present day it is extensively employed also as a source of heat. Coal gas is obtained by the "destructive distillation" of coal. This phrase sounds highly technical, but it simply means heating the coal strongly in a vessel or retort, closed except for one comparatively narrow exit, through which pass the products of the heating. Destructive distillation may be carried out on a small scale by packing the bowl of a clay tobacco pipe with coal, stopping up the mouth with clay, and putting the bowl in a fire so that the pipe stem projects. Smoke immediately begins to come from the end of the stem, and presently the issuing gas, if a light is brought to it, will take fire and continue burning with a bright flame. Any one who makes this simple experiment is producing coal gas.

That an inflammable vapour is obtained when coal is strongly heated was known about the end of the seventeenth century, for a certain Rev. John Clayton, who lived in Yorkshire about that time,

has left it on record that he distilled some coal in a retort in an open fire. He tells us that "at first there came over only phlegm, afterwards a black oil, and then likewise a spirit arose which I could noways condense." With this "spirit of coals," coal gas as we should call it, he filled a number of bladders; and he subsequently amused his friends by pricking holes in the bladders and lighting the gas as it escaped.

These experiments and others of a similar kind made by later investigators did not, however, lead to any practical application of coal gas for lighting purposes. For more than a hundred years after Clayton's time people continued to depend on oils and tallow as illuminants. It was left for a Scotsman, William Murdoch by name, to show what could be done with coal gas on a large scale. In 1792 he was staying in Cornwall, and employed his leisure time in experimenting with coal gas in a back yard. He succeeded in putting together a small apparatus from which he obtained enough gas to light his own house. Later, Murdoch was transferred to a firm near Birmingham, and there he continued his experiments. Finally, about ten years after he began his investigations, he was commissioned to light a cotton mill with coal gas, and this gave an opportunity of demonstrating clearly the great value and practical utility of his discovery.

In the *Philosophical Transactions* of the Royal Society for 1808 there appears a paper in which Murdoch describes the manufacture and use of coal gas, and proves its greater economy as compared with oils and tallow.

To the people of that time the wonderful thing about the coal gas flame was that it required no wick, as did the lamps and candles then in universal use. Many, indeed, thought there was something uncanny about coal gas, and considered it quite dangerous to light a gas lamp. There was in fact much prejudice against the new illuminant, but once a practical demonstration had been given of its great utility and convenience, it found favour rapidly. One side of Pall Mall was lighted with gas in 1807, and in 1810 the first gas company was started in London. In the nineteenth century the gas industry increased by leaps and bounds, and at the present time something like fifteen million tons of coal are used up in England every year for the purpose of gas manufacture. In recent times electricity has become a formidable competitor, but the invention of the incandescent mantle, the introduction of penny-in-the-slot meters, and the extended use of coal gas for heating purposes have combined to help the older industry.

The destructive distillation of coal was carried out by Murdoch for the sake of the gas which

was produced in the process. Other products are obtained also, but these were little considered in the early days. The distillate collecting in the tubes leading from the retorts, especially in the so-called "condensers" and "scrubber," consists (1) of tar, (2) of a watery liquid containing notable quantities of ammonia. We shall see in a

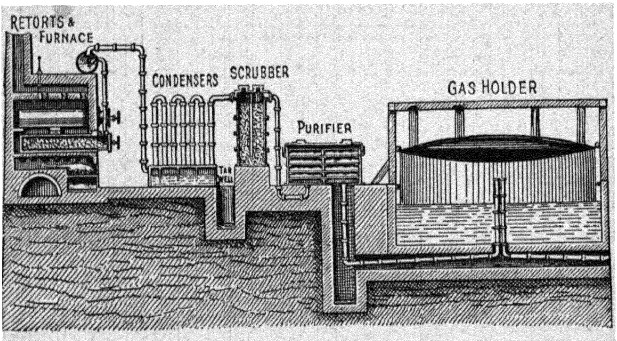


FIG. 17.—The manufacture of coal gas.

later chapter what can be done with these by-products, but in any case they do not count as fuels. In Murdoch's time there was no market either for the tar or the ammoniacal liquor; no useful purpose was then known for which they could be applied.

The coke, however, left in the retorts after the volatile constituents of the coal had been driven off, had a distinct value and could be sold as fuel. At the present day part of the coke is kept at the

gas-works and is utilised in the heating of the retorts. The rest is sold, chiefly for domestic use. Rather more than a ton and a half of coal is

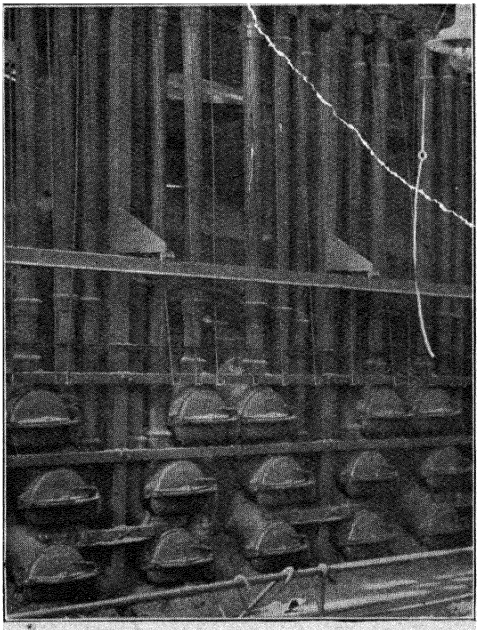


FIG. 18.—Gas retorts.

required to yield a ton of coke, and the latter material contains a considerably higher proportion of carbon than the coal. Gas coke, as the reader probably knows, is much harder to ignite than ordinary coal, and when once started, it burns with a smokeless flame.

Curiously enough, the destructive distillation of coal was carried on in England before Murdoch's time, but with the sole object of preparing coke, no attention being paid to the gas. The coke was required as a substitute for charcoal. Even by the middle of the eighteenth century the scarcity of wood was beginning to be felt in England and the price of charcoal was therefore rising. Now up to about that time iron manufacturers regularly used charcoal in the blast furnace in order to reduce the metal from its ores. It must be remembered that iron ores consist largely of the oxide of the metal, and that the chemical union between iron and oxygen breaks down when the oxide is heated with carbon. The oxygen prefers the carbon, and the iron is, therefore, left in the free metallic condition.

Iron manufacturers, then, are dependent on getting carbon in some form to put into the blast furnace along with the iron ore, and until about the middle of the eighteenth century wood charcoal was used for the purpose. In view, however, of the increasing cost of charcoal, the iron manufacturers began to cast about for a substitute, and thus it was that the production of coke from coal was initiated. Not only in the smelting of iron, but in metallurgical operations generally, that is, in the preparation of metals from their ores, large quantities of coke are required, and with the advance of the nineteenth

century the demand for this material rapidly increased. It is said that by about 1860 wood charcoal for metallurgical purposes had been completely displaced by coke throughout Europe, except in Sweden, Russia, and Austria, where want of coal or abundance of wood justified the continuance of the older practice.

At the present day in England ten to twenty million tons of coke are made from coal every year specially for use in metallurgical operations. The ovens in which this coke is prepared are heated either to a higher temperature or for a longer time than are the retorts in gas-works, and the result is that oven coke, as it is called, is more compact than gas coke.

For many technical purposes gaseous fuel is more convenient than solid fuel, and much ingenuity has been expended in devising methods of producing other combustible gases than coal gas. It is an interesting fact that by passing a current of steam over coke or hard coal heated to incandescence, a combustible vapour is obtained. This discovery was made long ago, but, as in so many other cases, it was a long time before the discovery was applied on the large scale to serve industrial purposes. The combustible vapour produced by passing steam through strongly heated coke or hard coal is known as "water gas," a name which has reference to the fact that water is required

for its production, and must not be understood as meaning that the gas consists of the vapour of water: this, of course, would not be combustible.

Water gas is a mixture consisting mainly of hydrogen and carbon monoxide, both of which are inflammable. It is perhaps desirable to point out that carbon unites chemically with oxygen in more than one proportion, and while the better known oxide of carbon, namely, carbon dioxide, is not combustible, carbon monoxide burns readily with a bluish flame. The interesting production of water gas from steam and coke depends on the fact that at a high temperature oxygen has more affinity for carbon than for hydrogen. Hence, under the conditions mentioned, the steam loses its oxygen and becomes hydrogen, while the carbon of the coke is converted into carbon monoxide. This means that a solid fuel is converted, partly at least, into a gaseous fuel, which, as already stated, presents many advantages in certain cases.

If water gas is to be used for lighting purposes, it must be "enriched," for, alone, it burns with a non-luminous flame. The enrichment consists in vaporising some oil and thoroughly mixing it with the water gas. This treatment confers luminosity on the flame and imparts a smell to the gas. Enrichment of this kind yields a product which is known as "carburetted" water gas, and is much safer than

the original. Carbon monoxide is a deadly poison, and gives no warning of its presence in the atmosphere of a room, for it has no smell. An escape of coal gas, which also contains carbon monoxide, and is, therefore, highly poisonous, is readily detected by its odour, and people are warned of the danger at once. Water gas, on the other hand, is itself free from smell, and its escape may not be noticed until too late. In the process of enrichment, however, it acquires a smell, and hence, from the public point of view, carburetted water gas is a much safer fuel.

In the United States of America carburetted water gas has come into great favour, and represents more than two-thirds of the illuminating gas supplied to the public. If one were to judge from the increasing number of deaths due to gas poisoning in that country, it would seem that the use of carburetted water gas for domestic purposes is not without its dangers. These facts, and the rapidly increasing manufacture of carburetted water gas in England, led some time ago to a Government enquiry into the whole matter. It was found that in this country it is not the practice to distribute pure carburetted water gas, but only to mix it with coal gas; the danger arising from leakages, therefore, is correspondingly less. It must be clearly understood that it is only when water gas

escapes unconsumed that danger arises. When it is burned the hydrogen is converted into water, and the carbon monoxide, the dangerous constituent, into carbon dioxide.

Chemists have shown that there is still another way in which a solid fuel may be converted into gaseous fuel, and that is by passing a current of air through a column of heated coke. At the end of the column where the air enters, the carbon combines with the oxygen to form carbon dioxide, but this compound, as it is swept forward through the rest of the heated column, gives up half of its oxygen to the coke, and carbon monoxide is formed. As we have already seen, this is a combustible gas and can be used as fuel. It is necessary, however, to remember that the carbon monoxide escaping from the column of coke will be mixed with the nitrogen of the air which was sent in at the other end, and which passes through unaltered. Nitrogen is not combustible, and hence the gaseous fuel obtained by passing a current of air through a column of heated coke, "generator gas" or "producer gas" as it is called, has a low heat value. But it is very cheaply made, and serves as an excellent fuel for glass melting, brick burning, the heating of gas retorts and similar operations. Producer gas, either alone or mixed with water gas, is indeed a fuel of great importance in the modern industrial world.

Another secondary fuel which is of considerable importance is the paraffin oil obtained by destructive distillation of the shale found in certain parts of Scotland, notably Linlithgow and Midlothian. This interesting mineral, described more fully as "bituminous shale," is charged with carbonaceous matter, and differs from coal in having a very much higher proportion of "ash" or incombustible residue. In ordinary coal the ash, or mineral matter, amounts on the average to 4 or 5 per cent; in shale, on the other hand, the proportion is 70 per cent or over. When the shale is subjected to destructive distillation in retorts it yields an oil from which paraffin, as well as other products, is obtained. The paraffin does not exist as such in the shale, but is produced at a high temperature from the carbonaceous matter present in the mineral. Paraffin is obtained also from American petroleum, but there it exists as such in the natural product.

Much more might be written about secondary fuels, and the interesting ways in which we have learned to manipulate the various forms of combustible material. Enough, however, has been said to show the reader that a vast amount of labour and ingenuity has been expended and is being expended to-day on the satisfactory utilisation of Nature's fuel resources. Urged by reasons of economy or convenience, men have learned to convert

the natural product into the form best suited for each particular object, and waste of power is more and more avoided. Indeed, it may be said that any industrial operation which depends on the use of fuel, but in which the fuel is not economically used, will before long be entirely superseded.

It is worth while noting also that the technical processes connected with the transformation of natural fuel have been rendered possible only by the co-operation of the chemist and the engineer. Very often it happens that a chemical change which proceeds easily and smoothly in the laboratory presents difficulties when an attempt is made to carry it out on the big scale in a factory. The construction of furnaces and the handling of large quantities of material require a knowledge and experience beyond that possessed by the laboratory chemist, and the engineer has to be called in. It is only by their co-operation that many of the problems of manufacturing chemistry have been solved.

CHAPTER VI

CHEMISTRY AND THE SAFETY OF HUMAN LIFE

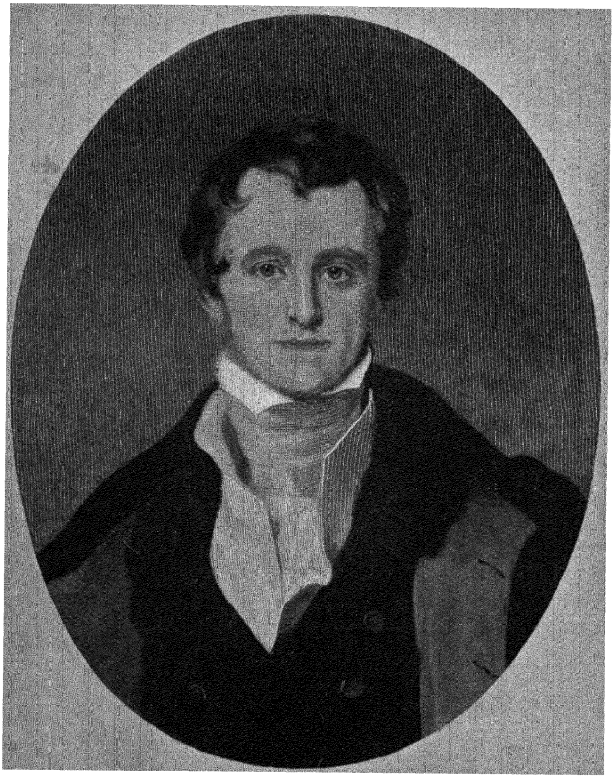
THE last two chapters have shown to what an enormous extent we are drawing on Nature's stores of fuel, and how varied are the ways in which this

fuel is treated in order to make it serve the needs of our modern civilised life. All this adaptation of natural resources, whether of fuel or of anything else, means a vast amount of labour and very often involves risk to those more immediately concerned. For it may happen that some most valuable and useful material can be produced only at the price of human lives, or that the manufacture of some article demanded by the modern world leads to ill-health among the workpeople.

The remarkable widening of social and industrial life which the last hundred years have witnessed has led to many cases of this kind, and these unfortunate results of the increasing demand for comforts and conveniences of every kind have very frequently been traced to subtle agencies of a chemical nature. The chemist, therefore, has often to deal with problems affecting the conditions of work in certain dangerous trades, and is called upon to suggest steps which shall secure the safety of the workers without unnecessary disturbance of the trade itself.

Perhaps the most striking example of such services to the toiling community has arisen in connection with coal-mining. About the beginning of last century public attention was much attracted to the disastrous explosions that so frequently occurred in coal mines. It has been stated that in

the North of England at that time these accidents



were becoming more frequent and more destructive every year. Accordingly a special committee was

formed at Sunderland to study the causes of these explosions and to search for means of preventing them, and this committee ultimately secured the help of the eminent chemist, Sir Humphry Davy. His efforts to solve the difficulty were rewarded with success, and it may safely be said that through his ingenuity the lives of many thousands of miners have been saved.

In order to appreciate the services which Davy has rendered to humanity, the reader must understand clearly how explosions in coal mines are brought about. It is well known that in the process of working coal underground an inflammable invisible gas is given off. Davy himself showed that, when large lumps of coal are broken under water, bubbles of a combustible vapour rise to the surface. This gas is commonly called "marsh gas," since it is produced also when vegetable matter decays under water; it is the chief constituent of the bubbles that rise when a stagnant marshy pool is stirred up with a stick. The miner, however, calls it "fire-damp." It is not only the breaking of the coal that gives rise to the escape of fire-damp; it frequently issues in considerable quantities from some hidden reservoir through fissures in the strata.

Now the accumulation of this inflammable gas in the mine is exceedingly dangerous, for in certain

proportions with air it forms an explosive mixture. The introduction of a naked light into such an explosive atmosphere has, of course, disastrous results. Even with good ventilation it is not always possible to avoid the collection of fire-damp in dangerous proportions, and it is plain, therefore, that the most hopeful way of tackling the difficulty is to deal with the method of lighting the mine.

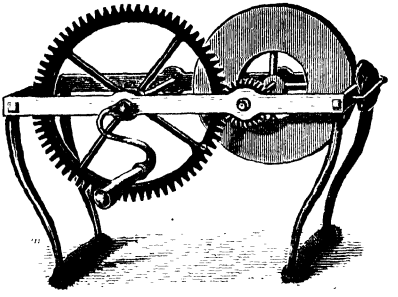


FIG. 19*a*.—Flint and steel wheel formerly used for illuminating coal mines.

At the time when Davy took up the problem, it was the custom to use candles or oil lamps, except that in parts of a mine where danger from fire-damp was apprehended light was produced by revolving a steel wheel in contact with flint. The sparks produced in this way furnished a very unsatisfactory illumination, but did not explode a mixture of fire-damp and air so readily as a common candle flame. This method of lighting, however, was not entirely free from danger, and the turning of the wheel required extra labour.

In the course of his experiments Sir Humphry Davy made the interesting observation that it is

very difficult for a flame to pass across a piece of wire gauze. It is, indeed, easy for any one to prove this. If a piece of copper-wire gauze is pressed down on a coal-gas flame, the latter is extinguished above the gauze while continuing to burn below. The extinction of the flame is not due to want of combustible gas, for if a lighted match is brought to the upper side of the gauze the unburnt gas immediately catches fire. Further, if a piece of gauze is held an inch or two above a burner from which coal gas is issuing, the gas above the gauze can be lit without the flame passing through to the lower side. The explanation is that copper-wire gauze is a first-rate heat conductor, and dissipates the heat of the flame so rapidly that on the further side the temperature is below the point of ignition.

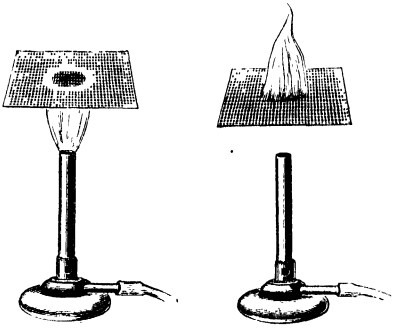


FIG. 20.—To illustrate Davy's experiments.

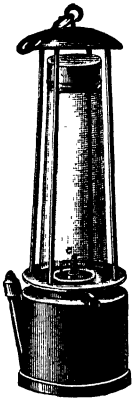


FIG. 21. Davy lamp.

These observations led Davy to suggest that

the flame of the miner's lamp should be surrounded with wire gauze, and actual experience showed that this device very much reduced the risk of explosions in coal mines. As a rule, a lamp of this kind may safely be taken into an atmosphere which contains fire-damp and air in dangerous proportions. The explosive mixture passes through the gauze and burns inside the lamp, so warning the miner of the presence of fire-damp. The gauze, however, stops the passage of the flame to the surrounding atmosphere, unless there is a very strong draught, in which case the flame may be blown through the gauze and ignite the explosive mixture outside.

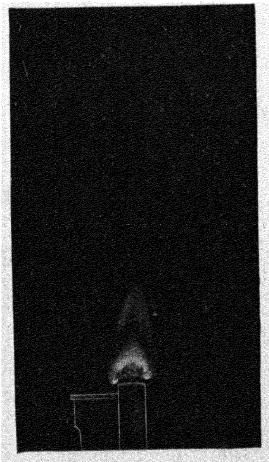
Experience has led to some modifications of the Davy lamp. A short glass cylinder is now put round the actual flame, and the wire gauze comes only higher up. The modern safety lamp is fitted also with an iron bonnet round about the gauze in order to afford protection from draughts.

It has been said above that when a Davy lamp is taken into an atmosphere containing fire-damp, the latter enters the lamp and burns there. The burning fire-damp presents the appearance of a so-called "cap" of pale blue flame, above the ordinary flame of the lamp. This fact has been made the basis of an interesting method for detecting fire-damp and estimating its amount. In the most

recent apparatus for this purpose a sort of safety lamp is employed, in which hydrogen or naphtha is burned. The "cap" which appears when this lamp is taken into an atmosphere containing fire-damp is more easily seen than in the ordinary form of safety lamp, for the hydrogen flame is less luminous than that of burning oil. The interesting point is that the length of



4 per cent marsh gas.



2 per cent marsh gas.



1 per cent marsh gas.

FIG. 22.—Flame caps.

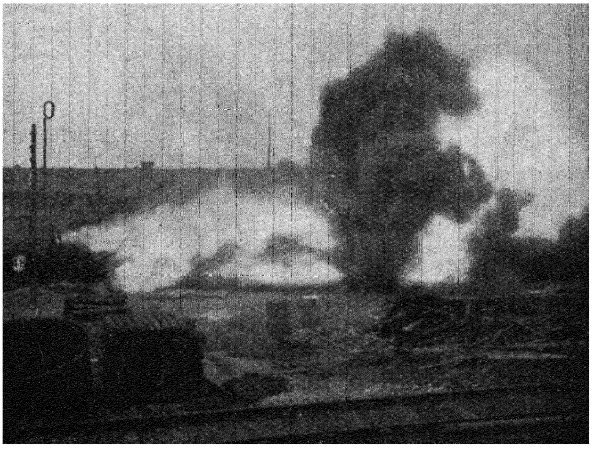
(By permission of the Wolf Safety Lamp Co.)

the "cap" increases with the amount of fire-damp, and such a lamp serves, therefore, to indicate the percentage of this dangerous gas in any atmosphere.

The extended introduction of safety lamps, coupled with improved ventilation and regulations regarding the use of explosives, has very much diminished the mortality from explosions in coal mines. The annual death-rate from this cause in the United Kingdom has during the last fifty years fallen from about 128 per hundred thousand persons employed to about 10. Yet every now and then some disastrous colliery explosion occurs to remind us that we are not yet masters of the situation, that science has still much to do on behalf of the toilers underground. The truth is that something else besides fire-damp may be concerned in bringing about such mishaps; and that is coal dust.

The atmosphere of a colliery, especially a dry one, is full of finely divided particles of coal, raised by the constant traffic along the underground roadways. Until comparatively recent times, however, most people refused to believe that coal dust was a source of danger in collieries, although it had been proved experimentally that such dust, along with a small proportion of fire-damp, was dangerously inflammable. But even the sceptics were aroused by the terrible disaster at Courrières

in France in 1906, a disaster which cost 1100 lives. It was generally admitted that this explosion was due to coal dust alone, and everybody now recognises the need for scientific study of this problem.



Photo—W. E. Garforth.

FIG. 23.—A coal-dust explosion at an experimental gallery, Altofts, Yorkshire.

Not only in France, but also in this country, experimental galleries for the production and study of explosions have been erected, and we may hope that before long the influence of coal dust in causing and propagating explosions will be thoroughly understood. Already it has been clearly proved that, even in the absence of fire-damp, a

mixture of coal dust and air can be exploded by the firing of a dynamite cartridge.

In this connection it is interesting to recall the curious explosions which have sometimes occurred in flour mills, and have been traced to the explosive character of a mixture of flour dust and air. Some forty years ago there was a disastrous explosion in a Glasgow flour mill, as a result of which the building was wrecked and several persons were killed. It turned out on subsequent investigation that the "feed" of wheat to the grinding stones had stopped for a little, and that a spark produced by the friction of the stones on one another had ignited the mixture of fine flour dust and air which was in the vicinity.

Another problem which science has had to solve in connection with colliery explosions is the foul atmosphere prevailing in the mine after such disasters. The gas remaining in a mine at the place where an explosion has occurred is known as "after-damp," and is extremely poisonous owing to the fact that it contains carbon monoxide. If the fire-damp or coal dust involved in an explosion underwent complete combustion, the only oxide of carbon that would be found in the air of the mine subsequently would be carbon dioxide, which is not an actively poisonous gas. It generally happens, however, that the combustion of the fire-damp or coal dust is

incomplete, with the result that the carbon is less highly oxidised and carbon monoxide is formed.

This gas has no smell, or colour, or any irritating properties by which it may be recognised, but it is nevertheless a deadly poison. Air containing only two or three parts of carbon monoxide per thousand would lead to the death of any person who breathed it for a time. Now the after-damp of a colliery explosion contains twenty to fifty parts of carbon monoxide per thousand, and it is evident that the miners involved in such an explosion have little chance of escape, even although they may not be injured by the explosion itself. It is estimated that the majority of the victims in these disasters are not burned, but poisoned.

In view of these facts, it is obviously very dangerous for any one to enter a colliery after an explosion has taken place, and the work of searching for possible survivors and of bringing out the bodies of the dead is full of risk. This difficulty, however, has been successfully overcome by science. Apparatus has been devised which provides each member of a search or rescue party with his own atmosphere, and cuts him off from the poisonous air round about him. Such apparatus naturally is based on a knowledge of the chemistry of breathing.

This matter has been dealt with in the first chapter, but it may be well to remind the reader that

in respiration a supply of oxygen is necessary, and that the carbon dioxide produced must not be allowed to accumulate. These points are duly attended to in the construction of rescue apparatus for use in mines. The mouth and nostrils are connected by means of tubes with cylinders of compressed oxygen gas, carried on the back, and with an air bag strapped in front of the bearer.

This bag contains a quantity of caustic soda, a substance which absorbs carbon dioxide with great readiness. The air expired by the wearer of the apparatus passes into the bag and is there deprived of the carbon dioxide which it contains, while the oxygen consumed in the process of breathing is replaced by a fresh supply from the cylinders. This portable respirating apparatus is entirely self-contained; the person provided with it is independent of the surrounding atmosphere, and may venture safely into places charged with foul and deadly vapours.

The efforts, then, of chemists and other men of science have much diminished the dangers from fire and poison that lurk in the coal-pit, but the risks are still there. It is well for those who sit cosily at their own fireside, or travel swiftly through the country in an express train, to remember that these comforts and conveniences are procured at the risk of human lives. Reflection will show, indeed, that

the production of many things which we take as a matter of course in these modern days may involve injury to the workman who produces them.

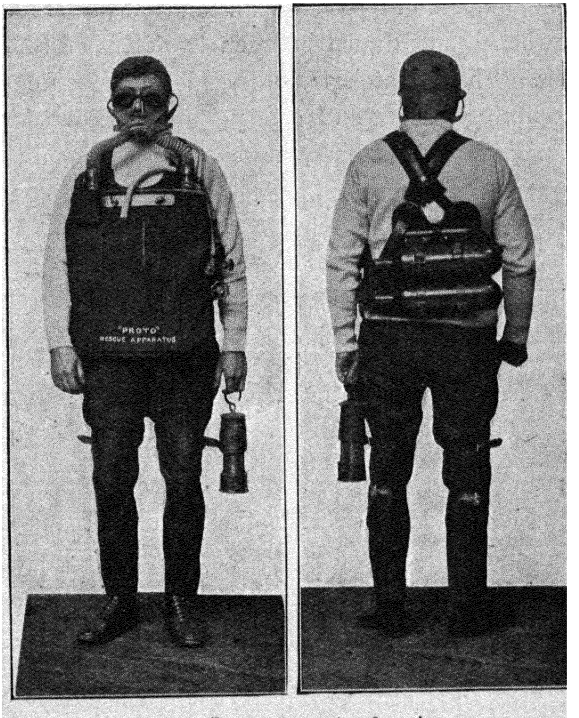


FIG. 24.—Rescue apparatus for mines.

How lost we should feel ourselves if all at once we were without lucifer matches! Yet it is not so very long ago since this wonderfully convenient way of making fire was discovered. Only a little

more than eighty years ago the first really efficient matches were produced in England. They were made of wooden splints or bits of cardboard covered with sulphur and tipped with a mixture which took fire when it was drawn between two folds of sand-paper. These matches were sold at the rate of one shilling per box of eighty-four! The modern manufacture of matches, however, dates from the time when phosphorus was first used in the tipping mixture. From one point of view this was a great advance, from another it was the introduction of a sinister factor into the match industry.

The element phosphorus has been known for two hundred and fifty years. It is a whitish or yellowish waxy solid, and has such affinity for oxygen that it must be kept out of contact with air; under water, for example. It melts in warm water, it is volatile even at the ordinary temperature, and if exposed to air gives off vapour. Phosphorus catches fire with great readiness, and is very poisonous. The ease with which it is ignited explains its usefulness in the match industry, for mere friction suffices to set it on fire; and hence a match tipped with a mixture containing 5 to 10 per cent of phosphorus will strike anywhere. This is obviously a great convenience, although at the same time it means a certain risk of fire.

Experience of these "strike-anywhere" matches soon showed, however, that there were other and more subtle dangers involved in their manufacture and use. The highly poisonous nature of yellow phosphorus, alluded to above, betrayed itself in the form of disease among the match factory workers. Those persons more especially who were concerned in tipping the matches with the phosphorus composition were liable to a serious malady known as "phossy jaw," one of the marks of which is inflammation and decay of the jaw-bone. The workers also who put the matches in boxes were exposed to the risk of the same disease. It is true that good ventilation and insistence on cleanliness on the part of the workers did much to lessen the dangers of the match industry, but even during the last twenty years of the nineteenth century there were in this country nineteen fatal cases of phosphorus poisoning, besides a much larger number of cases where the disease occurred but was more or less successfully treated.

The manufacture of matches containing yellow phosphorus was obviously, in view of the facts just mentioned, a case in which public convenience was in conflict with the interests of the workpeople, and the difficulty was long realised as serious. The real attempts that have been made to solve the problem date back to the year 1845, when another

variety of phosphorus was discovered. This element has, as it were, a double identity, and exists not only in the yellow, poisonous, easily inflammable and vaporisable form already described, but also as a red, non-poisonous, non-volatile substance, which cannot be ignited by friction on any rough surface. In order to set fire to red phosphorus it must be rubbed on a place where there are substances rich in oxygen, such as chlorate of potash or red lead.

This red phosphorus can be produced easily from the yellow variety under certain conditions, and the proposal was therefore made that in the manufacture of matches the red non-poisonous form should take the place of the other. This led to the production of "safety" matches, which are devoid of yellow phosphorus and accordingly will not strike except on a specially prepared surface. In reality the red phosphorus is not in the head of the safety match itself but in the brown layer pasted on the side of the box.

The fact, however, that safety matches cannot be struck on any random surface, combined with the conservative habits of the British people, was against their general use in this country, although this would have led to the better health of the workers in the match industry. It has been stated that about 1900 only three or four tons of red phosphorus were used annually in the preparation

of safety matches in Britain, while as much as sixty tons of the yellow variety was turned into the ordinary strike-anywhere matches.

Another step in the solution of the problem has been made recently by the discovery of a suitable tipping composition which contains no free phosphorus, but a compound of phosphorus and sulphur. This sulphide of phosphorus is non-poisonous, and matches tipped with a paste containing it will strike anywhere. It is now possible, therefore, to get rid of the one disadvantage of safety matches and at the same time to avoid the risks involved in the use of yellow phosphorus. Largely on the strength of this discovery there has arisen in Europe, during the last ten years, a powerful movement in favour of prohibiting altogether the use of yellow phosphorus in the manufacture of matches. In Britain the movement has resulted in an Act of Parliament which prohibits both the making and the importation of matches containing yellow phosphorus. We may hope, therefore, that "phossy jaw" will soon be a disease of merely historical interest.

Another element that has an evil reputation in connection with the health of the community is lead. This material, either by itself or in the form of its compounds, is utilised in many different ways in modern life, but in certain circumstances it may give rise to serious ill-health. If even minute

quantities of lead in the form of its more soluble compounds are taken into the system, cumulative poisoning follows, showing itself in severe stomach pains, loss of appetite, nervous prostration, and even paralysis.

Lead poisoning is occasionally brought about through the agency of drinking water. Everybody knows that lead pipes are extensively used for the conveyance of water, and it has been found that certain waters, especially those of moorland origin, have the power of dissolving lead. It is well, therefore, to avoid the employment of great lengths of lead piping for carrying water, and lead cisterns are not to be recommended.

One of the commercially most important and valuable derivatives of lead is the carbonate, known commonly as white lead. This substance is a very fine white powder and is in great demand in both paint and pottery manufacture. The making of white lead is fraught with considerable danger to the workers, for in some of the processes there is abundant opportunity for dust or fumes containing lead to gain access to the system. These risks have long been known, and there is no doubt that careful attention to the ventilation of the factories and to the personal condition of the workers has done great good.

The question has also been raised whether there

is any other substance which would be as good as white lead from the painter's point of view, and yet would be less objectionable on health grounds. Oxide of zinc (*i.e.* a compound of the metal zinc with oxygen) has been recommended, and although some architects and builders hold that this material is inferior to white lead, there is no doubt that it is at least a very efficient substitute. It is noteworthy that a law has recently been enacted in France according to which it will, after a certain number of years, be illegal to use white lead for any painting whatsoever. This shows how public interest has been enlisted on behalf of the workers in the white lead industry, and it is probable that other European countries will follow the example of France at no distant date.

Much discussion has taken place in England of late years in regard to the use of lead compounds in the pottery trade. The glaze on china and earthenware is obtained by dipping the articles in a creamy liquid containing lead carbonate, and then drying and firing. In the course of the firing the glaze is fused by the heat and forms the glassy surface we are accustomed to see on china and earthenware goods. The operations, however, connected with the production of this glaze have resulted in the constant occurrence of lead poisoning in the potteries.

It is another instance of a conflict between the demands of modern life and the interests of the workers. Alterations, it is true, have been made in the method of preparing the glazes, and these have led to a marked reduction in the number of cases of poisoning. Efforts to find a substitute for lead have not been entirely successful, although encouraging progress has been made in this direction. Pottery made with leadless glaze is on the market, but this glaze is not suitable for every kind of article. We may be confident, however, that in the course of time science will succeed in reconciling the health interests of the workers with the demand for the best glaze that can be produced.

It will be apparent from what has been said in the foregoing pages that in drawing upon natural resources, and in making from these the various products required in modern civilised life, we frequently encounter difficulties of a very subtle kind. Each industry has its own peculiar risks, and it is part of the work of the man of science, not only to discover new products and invent new processes which shall be a boon to the community as a whole, but also to suggest means of safeguarding the industrial workers who serve the community.

CHAPTER VII

RAW MATERIALS, REFUSE, AND BY-PRODUCTS

NATURE supplies a large number of things ready-made for the use of man. Coal, salt, oil, and sugar are examples of products which have only to be mined, or otherwise extracted from their natural surroundings, in order that they shall be available for human purposes. In a very great number of cases, however, the substances required for the manifold objects of industrial and social life are not so easily obtained; they may not occur in nature at all or only in very small quantity, so that they have to be made from certain raw materials found here and there over the surface of the globe. The smelting of iron and other metals, the burning of limestone, the manufacture of soap, soda, coal gas, and dye-stuffs, are examples of chemical industries in which raw materials are converted by various artificial processes into useful products.

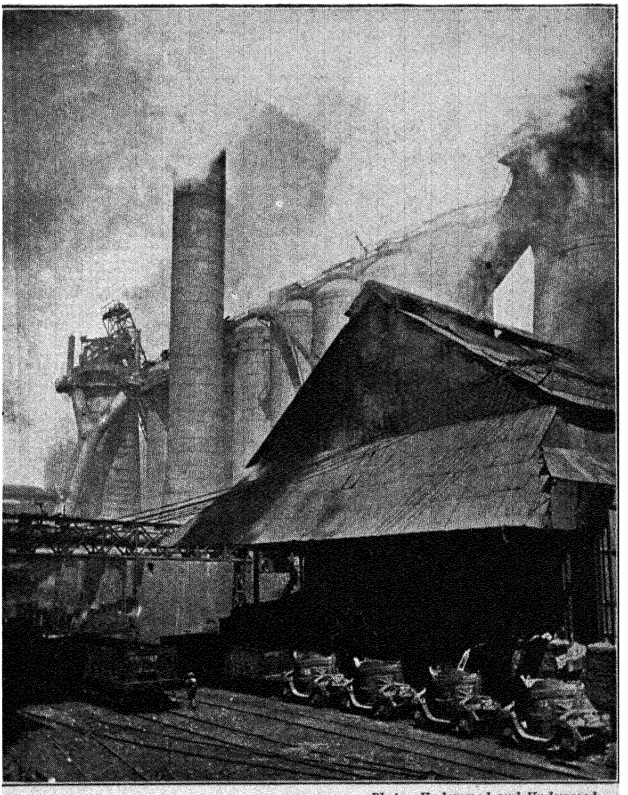
It is not easy to picture modern life in any civilised country without iron. The quantity of the metal required for bridges and ships, on railways, and in the manufacture of all sorts of machinery, is enormous, and in Great Britain alone countless blast furnaces are worked night and day for the

supply of this demand. Iron is not to be had for the picking up, as gold is in certain parts of the world; some meteorites, it is true, are largely composed of metallic iron, but it will be evident even to the uninitiated that this source of the metal cannot have any commercial importance.

There are, however, in the earth's crust very large quantities of iron in a state of chemical combination with oxygen or sulphur, and these compounds, mixed naturally with earthy matter and other minerals, constitute the "ores" of iron. The sulphur ores cannot be used directly for the production of iron, but the principle of the method by which the metal is obtained from its oxide in the blast furnace is very simple. The ore containing the compound of iron and oxygen is mixed with coke: in the furnace this coke is partially burned by a blast of hot air, and the carbon monoxide thus produced deprives the iron of its oxygen, so that the metal is left in the free state and can be run out in the molten condition.

Reference has been made already to the burning of limestone as a chemical industry. As everybody knows, limestone is found in enormous deposits in the earth's crust, and it must be borne in mind that chalk and marble are varieties of the same substance. Its chemical name is carbonate of lime, or calcium carbonate, and the application of

strong heat causes it to break up into calcium oxide, or quicklime, and carbon dioxide, which escapes as



Photo—Underwood and Underwood.

FIG. 25.—Red-hot iron flowing from a blast furnace, Pittsburg, Penn.

a gas. The "burning" of limestone is not to be taken literally, for the process consists only in the

strong heating of the raw material in kilns; the lime itself does not burn. The product of this industry, quicklime, and slaked lime obtained from it, are in great demand. This is connected with the fact that alkalis, which are the opposite of acids

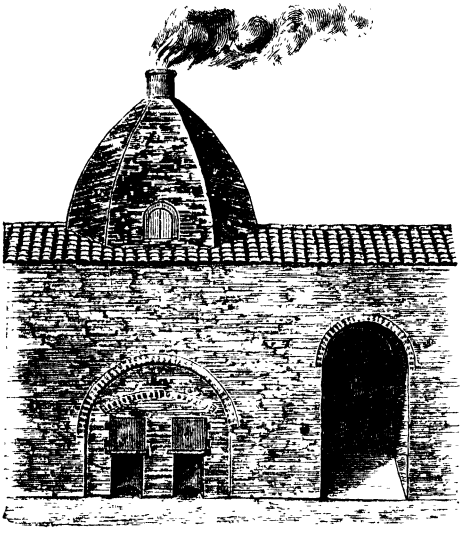


FIG. 26.—Lime kiln (front view).

and neutralise them to form salts, are required for many technical processes. Lime is the cheapest alkaline substance, and, besides being used in mortar and cement, is employed, for instance, in the manufacture of glass, and in the treatment of fats for the production of candles.

So with the other chemical industries quoted above: in each case certain naturally occurring substances, the raw materials, are treated in such a way as to give rise to various useful products. At the same time, however, other things are produced

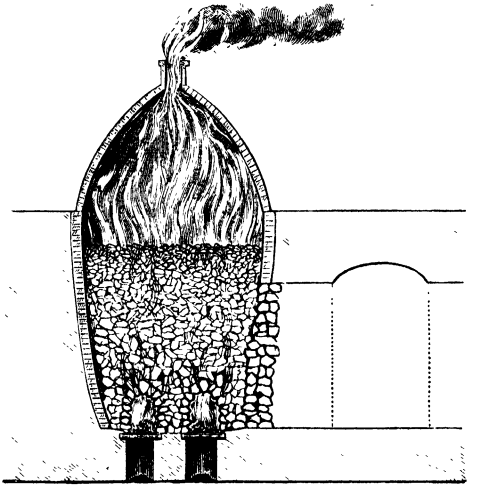


FIG. 27.—Lime kiln (section).

besides the products which are the main object of the particular chemical industry in question, and the accumulation of these waste products is a frequent source of trouble and expense to the manufacturer.

As an example of this, the smelting of iron may be taken. It has already been stated that in

principle the conversion of iron oxide into iron with the help of coke in a blast furnace is a fairly simple matter. Iron ore, however, contains not only the oxide of the metal but a lot of earthy material as well. In order to get rid of the latter, limestone is fed into the furnace along with ore and coke; the lime produced from this at a high temperature unites with the earthy material of the ore and forms a fluid material known as "slag." Since it is lighter than iron, the slag floats on the surface of the molten metal and is run out of the furnace at an opening provided for the purpose. It becomes solid when it cools and then looks like something between glass and cinders. This unpromising material is the waste product of the iron-smelting industry, and if the modern world will have iron, it must take the slag also.

In the chief iron-making countries of the world about fifty million tons of blast-furnace slag are produced annually, and it is plain that the mere removal of such enormous quantities of rubbish must be a costly business. If the foundry is on the sea-coast the slag is generally loaded on barges, taken out to sea and tipped overboard. Where this method of disposing of the slag is not available, as in the Black Country, it is allowed to accumulate in vast, unsightly mounds. Blast furnace slag has got the name of "smelter's refuse,"

and these slag mounds are simply some of the rubbish heaps of our modern industrial civilisation.

The name "refuse" is, however, not quite so accurate a description of slag nowadays, for various ways have been devised whereby some, at least,

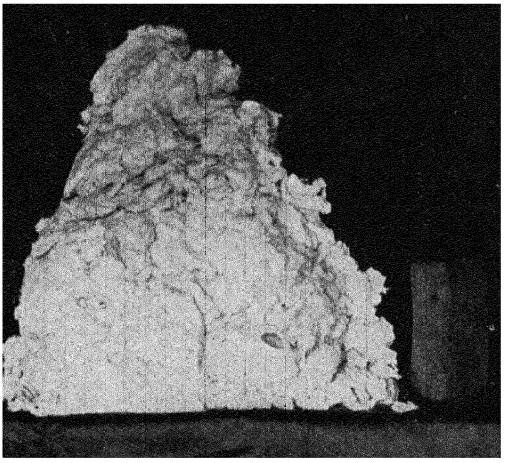


FIG. 28.—A block of slag and an equally heavy heap of slag wool.

of this waste product is turned to useful account. Large quantities are used in reclaiming land, in building breakwaters, and for packing between railway sleepers; much, too, is employed in the filter-beds which are required in the modern purification of sewage, while the making of cement and of slag wool are other directions in which this waste product of the blast furnace is utilised.

Slag wool is totally different in appearance from the original slag, and the method by which it is obtained is quite ingenious. A jet of steam is blown against the molten slag, with the result that small globules are produced, each with a long thread or tail adhering to it. These threads are so fine that in the mass they are like so much cotton wool, from which, however, the slag wool differs in one important respect. It is non-inflammable. Further, it is a bad conductor of heat, and so finds useful application in covering steam pipes and boilers. It is employed, too, between floors, for the purpose of deadening sound.

Another kind of slag, turned out from steel works, has useful properties as a manure. When pig-iron, contaminated with a small quantity of phosphorus, is used for the production of steel, the impurity is got rid of by a blast of air, which oxidises the phosphorus and converts it into phosphate. It appears in the slag as phosphate of lime, and it is the presence of this substance which makes "basic slag," as it is called, a valuable material for agricultural purposes.

There are other waste products of the blast furnace, not so obvious, it is true, as the slag, but none the less important from the point of view of economy. Thus the heat carried away with the slag is a distinct loss, for it must be remembered

that heat, although it cannot be weighed, costs money just as much as things which are more tangible. The waste in this direction is very considerable, for the slag is red hot when it is run out, and a single blast furnace may give from 500 to 1000 tons of slag in a week. It is possible, however, to utilise in various ways the heat of the molten slag. One plan, for instance, adopted in a foundry which was run in connection with a salt works, was to put the hot slag underneath the pans in which brine was being evaporated. This meant obviously that so much less fuel was required for the heating of the pans, and a saving was effected.

Then again, the gases produced in the blast-furnace by the chemical interaction of the air, the coke, and the iron ore are inflammable, owing mainly to the carbon monoxide which is present. At one time these gases were simply allowed to burn at the top of the furnace, but in up-to-date iron works they are led away in pipes and burned where they can do some good. Very often they are used to heat the air which is to be blown into the furnace, and this means that less fuel is necessary in the furnace itself. In other cases the gases are purified from dust and tarry matter and are then employed in gas engines.

It is clear, therefore, that in modern iron works

something which was previously allowed to escape is actually a source of power, and is made to contribute to the cost of the smelting process. The history of industry is, indeed, showing more and more clearly every year that any manufacturing concern which neglects such economies, and does not utilise all waste products to the utmost possible extent, is bound to go to the wall. In reality the success of a chemical industry depends to a large extent on the "by-products," that is on the substances, other than the main product, which crop up in the course of manufacture.

Perhaps the most striking and romantic example of the part played by the by-product in chemical manufacture is furnished by the history of the alkali trade in this country. Up to the end of the eighteenth century, potash (potassium carbonate), obtained from the ashes of burnt wood, was the more important and cheaper alkali, although soda (sodium carbonate) was known to occur in certain natural deposits in Egypt and was imported into Europe. The manufacture of potash tended, however, to become more and more costly as the forests disappeared, and the great demand for alkali led people to cast about for a cheap way of making soda instead of potash. That alkali was required in great and increasing quantities is intelligible, for the manufacture of both glass and soap, to mention

two examples, involves the use of this material in one form or another.

Now it was well known that sodium, the metal which enters into the composition of the compound sodium carbonate or soda, occurs most commonly in nature in combination with chlorine as sodium chloride (common salt). This substance is found in enormous quantities in sea-water and salt lakes, in brine springs and as rock-salt, and it was apparent that if a straightforward process for converting salt into soda could be devised, the product would be much cheaper than any alkali available at the time. With this in view, the French Academy of Sciences offered in 1775 a prize of £12,000 for a solution of the problem.

This stimulus led to a number of processes being suggested for the production of soda from common salt, but the only satisfactory one was that proposed by Leblanc. His name will always be remembered in connection with the foundation of the great soda industry, but he himself had little profit from the discovery. He never received the promised prize; the patent which he had been awarded in 1791 was taken from him in the stormy times that followed, he and his family were reduced to poverty, and ultimately, in disgust and despair, he took his own life.

In order that the fortunes of the Leblanc process

for manufacturing soda may be properly appreciated, it is necessary to know a little about the process itself. As already stated, the raw material of this manufacture is common salt, and in the first stage of the process this substance is heated with sulphuric acid—"oil of vitriol," as it is sometimes called. The result of this treatment is a chemical change by which two new substances are produced, namely, sulphate of soda or "salt cake," and hydrochloric acid. For the direct purpose of making carbonate of soda only the former of these is necessary, so in the early days of the industry the hydrochloric acid was a waste product. In one sense there was no difficulty in getting rid of it, for hydrochloric acid comes off as a gas when salt is heated with sulphuric acid; all that was required, therefore, was to provide the salt-cake furnace with a chimney up which the hydrochloric acid went of its own accord.

The results were startling. The acid fumes which belched forth from the chimneys of the alkali works brought devastation on the surrounding country. Not only was the neighbourhood of the works pervaded by a most objectionable odour, but everything made of iron was corroded and vegetation disappeared. Complaints were frequent, and alkali works were extremely unpopular institutions.

The manufacturers thought to remedy the

nuisance by building chimneys of enormous height, but hydrochloric acid is a vapour heavier than air, and the only result of these efforts was that the noxious gas descended on still wider areas. What was to be done? Soda was an industrial necessity, and yet the waste product of the first stage of the manufacturing process was an insufferable nuisance to the community. An interesting side-light is thrown on the position of matters during the early years of the Leblanc soda industry in this country by a patent, taken out in 1839, for the construction of *floating* salt-cake furnaces, which were to be towed out to sea when in operation, and there allowed to do their worst. The patent states that the object was "to remove entirely all deleterious vapour from the surface of vegetation." It is quaintly added, "the situation and distance from land at which the vessel must be moored when working will entirely depend upon the character of the coast, and upon the varying circumstances of the wind."

One device which promised to give relief, and was widely adopted, was to condense the fumes. Hydrochloric acid gas is very readily absorbed by water, and by passing the vapours from the salt-cake furnaces through towers packed with coke over which water was kept running, it was easy to condense practically the whole of the acid.

The adoption of this plan naturally meant a great improvement in the character of the atmosphere round the alkali works; but fresh difficulties arose, for the manufacturers were now left with enormous quantities of the acid solution on their hands.

There was very little market demand for this, and the only thing to do was to tip this fuming, corrosive liquid into the nearest stream. The result of this was to kill the fish, and those immediately interested in the streams naturally objected to such pollution of their waters. Disputes occurred constantly, and for many long years the alkali works continued to be a source of annoyance to the neighbourhood.

Yet, within a very short space of time, all this was changed, and the hydrochloric acid, which had been such a nuisance to everybody concerned, manufacturers and community alike, was all disposed of for useful purposes. What had been a cause of trouble became a source of profit, the waste product became a valuable by-product.

The history of this transformation shows very clearly how close is the connection and interdependence of various branches of industrial activity. One of the main causes which brought about the utilisation of the waste hydrochloric acid from alkali works was the increased demand for paper in the years following 1861, when the duty on paper was re-

pealed. Cotton and linen rags had up to that time served for the manufacture of paper, but in consequence of the increased demand, straw, wood, and esparto grass were now employed as raw materials. In the course of their conversion into paper these materials had to be bleached, and this was best done by the use of chlorine, which is directly obtainable from hydrochloric acid. The increased demand for paper goods was, therefore, a stimulus to the alkali manufacturers to avoid, so far as possible, the loss of any hydrochloric acid — the very substance which, at a somewhat earlier date, they would have given anything to be rid of.

The second stage in the manufacture of soda by Leblanc's process also brought trouble to the manufacturers in the shape of waste products. The salt cake, or sulphate of soda, obtained in the first part of the process, is mixed with limestone and coal dust and the mixture is heated in a furnace. The resulting product is known as "black ash," and consists chiefly of carbonate of soda and sulphide of lime. The former is the object of the whole manufacturing process, and may be dissolved out from the black ash by water. The insoluble portion, consisting chiefly of sulphide of lime, was for a long time simply a waste product, and as such was dumped down outside the alkali works. The manufacturers would have been glad to recover the

valuable sulphur which was thus locked up in the "alkali waste," but no method of doing this was known.

These heaps of alkali waste came to assume enormous proportions, as is quite intelligible when

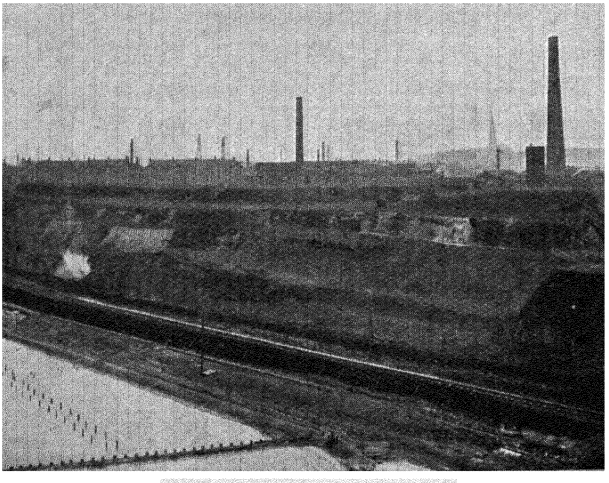


FIG. 29.—Heaps of alkali waste.

one takes into account the quantity of soda which is manufactured in England. One such heap, covering an area of 450 acres, was in 1888 receiving an addition of 1000 tons of alkali waste daily. These rubbish heaps were not only most unsightly, but under the influence of air and moisture they gave rise to a most objectionable odour, so that in a

second direction the alkali trade has been something of a public nuisance.

Science, however, has triumphed in the end and achieved a result which has benefited both the community and the manufacturer. Chemists have discovered a way of extracting the sulphur from alkali waste, and the heaps of this undesirable refuse are no longer increasing. With the removal of the sulphur from alkali waste, the objectionable qualities of the latter disappear, and it is gratifying to know that although we cannot dispose of the rubbish of the past, we are not accumulating fresh trouble for those who come after.

The recovery of the sulphur from alkali waste has been a great boon to the manufacturers of soda by the Leblanc process; for other ways of making soda have been discovered, and if the older method was to survive the stress of competition, it was absolutely necessary to avoid anything going to waste. The remarkable thing is that the chief object of the Leblanc process nowadays is no longer the manufacture of carbonate of soda. It is the once despised hydrochloric acid which is now the mainstay of the manufacture, and if it were not for this and other by-products the process would be by this time only a matter of history.

CHAPTER VIII

MORE ABOUT BY-PRODUCTS

THERE are other cases besides the soda industry in which the by-product has played an important part. There is, for instance, the industry of gas manufacture. Reference has been made already to coal gas as a secondary fuel, and to the circumstances in which it was first made. The reader may be reminded that coal gas is produced when coal is heated in retorts to a high temperature and so forced to give up a large quantity of volatile matter. Part of the material distilled from the coal condenses when it is cooled, and yields coal tar and a watery liquid containing ammonia. These, along with the coal gas, and the coke left behind in the retorts after all the volatile matter has been driven off, constitute the main products at the disposal of the gas manufacturer. The gas and the coke are sold as fuel, but what does he do with the coal tar and the ammoniacal liquor? Are they simply refuse, or can they be turned to any useful purpose?

In the early days of gas manufacture the tar was regarded as an unmitigated nuisance. There was no market for it, and any one who knows the unlovely properties of tar will understand that

it could not be thrown away without offending the eyes and nose of the community. A good deal of the coal tar was burned under the retorts in which the coal was heated for the production of gas. There were considerable difficulties, however, in the proper use of coal tar as a fuel, and for a generation after the manufacture of coal gas began the tar was looked on as a nuisance more than anything else.

Coal tar is a mixture of various substances which are best separated from one another by distillation, the same process as is employed in isolating the constituents of natural petroleum. The distillation of tar was practised only to a small extent in the early days of gas manufacture, and two men who carried on this process at that time have stated that the Gas Company supplied the tar without charge, on condition only that they paid the cost of removal. This fact alone shows how little value was then placed on coal tar. The distillation of this unsavoury material was carried on in order chiefly to separate its most volatile portion, which was known as "naphtha." Apart from its use as an illuminating agent, naphtha was used for dissolving indiarubber in the manufacture of waterproof material. This was first done by Mr. Mackintosh of Glasgow, whose name is now inseparably associated with the articles he produced.

To some extent also coal tar was employed in the manufacture of roofing-felt, and as a sort of paint for ships and wooden structures of various kinds. For this latter purpose, indeed, tar had been specially prepared before the days of gas manufacture. A more extensive opening for the utilisation of coal tar was made about 1840, when the process of "pickling" timber was introduced. Wood which was to be exposed to the action of moisture, especially below the surface of the ground, was impregnated with the heavy oil distilled from coal tar. Railway sleepers, for instance, were treated in this way. This was a valuable outlet for part of the coal tar, and gave a considerable stimulus to tar distilling on a large scale.

All these applications, however, absorbed only a part of the coal tar produced at the gas-works. It must be remembered that during the first half of the nineteenth century gas manufacture was rapidly extending, and the amount of the by-product, coal tar, naturally increased in the same proportion. The position of matters, however, underwent a remarkable change after the year 1856, which marks an epoch in the application of science to industry. It was in that year that Sir William Perkin, then a lad of eighteen, discovered that a beautiful dye, afterwards known as mauve, could be produced very easily in the laboratory from aniline. This was a fact of enormous import-

ance, for Perkin's discovery led to the artificial production of a great many of these beautiful colouring matters commonly known as aniline dyes.

The significance of the discovery of mauve and other similar dyes in regard to the utilisation of coal tar lay in this, that coal tar is the source from which aniline is obtained. The quantity of this substance which exists as such in coal tar is very small, and it is not easily extracted in a pure condition. What is more important is that coal tar contains about one per cent of the hydrocarbon called benzene, which is easily separated, and from which aniline can be readily produced. For some time before Perkin made his wonderful discovery it was known that there was benzene in coal tar, but this fact was of no commercial importance until it was realised that benzene could easily be converted into aniline, and that this substance in its turn was the starting-point in the manufacture of valuable dyes. All this conferred a new value on coal tar, and opened a new era in the history of the tar-distilling industry.

In the course of time other hydrocarbons which are present in coal tar, notably naphthalene and anthracene, were shown to be capable of yielding beautiful dyes, so that the refuse of the gas-works has been more and more turned to useful purposes. Since 1856 the artificial dye industry has become

a big affair, especially in Germany, and the conversion of coal into colour is a very important branch of applied chemistry.

The production of beautiful substances from such unpromising material as coal tar strikes the imagination, and illustrates very forcibly the part which chemical science can play in the utilisation of apparently waste products. It ought to be borne in mind, moreover, that besides colouring matters there are countless other useful products derived from coal tar. *Punch* was once moved to say that "You can make anything from a salve to a star, if you only know how, from black coal tar!" There is indeed an extraordinary variety of substances used in the course of daily life which, if we trace them back, are found to spring from that unlikely source.

One product obtained from coal tar in considerable quantity is carbolic acid, which is so widely employed for disinfecting and antiseptic purposes, and the peculiar smell of which is familiar to everybody. Carbolic acid, too, is the starting-point for the manufacture of picric acid, extensively used in the production of explosives, such as melinite and lyddite. The benzene and other hydrocarbons present in coal tar can be made to yield not only dyes, but also perfumes, anæsthetics, photographic developer, as well as drugs like antipyrine and

phenacetin. From the same source is obtained also the curious substance known as saccharin, the sweetening power of which is said to be three hundred times as great as that of sugar. It thus appears that by chemical treatment even coal tar can be made to minister in quite an exceptional degree to the needs and comforts of civilised man.

The attention of the reader was directed in the beginning of the chapter to the fact that the production of gas by the distillation of coal gives rise incidentally to coal tar and ammoniacal liquor. We have seen how chemists have learned in the course of time to utilise the coal tar: it will be interesting to glance for a little at the history of the ammoniacal liquor.

Ammonia, it may be well to point out, is a chemical compound of nitrogen and hydrogen. It is a colourless alkaline gas, with a characteristic pungent smell, and very soluble in water. The so-called "liquid ammonia" which is sold in druggists' and other shops is merely a strong solution of ammonia gas in water. Since nitrogen enters into the composition of every living thing, both animal and vegetable, we need not be surprised that it should be found in coal, for this product represents the decomposed vegetation of a past age. It is probable also that animal remains are responsible for a good deal of the nitrogen which is found in coal.

Nitrogen does not exist as such in the coal, but in the form of complex compounds, which are broken up when the coal is heated. When the coal is burned in the ordinary way, the nitrogen in these complex compounds is mostly liberated in the free state and escapes into the atmosphere. If, however, the heating takes place in closed retorts, as in the process of gas manufacture, a large part of the nitrogen from the coal combines with hydrogen, also from the coal, to form ammonia.

Now although nitrogen is present in coal only to a small extent,—from one to two per cent,—and although only part of this nitrogen is converted into ammonia, it is evident that a very large quantity of this substance must be produced in British gas-works every year. We have only to bear in mind that in this country the quantity of coal which is annually consumed in the manufacture of coal gas and coke is between 20 and 30 million tons. As a matter of fact, about 250,000 tons of sulphate of ammonia are turned out every year from British gas- and coke-works. A fair quantity of sulphate of ammonia is produced also in the distillation of Scottish shale, but coal is by far the most important source of this substance.

At the time when coal gas was first manufactured, about one hundred years ago, it was well known

that ammonia was produced in the process. Not only so: the manufacturers hoped to sell the ammonia and thus reduce the cost of the gas. This expectation, however, was not fulfilled; there was no market for the ammonia, and the amount produced in the gas-works was far greater than the demand. Many of the manufacturers did not attempt to use the ammonia, and merely tipped the ammoniacal liquor into sewer, river, or sea, according to the position of the works. As the ammoniacal liquor has a highly objectionable smell, this practice gave rise to many complaints, and led people to form an unfavourable opinion of gas-lighting itself. The disposal of the ammonia, therefore, was a constant problem to the manufacturers.

Now all this has been changed. The ammonia, instead of being a worry and a nuisance, is a valuable source of profit to the gas manufacturers, a result brought about in large measure by the application of chemistry to agriculture. The scientific study of the food of plants has shown that the carbon dioxide which is so necessary is taken in through the leaves, but that the nitrogen required finds its way into the plant *via* the soil and the roots. Some plants, such as peas and vetches, are provided with special means of absorbing atmospheric nitrogen; on their roots there are peculiar swellings or "nodules"

which contain micro-organisms capable of dealing with nitrogen and rendering it suitable for use as food by the plant. In the great majority of cases, however, plants are unable to utilise the nitrogen of the atmosphere directly; it must be presented to them in the form of a nitrate, that is, a salt derived from nitric acid and an alkali, such as soda or potash.

Nature itself provides for a certain supply of this nitrogenous food to plants. When electric discharges take place in the atmosphere, combination takes place to a small extent between the nitrogen and the oxygen, and nitric acid is formed. This, together with the ammonia given off from decaying organic matter, is washed into the soil by the rain, and is then available for absorption by the roots of plants. It has been estimated that in one or other of these forms, four or five pounds of nitrogen are annually washed into an acre of soil. Whilst nitrates are the most digestible form of nitrogen so far as the plant is concerned, the ammonia and its compounds which are carried into the soil are also utilised as food, for there are in the soil numbers of bacteria which convert ammonia compounds into nitrates.

A clear understanding of the way in which plants feed was necessary before the manuring and enrichment of the soil could be carried out on a scientific

basis. It is true that for long ages the farmer

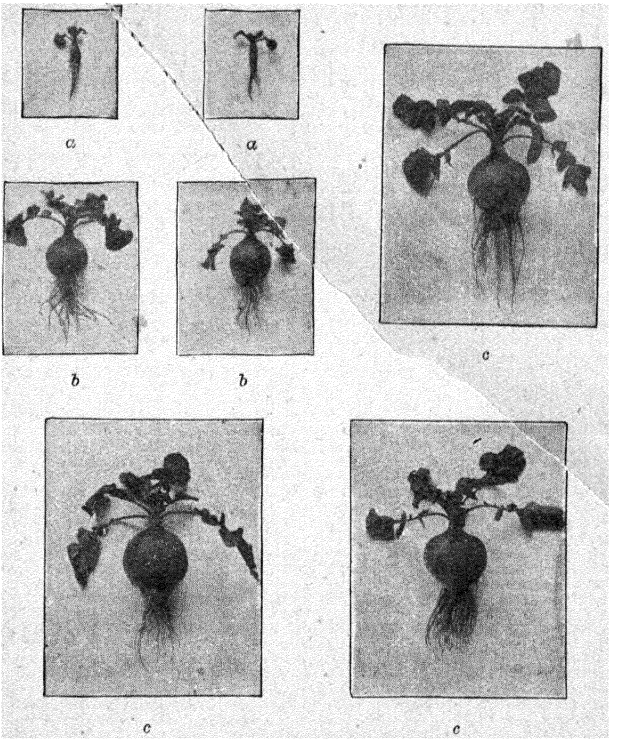


FIG. 30.—These turnips were grown on adjacent plots. The samples illustrate the effect of (*a*) leaving the ground unmanured for many years, (*b*) using mineral manure only, (*c*) using nitrogenous as well as mineral manure.

(*By kind permission of the Royal Agricultural Society of England.*)

has regularly used manure on his land, but until the chemist and the agriculturist joined hands this

was done without any clear idea of the d underlying principles. The waste products of the animal body contain much that is valuable for enriching the soil, and hence farm-yard dung is an excellent manure. This, of course, was known long ago, but nowadays we can supply to a soil the particular kind of food it requires in the form of chemical compounds.

So far as nitrogenous plant food is concerned, the compounds chiefly employed are nitrate of soda and sulphate of ammonia. There are in Chile large natural deposits of the former substance, and every year one and a half to two million tons are exported from that country for use chiefly as manure. What is of main interest, however, in connection with the subject of this chapter is the fact that sulphate of ammonia is now very extensively used as a nitrogenous manure. Here it is that the application of science to agriculture has reacted so favourably on the process of gas manufacture. A useful and valuable outlet has been found for what was once a source of trouble, and instead of throwing out the ammoniacal liquor to be a nuisance to others, the gas manufacturer sells sulphate of ammonia at a good price to the farmer, who gets a return in the shape of more abundant crops.

A hundred years ago, when gas-lighting was in its infancy, the coal tar and the ammoniacal liquor

were serious encumbrances to the progress of the new industry. The course of events has proved that from the point of view of the gas manufacturer they were merely blessings in disguise; if it were not for the profits made by selling these by-products, it would be much more difficult for the gas industry to hold its own in competition with electric lighting. We have here another example of the way in which the fortunes of an industry depend on the extent to which waste products are successfully utilised. It is plain, too, that success in this direction depends on the application of scientific methods.

CHAPTER IX

THE CHEMICAL LABORATORY IN COMPETITION WITH NATURE

THE merely physical obstacles which lie in the path of human progress have been, to a very large extent, overcome. From the days of Columbus onwards, man has been learning to pass with comparative safety and rapidity across the wastes of water that separate one continent from another. Impassable rivers have been bridged, unscalable mountains have been tunnelled, and messages are flashed from one country to another, annihilating time and

distance. Now, in these last days, the wit of man has devised even means of travelling through the thin and unsubstantial air. All these successful attempts to subdue Nature are the result of much patient study of her secrets. Man must have a knowledge of natural laws before he can apply them for his own benefit.

The chemist, too, has been advancing on similar lines. He has spent much time and energy in discovering what things are made of, in utilising naturally occurring substances, in studying the subtle chemical changes that go on around us, and, last but not least, in trying to make in the laboratory the many wonderful products which Nature yields. This attempt to compete with Nature is, indeed, one of the most interesting aspects of modern chemistry, and although it is still beyond the wit of man to make the simplest *living* material, it is astonishing how many of the complex substances produced ordinarily in the tissues of animals and plants can now be made in the chemical laboratory.

It will be well, however, to consider first some instances showing how far the artificial production of inorganic products has been successful. By inorganic products we mean those substances which may be described as dead matter, and do not owe their origin to the activity of any living organism.

The chemist has contrived to produce in the laboratory and in the factory many inorganic substances, the natural supply of which is not sufficient to meet his wants.

In a previous chapter we have learned something of the great soda industry, and of its interesting history. Now carbonate of soda is found naturally in small quantities, but when we remember its extensive use in the manufacture of soap and glass, it is obvious that this source of supply would be totally inadequate. For more than one hundred years now the civilised community has depended for its supply of carbonate of soda on the artificial product alone. What Leblanc and other chemists have done is to show how a valuable and useful material, occurring in very small quantities in the crust of the earth, can easily be made from another substance, common salt, which is available to an almost unlimited extent.

In recent years an interesting situation has arisen in connection with the world's supply of nitrates (that is, salts derived from nitric acid and an alkali). These substances are chiefly valuable to man in two very different ways—first as manure, and secondly as the source of nitric acid, the basis of a great many explosives. The most important nitrates occurring naturally are nitre or saltpetre, which is nitrate of potash, and Chile saltpetre,

which is nitrate of soda. Enormous deposits of the latter substance are found in Chile, from which country, as stated in the last chapter, from one to two million tons are exported every year.

The extent of these beds, however, is not unlimited, and a few years ago Sir William Crookes and others pointed out that if the export of the Chile saltpetre continued at its present rate, this valuable store of nitrogenous manure would soon be exhausted. The want of manure would in its turn have a very serious effect on the supply of wheat and other food. It is true, as we have already seen, that sulphate of ammonia, obtained as a by-product in the manufacture of gas and coke, can be used, and is very largely used, as a nitrogenous manure; but the supply of this substance, although not likely to fail for a long time to come, is quite insufficient to meet the farmer's demand for nitrogen.

In these circumstances, then, men of science have lately been looking around for a fresh source of nitrogen. The obvious suggestion is that enormous quantities of nitrogen are available in the atmosphere, and that we should utilise some of this vast supply. There is no doubt as to the enormous amount available, for four-fifths of the atmosphere consists of nitrogen, and the actual weight of this gas is about twelve pounds for

every square inch of the earth's surface. Some one has calculated that if, instead of Chile saltpetre, we could employ the equivalent amount of nitrogen from the atmosphere, there would be no shortage of nitrogenous manure for about ten thousand million years!

The difficulty is, not to find the nitrogen, but to get it into such a form as will be acceptable to the plant. As was pointed out in the last chapter, the great majority of plants are unable to utilise nitrogen directly: it must be presented to them in the form of a nitrate. The problem, therefore, reduces itself to this: Is there any satisfactory and economical way of persuading the free nitrogen of the atmosphere to enter into combination with other elements and yield nitrates? It would, of course, be sufficient if the nitrogen could be made to yield ammonia compounds, for these, under the influence of organisms in the soil, are converted into nitrates.

Within the last ten years many men of science have been trying to work out this problem, and it is satisfactory to know that success has been achieved. There are factories working to-day, notably in Norway, turning out large quantities of artificial nitrate, the nitrogen of which was once in the atmosphere as a free gas. The method of manufacture is in many respects

similar to the process by which nitrates are produced in Nature. It has already been pointed out that when an electric discharge takes place in the atmosphere chemical combination between nitrogen and oxygen takes place to some small extent, and the nitric acid produced in this way is washed into the soil by the rain and so becomes available for plant food.

In the artificial process, a current of air is passed through a vessel in which a powerful electric discharge is taking place, with the result that a part of the nitrogen and oxygen combine, producing nitric acid: this is then absorbed in water and converted into nitrate of lime or nitrate of soda by the addition of lime or soda. The necessity for a powerful electric discharge explains why many of the factories for the artificial production of nitrates are to be found in Norway, where plentiful waterfalls supply cheap water-power for generating electricity. If it were not possible to get electricity thus cheaply, the artificial nitrate would be unable to compete with the saltpetre from Chile.

Another unique natural product which many persons have attempted to imitate is the diamond. This gem is worth far more than its weight in gold, and a fortune awaits any one who discovers how to make real diamonds in his own laboratory. The astonishing fact is that from the chemical point of

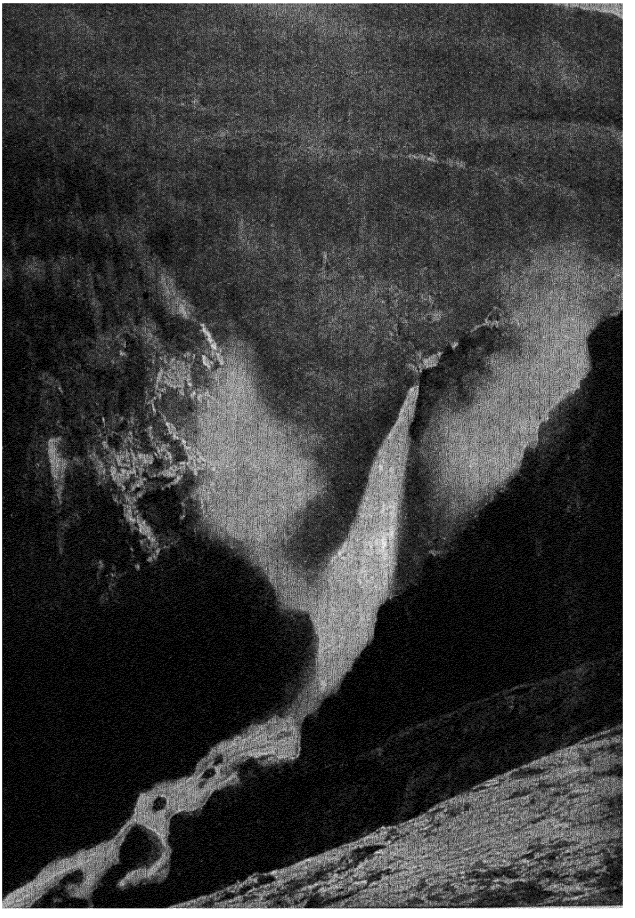


FIG. 31.—A Norwegian waterfall, the power of which is partly utilised in the production of nitrate.

view the diamond is the same as charcoal: both consist of the element carbon, the difference being that the diamond is crystalline, while charcoal is non-crystalline. There is no lack, therefore, of the material; the difficulty consists in getting carbon in the crystalline condition which is the wonderful feature of the diamond.

In one sense it is correct to say that artificial diamonds have been made. For laboratory experiments in this direction have been successful, although the gems obtained were too small to have any commercial value. The well-known French chemist Moissan, starting with the idea that diamonds are carbon which has crystallised under great pressure, proceeded to imitate these conditions by dissolving ordinary non-crystalline carbon in molten iron, and then suddenly cooling the outside of the crucible containing the metal. In this way the iron next the walls of the crucible became a solid crust while the metal in the interior was still molten. This enclosed molten portion crystallised gradually, but since iron, like water, increases in bulk when it passes from the liquid to the solid state, this process of crystallisation took place under great pressure, and the conditions, therefore, were realised in which Moissan expected diamonds to be formed. When the contents of the crucible had become quite cold they were broken up and

tiny fragments of diamonds were actually found, although too small, as already stated, to have any commercial value.

These tiny artificial diamonds, it is necessary to remember, were not mere imitations; they were the real article and consisted of carbon only. Imitation diamonds are turned out in large quantities and are made of so-called "paste," a soft heavy kind of glass which contains no carbon whatever. Radium is useful in distinguishing imitation from real diamonds. The gems are brought close to a fragment of radium salt in a dark room, when the real diamonds will glow with a kind of phosphorescence, while the imitation gems are not affected.

The laboratory competes with Nature more successfully in regard to other precious stones than the diamond. The manufacture of artificial rubies is a full-fledged industry, while sapphires also can be produced in the laboratory. It is necessary, perhaps, to emphasise the fact that these artificial gems, or "synthetic" gems, as they are sometimes called, are essentially the same as the natural stones. There are plenty of imitation rubies on the market, but they are merely made of "paste," and are chemically quite distinct from the real gems.

From the chemical point of view, the ruby

is a very simple substance, consisting almost entirely of alumina, the oxide of the metal aluminium, in the crystalline state. This in itself would be quite colourless, and the beautiful red colour of the ruby is due to a small quantity of chromium oxide which it contains. Alumina, which



FIG. 32.—The manufacture of rubies.
(By permission of Mr. E. Hopkins.)

forms the basis of the ruby, is exceedingly plentiful and very cheap; like the carbon of which the diamond consists, it is very easily obtained. The difficulty in the artificial production of the ruby is to get the white powdery alumina into the crystalline and flawless condition of the best natural gems. It has taken much time and trouble to find out how this can be done, but nowadays

synthetic rubies are made which are almost indistinguishable from the natural stones.

A very high temperature is required to melt

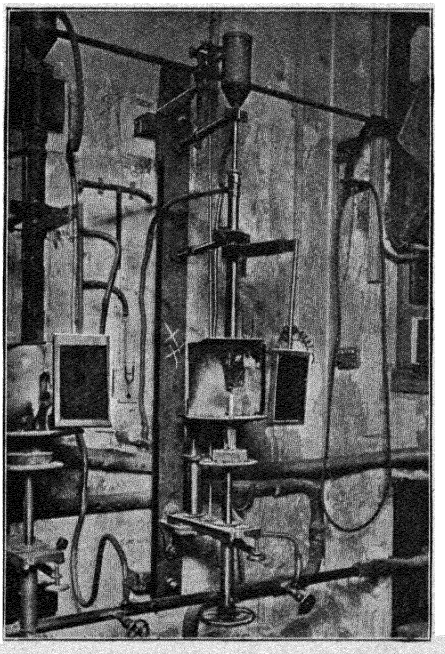


FIG. 33.—The manufacture of rubies—the blowpipe.
(*By permission of Mr. E. Hopkins.*)

alumina, but this is secured by means of what is known as a blowpipe, in which either hydrogen or coal gas is burned with oxygen. Such a flame is extremely hot, and if the powdered alumina, containing some chromium oxide to give it the

desired red colour, is fed into the flame, a little at a time, it is melted. The tiny drops of melted alumina are accumulated on a porcelain receiver just below the flame; then, when the mass or "boule," as it is called, is big enough, the flame is extinguished and the melted alumina becomes solid. On examination the boule is found to be crystalline throughout, and it is then handed over to the gem-cutter, who treats it exactly as he would a natural ruby. One difficulty in the production of the synthetic ruby is to avoid the enclosure of tiny air-bubbles in the boule, but careful manipulation of the process which has just been described yields gems that are practically free from these flaws.

The synthesis of the ruby is quite a modern achievement, but a somewhat similar event is included in the records of the early part of last century, in connection with another highly-prized mineral. This was the so-called *lapis lazuli*, found chiefly in China and Persia, and much valued for its splendid blue colour. It was employed for ornamental and decorative purposes, and when crushed, washed and purified, it yielded an excellent pigment, or colouring matter, known as ultramarine. It appears that as early as the beginning of the sixteenth century this blue pigment was brought to London from "beyond the seas"—whence its name.

The *lapis lazuli* was somewhat rare and could

be obtained only in out-of-the-way places; the process, too, of extracting the ultramarine from the mineral was very tedious, and it is therefore not surprising that the pigment was very costly. About the beginning of last century it fetched about fifty shillings per ounce. This high price prohibited any very extensive use of ultramarine, although its valuable qualities as a pigment were well known. The difficulty of procuring an adequate supply of this useful material was solved in 1828, after a prize of 6000 francs (£240) had been offered in France for the best practical method of manufacturing it. A clue to the most likely way of obtaining artificial ultramarine had been furnished by the observation, made in 1814, that a blue colour was formed in certain black ash furnaces, used in connection with the Leblanc soda process. This casual observation led up to the successful artificial production of ultramarine.

From 1828 onwards the manufacture of this valuable pigment has steadily grown, and at the present time about 10,000 tons are produced every year, chiefly in Germany. The details of the manufacturing process are trade secrets, but the raw materials employed are pure clay, sulphate of soda, carbonate of soda, sulphur, and charcoal. Since these substances are all very easily obtained and relatively cheap, one result of the discovery of

artificial ultramarine has been to lower the price of the pigment in a most remarkable fashion. As already stated, the natural ultramarine cost, at the beginning of the nineteenth century, from £2 to £3 per ounce; nowadays the artificial product can be purchased for less than thirty shillings per cwt. Ultramarine is used extensively for wall-painting, in the printing of paper-hangings and calico, and as a corrective of the yellowish tinge often shown by articles which are supposed to be white, such as linen and paper. Comparatively large quantities, too, are employed in producing the pale-blue writing paper common in this country.

CHAPTER X

THE WONDERFUL RESULTS OF SYNTHETIC CHEMISTRY

STILL more striking than the artificial production of soda, nitrate, rubies, or ultramarine, is the success which has attended the efforts of the chemist to make organic substances. These are commonly produced in Nature by the agency of plants and animals, that is, through the activity of a living organism, and for long it was believed that *only* in this way could these substances be obtained. The year 1828, however, in which artificial ultramarine

was first produced, witnessed another and far more important discovery — one that suggested the possibility of preparing organic substances from inorganic material without the aid of animal or plant.

This epoch-making discovery was made by the well-known German chemist Wöhler, who was at that time a teacher of chemistry in Berlin. The starting-point of his experiments was a compound known as ammonium cyanate. This was regarded as an inorganic substance and is, indeed, capable of being built up or "synthesised" from the elements carbon, hydrogen, oxygen and nitrogen which enter into its composition. The fact that ammonium cyanate can thus be prepared in the laboratory shows that its production does not depend on the activity of any living organism.

Yet Wöhler found, to his great surprise, that when a solution of ammonium cyanate in water was merely evaporated to dryness a large proportion of it was changed into the substance known as urea, or carbamide. Now this is essentially an animal product, for it is in the form of carbamide that the waste nitrogen of the human body is got rid of. A grown man produces on the average about one ounce of this substance every day.

For the first time, then, there was made in the laboratory a substance which was undoubtedly

organic. Since that notable discovery of Wöhler's in 1828, chemists have tried, with wonderful success, to synthesise, *i.e.* to build up artificially, numberless organic substances of the most complex kind. Before this is possible, it is, of course, necessary to understand the structure of these compounds, to "analyse" or break down the naturally occurring product and discover the simpler materials out of which it can probably be built up. This has been successfully done, for instance, with glucose, or grape sugar, the sweet substance which is found in honey and in many fruits. By a series of steps, which cannot be described here, it is possible to make this sugar in the laboratory from formaldehyde, a substance which, under the name of formalin, is often used in solution for disinfecting purposes. Formaldehyde, in its turn, can be prepared indirectly from purely inorganic materials; hence we may fairly say that the chemist can make glucose in his laboratory without the aid of any living organism.

This result is of the highest interest from the purely scientific point of view, and it is only one of many similar achievements. The reader, however, will probably ask what is the use of synthesising sugar when we can get any quantity of it from the vegetable world? Now, while it is quite true that synthetic glucose cannot compete with or replace

the abundant natural product, it should be pointed out that the person who estimates the value of any scientific discovery merely by the pounds, shillings, and pence into which it can be translated, takes a very narrow view of things. Knowledge is worth getting for its own sake, and the lovers of science may reflect with pride on the devotion which the workers of the past have shown in the pursuit of Nature's secrets, without any prospect of a money return. Their discoveries may have meant years of hard toil, and yet they had no reward in the shape of hard cash; they had simply the pleasure of doing the work—the honour and the glory of having accomplished something.

There are still many men of science who spend their lives in trying to discover Nature's secrets for the sake of knowledge alone, but there is no doubt that nowadays the commercial side of chemistry is much more prominent. It must be so, for the applications of chemistry in modern life are innumerable, and the laboratory is in many cases an essential part of the factory—its brains, in fact. Hence it comes that chemical discoveries made under these conditions may have a very definite money value. Frequently it happens that a discovery, which, at the time it was made, was of purely scientific interest, turns out later to be of great commercial value. A process which has been

worked out in the laboratory may become of great importance on the factory scale.

Now the synthesis of organic substances, dating back to Wöhler's wonderful discovery in 1828, has come to play a remarkable part in technical chemistry. It is true that the synthesis of glucose and hundreds of other substances has no direct influence whatever on practical life, and has little interest for anybody outside a chemical laboratory. There are, however, some remarkable cases in which the discoveries of synthetic chemistry have entirely altered the character of an industry, and these are worth some attention.

A very interesting example of the way in which a synthetic organic substance may come into the market as a competitor of the natural product is furnished by the history of alizarin. This is a valuable dye-stuff which has been known for a very long time. Cloth dyed with alizarin has been found on Egyptian mummies, and there are references to it in the works of Pliny and other Latin writers. The natural dye was obtained from the madder root, and hence large areas of France, Holland, Italy, and Turkey were devoted to the cultivation of that plant. As attempts made to grow the plant in England met with but indifferent success, the madder required in this country had to be imported.

It is very instructive to learn that the quantity of madder brought into England in 1868 amounted to over 15,000 tons, while in 1892 the quantity was only about 200 tons. What was responsible for this remarkable falling off in the imports of madder? Simply this, that chemists had discovered the synthesis of alizarin, and accordingly this venerable product of the vegetable world was in the course of a few years almost completely hustled out of the market. The mere discovery of a way to make alizarin in the laboratory would not have led to this result, but the artificial product was cheaper than the natural dye, and could thus compete successfully with it.

The introduction of artificial alizarin meant economy in more ways than one. The raw material of the new industry was the hydrocarbon anthracene, a coal tar by-product which was formerly of no use, and, moreover, the areas hitherto employed in the cultivation of the madder plant were now available for raising other crops. It is only right, however, to remember that the advance of science, when it leads to industrial changes of this kind, frequently means unemployment and privation to hundreds of workers. What is for the benefit of society as a whole, may yet involve suffering to individuals. The people engaged in the cultivation of madder

found their occupation slipping from them as the demand for natural alizarin decreased—a consequence which the advance of science often brings in its train. The last ten years, for instance, have witnessed a remarkable substitution of motor power for horse traction on the streets of our large cities, but this change has meant much hardship to the drivers of the older vehicles.

Natural alizarin has been ousted from the market by the artificial product, and it almost seems as if that other well-known dye-stuff, indigo, were to share a similar fate. Until very recent times our supply of this valuable colouring matter was obtained chiefly from India, and the value of the exports of indigo from that country was £3,570,000 as late as 1895. The natural product has, however, been very hard hit by the artificial dye, one evidence of which is that by 1910 the exports from India were worth only £234,000. Indeed, it is estimated that of the total quantity of indigo now consumed in the different countries of the world, more than four-fifths is the artificial product.

It is some considerable time since chemists discovered how indigo could be made in the laboratory from comparatively simple substances. The artificial product, however, has become a formidable competitor with the natural dye only

in recent years, for the laboratory process first known was rather costly and the synthetic material was too dear to compete with indigo from India. In the commercial world, naturally, dividends are a prime consideration, and it was useless to make quantities of artificial indigo unless it was able

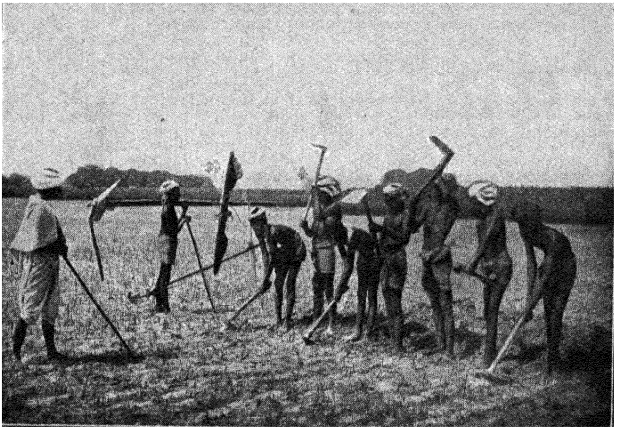


FIG. 34.—Work on an indigo plantation.

to compete on something like equal terms with the other. Meanwhile chemists were wrestling with the difficulties that cropped up in the artificial production of indigo. These were gradually overcome, the process was improved, and at last it became possible to turn out indigo from the factory as cheap as the natural dye, so that the supremacy of the latter has been challenged successfully.

The raw materials required in the production of synthetic indigo are (1) the hydrocarbon naphthalene, (2) ammonia—both these substances being obtained as by-products in the manufacture of coal gas; (3) acetic acid, from wood, and (4) oxygen, from the air. It is interesting to know that one of the improvements introduced into the original artificial process was discovered quite by chance. One of the chief steps in the process is the conversion of the naphthalene into a substance known as phthalic acid, and for a time it was customary to bring about this change by the agency of hot sulphuric acid. The change, however, took place slowly, and it was therefore desirable to make some improvement in the method of converting the naphthalene into phthalic acid.

In the course of some experiments carried out with this object, the bulb of a thermometer was accidentally broken, and the mercury ran out into the hot mixture of naphthalene and sulphuric acid. It was at once noticed that, in the presence of mercury, naphthalene was much more rapidly converted into phthalic acid, and this chance observation led to the desired improvement of the process.

Another product of the vegetable world which has lately been threatened by its synthetic rival is camphor. This substance is applied to some extent

for medicinal and household purposes, but by far its most important use is in the manufacture of celluloid, the highly inflammable material which is employed in the production of such various articles as piano keys, combs, billiard balls, and photographic films. Altogether the world requires some 4000 or 5000 tons of camphor every year,

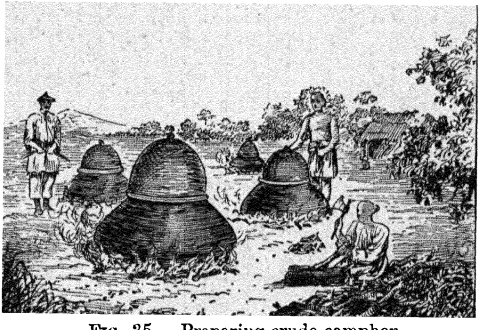


FIG. 35.—Preparing crude camphor.

and this has been supplied almost entirely by China and Japan. True Japanese camphor is obtained from a tree belonging to the laurel family. The wood is cut into small pieces and subjected to the action of steam. This carries off the volatile camphor, which is then condensed in a cool vessel.

Formosa, in particular, supplies large quantities of camphor, and when, after the Chino-Japanese war in 1894, this island passed into the possession

of Japan, the production of camphor was made a Government monopoly. As a consequence, the price went up. Those interested in the celluloid industry naturally disliked this turn of events, and were afraid lest the Japanese Government might attempt also to control the manufacture of celluloid. All these circumstances stimulated the attempt to produce synthetic camphor, and chemists at last succeeded in preparing it from turpentine oil. Not only so, but the synthetic product can be turned out at a cost which enables it to compete with camphor from Japan. The struggle between the natural and the synthetic products is in full swing at the present time, and it is not possible to say what the outcome will be. As already stated, the raw material required for the manufactured camphor is turpentine, and the result of the struggle will therefore largely depend on whether a plentiful supply of turpentine is available at a moderate price.

It is worth while noting that in addition to natural camphor and synthetic camphor there is also on the market a product known as "artificial camphor." This material has indeed an odour resembling that of true camphor, but is really quite a different substance. Synthetic camphor, on the other hand, is chemically identical with the natural product.

During the last few years much has been heard of india-rubber. This valuable natural product has been required in ever-increasing quantities in civilised countries, and a great stimulus has lately



FIG. 36.—A rubber plantation.
(By permission of Messrs. M. P. Evans & Co.)

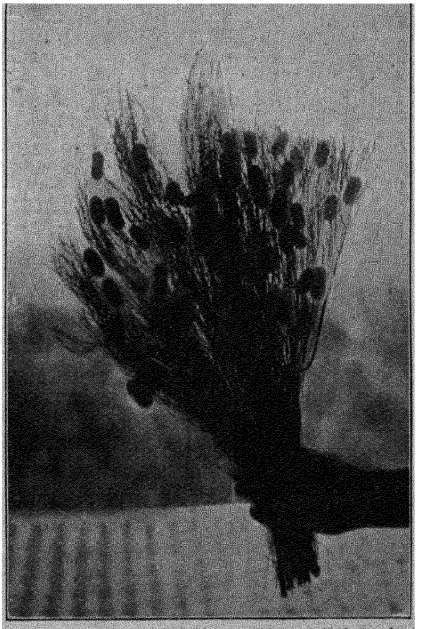
been given to the cultivation of rubber-bearing trees in different parts of the world. The total production of raw rubber is probably about 70,000 tons every year, but as it fetches from £10 to £15 a hundredweight it is evident that the commercial

importance of the industry is very considerable. India-rubber is obtained from certain trees which, when tapped by cutting through the outer bark, yield a milky fluid, or "latex," of a more or less viscous nature. The latex is coagulated into solid rubber, either by the action of heat and wood smoke, or by the addition of acetic acid.

The production of synthetic rubber is an alluring prospect to the chemist and the manufacturer, and it has already been successfully effected on a small scale. The chief step in the production of synthetic rubber is the preparation of a liquid hydrocarbon known as isoprene, which has long been known to stand in some close relationship to rubber. When rubber, for instance, is subjected to destructive distillation, it yields a mixture of hydrocarbons, among which isoprene is prominent. Now it has been found that isoprene, if kept for a time in contact with the metal sodium, is converted into solid rubber.

Isoprene itself may be obtained by the destructive distillation of turpentine, and this substance might be used as the starting-point for the production of synthetic rubber. The quantity of isoprene thus obtainable is, however, small in comparison with the amount of turpentine used, so that the process is a costly one. A much cheaper raw material is starch, which is obtainable in unlimited quantities,

and from which isoprene can be produced by indirect means. The production of synthetic rubber is therefore an accomplished fact, but it will probably be some time before rubber cultivation goes the way of madder fields and indigo plantations.



Photo—Underwood and Underwood.

FIG. 37.—Silkworm cocoons.

Enough has been said to show the reader what wonderful results have already followed the attempts of chemists to build up animal and vegetable products from simpler substances. It must be borne in mind that in the cases quoted above, alizarin, indigo, camphor, and rubber, the 'synthetic' materials are chemically identical with the natural substances and not mere substitutes or imitations. There are other natural products which the chemist has been unable to

reproduce so completely: in such cases he has to be content to imitate as closely as he can. Silk furnishes a good instance of this.

Real silk is obtained, as the reader probably knows, from the silkworm, but at the present day very large quantities of "artificial" silk are produced. Unlike alizarin, indigo, and camphor, silk is not one definite chemical compound; the fibres consist of at least two nitrogenous compounds, one of which is found as a coating on the other. Artificial or imitation silk is quite different chemically, and resembles the natural product only in its physical properties. The raw material for the manufacture of artificial silk is cellulose, a compound of carbon, hydrogen, and oxygen. One process consists in changing cotton-wool, which is nearly pure cellulose, into gun-cotton, and then squirting a solution of this through a very fine nozzle into the air or into water. The filaments obtained in this way have many striking points of resemblance to fibres of true silk.

In other manufacturing processes the cellulose is dissolved directly, and the solution is squirted into filaments in the way described. It is a remarkable fact that artificial silk has so far hardly come into competition with the natural product. The qualities and physical characters of the two materials are not by any means the same,

and the artificial variety is being applied to purposes for which natural silk has not been used.

CHAPTER XI

CHEMISTRY IN THE SERVICE OF THE PUBLIC

THE attention of the reader has already been directed to the fact that in the manufacture of many products required in modern civilised life, the workers are subject to various risks of a subtle kind. In order to secure the good health of those engaged in such dangerous trades the assistance of the chemist has frequently been invoked, and in this capacity he has been able to make a valuable contribution to the well-being of the community. But in addition to these examples there are countless other cases, less familiar perhaps to the average person, in which the chemist is doing good work in the interests of the public.

We call ourselves a civilised community, and yet it is a melancholy fact that there are many "of the baser sort" who are continually preying on the social body of which they are supposed to be members. It is not only thieves and pickpockets who belong to this class, but also those more subtle foes of the community who practise deceit and

fraud of various kinds. There are, for instance, the men who seek to increase their profits by watering milk, by "improving" jam, by selling margarine as butter, and by offering to the public quantities of material inferior in quality to the samples which have been shown.

Just as trained detectives are required to watch the expert criminals in all our large towns, and bring every crime home to its author, so in every civilised country there is a body of skilled chemists on the look-out for those rogues who adulterate food and other products supplied to the public. The fraud practised in this way is often so skilfully concealed that the man in the street would be deceived at every turn. Thanks, however, to our public analysts and to the chemists in the Government Laboratory, many of these rogues are detected and punished, and the practice of adulteration is distinctly risky in consequence.

The amount of work thus carried out for the safeguarding of the public interest and the public purse is not generally known. The following example, perhaps, may be useful in giving the reader an idea of what is done in this way. It is the practice of the Customs officers to examine specimens of the tea imported into the United Kingdom, and in the year 1910 over 10,000 samples were taken and investigated. Of these between 600 and 700

were found to be unsatisfactory as regards purity, and the packages from which the samples were taken, containing altogether about 120,000 pounds of tea, were accordingly rejected. Compared with the total quantity of tea imported annually into this country the amount rejected is small, but the facts quoted show clearly the need for vigilance on the part of our public chemists.

These scientific detectives find it necessary to keep a strict eye also on the milk and butter which form so important a part of our food. Cheese is less liable to adulteration than either milk or butter, for when once a cheese has been made it is not possible to add moisture to it or remove fat from it. On the other hand, it is very easy either to add water to milk, or to abstract some of the fat which it contains, and it is humiliating to learn that of the thousands of milk samples taken all over the country 1 in 10 on the average is found to have been tampered with. In one part of the country in 1909, adulteration was actually detected in about one out of every four samples of milk taken.

To detect this adulteration with certainty requires both experience and skill. It might be thought that the addition of water to milk or the removal of fat would be revealed by simply ascertaining the "gravity" of the milk, that is, finding how much heavier the milk is than

water, bulk for bulk. This time-honoured method dates from the days of Archimedes, who was able to prove that a certain crown made for the king of Syracuse was not pure gold, as had been stated, but contained some baser metal. The gravity method, however, cannot be relied on in the case of milk. The fat particles are lighter than the liquid in which they float, and hence "skimmed" milk is heavier, bulk for bulk, than the original milk—in other words its gravity is higher. If, now, a little water is added to the skimmed milk, the gravity is reduced, and may be brought back to the same value as that of the original milk.

By a judicious combination, therefore, of skimming and watering, the milk adulterator can obtain a liquid which is, bulk for bulk, as heavy as pure milk. The use of the gravity method would fail to detect this kind of adulteration. It is true, the appearance of this "milk" might not be very satisfactory, but this can be corrected by putting in a little yellow colouring matter which gives the liquid a thick creamy look.

All this fraud is readily detected by the skilled chemist, who finds the percentage of fat present in the milk by methods which need not be described here. Pure milk contains, on the average, about 4 per cent of fat, but it is necessary to make an allowance for slight variations in the milk obtained from

different cows and at different seasons. It may safely be said, however, that if a sample of milk is found to contain less than 3 per cent of fat, it has almost certainly been tampered with.

Even when the chemist has proved that a given milk sample is unsatisfactory, it is often difficult to fix with certainty on the person responsible for the adulteration. It must be remembered that, between the cow and the consumer, especially if the latter resides in a large town, the milk passes through many hands. When adulteration has been proved, the milk-seller may refer the authorities to the farmer, and the farmer may attempt to transfer the blame to the cow. Or, perhaps, both milk-seller and farmer may agree in suggesting that the deficiency in fat should be attributed to the officials of the railway company which carried the milk from the country to the town. A porter was actually detected once at a London station removing milk from a can and replacing it by water!

In the case of butter, adulteration may take the form either of adding excess of water, or of replacing the butter fat by another variety, such as beef fat or lard. The regular examination of the butter made and sold in different parts of the country, as well as of the product imported from abroad, brings to light every now and then cases where butter contains more than the normal 16 per cent of water, or

is contaminated with fats other than milk fat. Not that these other fats are necessarily unwholesome, but it is fraudulent to pass them off as butter.

Margarine is an instance of an artificial mixture of animal fats, which is quite suitable for human food, and is manufactured in large quantities at the present time. It was made first of all during the Franco-German war, when the Parisians ran short of butter—a fact that might suggest the undesirability of using margarine except as a last resort. Nowadays, however, with improved methods of manufacture, the product is cleaner and more wholesome. There is really no reasonable objection to the use of margarine, provided only that it is properly made and sold under its own name. It is just in securing the observance of these conditions that our public analysts render service to the community and protect the consumer from fraud. Even the cheaper fats are occasionally adulterated, and a case is on record in which a consignment of so-called "pastry margarine" from Holland was found to contain 10 per cent of solid paraffin!

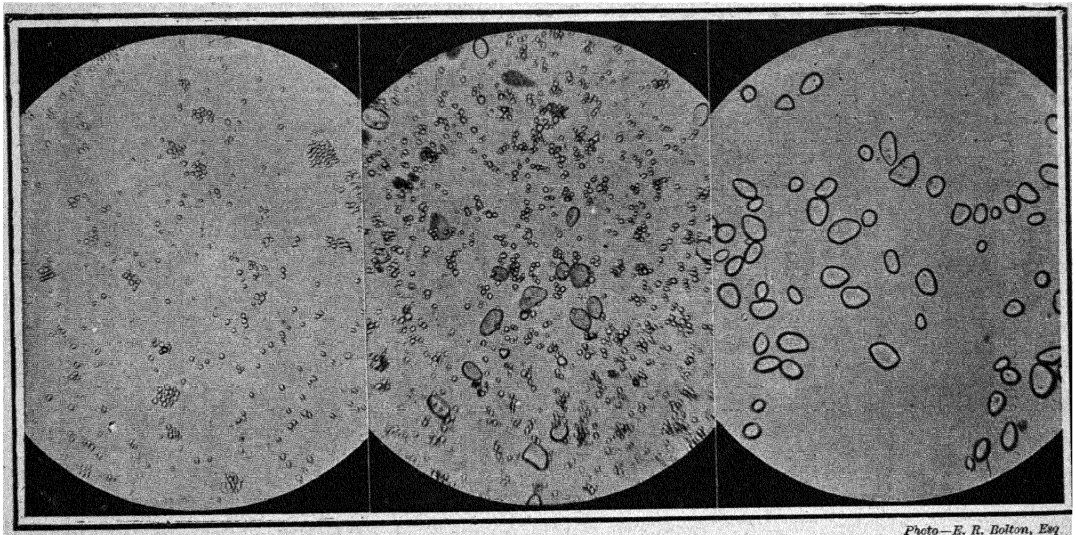
In the investigation of certain food-stuffs the microscope furnishes valuable information to the analyst. It may be used, for instance, in the detection of "faked" or adulterated jam. Unfortunately the labels on the grocer's jam jars frequently give a very misleading account of the con-

tents, and in many cases preserves are "improved" beyond recognition. "Strawberry jam" may contain apple pulp, while rhubarb and even turnip are sometimes employed by dishonest manufacturers to replace the dearer kinds of fruit.

The practice of adulteration even goes so far as to imitate raspberry jam by taking fruit juice and adding to it some foreign seeds. Indeed, a story is told of a certain grocer who had been regularly supplied with raspberry jam of doubtful purity, and who, receiving a consignment of the really pure article from another firm, returned it on the ground that it contained an unnaturally large number of seeds! By any one, however, who is familiar with the structure and appearance of raspberry seeds, the presence of strange seeds is detected immediately.

The microscope further permits the recognition of foreign constituents in jam, on the ground of the simple fact that each fruit has its own characteristic cellular structure. Hence a so-called black-currant jam which has been adulterated with apples will be found to contain apple cells when examined under the microscope.

Chocolate is another food-stuff liable to adulteration of a kind which may be readily detected with the help of the microscope. It is obtained from the cocoa bean, which consists of an outer shell



Photo—E. R. Bolton, Esq.

From rice. From arrowroot adulterated with rice. From arrowroot.

FIG. 38.—Starch granules (magnified the same number of diameters).

and an interior part or kernel. The latter, when crushed, forms the so-called cocoa nibs, and these contain nearly half their weight of cocoa butter, in contrast to the shells of the bean, which contain only 2 or 3 per cent of this fat. Since the shells cost only about one-tenth as much as the nibs, the chocolate manufacturer is tempted to add powdered shells to the ground nibs, and it is to be feared that he does not always resist the temptation. This adulteration, however, is at once detected under the microscope by the experienced eye of the analyst.

Another case where differences in structure are useful in revealing the history and character of a product occurs in connection with starchy foods. Starch is found in a very great variety of plants, but the specimens obtained from different sources, whilst they are identical in their chemical composition, yet consist of microscopic granules quite distinct in shape and size. An analyst, therefore, who has had experience in the examination of starch, will be able to say at once whether a particular specimen has been obtained from potatoes, rice, maize, or arrowroot, and in cases of adulteration he will recognise the presence of two or more distinct kinds of granules. The inducement to adulteration in the case of starch depends on the fact that some varieties are more expensive than others; arrowroot, for example, costs more than potato starch.

Much of the work done by our analytical chemists is concerned with the beverages supplied to the public. The case of milk has already been under discussion, but there are various artificial drinks, more especially those containing alcohol, which are subject to strict supervision, not only for the sake of public health but also in the interests of the national exchequer. For alcohol contributes to the revenue of the country, and there are accordingly numbers of Government officials whose work it is to supervise the manufacture and the importation of this dutiable article. In this task they must have the assistance of skilled chemists, for only a part of the alcohol imported or manufactured appears in the form of beverages like beer, wine, or whisky. Spirit is used in the preparation of very varied products, and the chemists of the Government Laboratory have therefore to examine such imported articles as lime juice, blacking and polishes, confectionery, drugs, perfumes and toilet preparations, flavouring essences, painters' colours and varnishes.

The quality of the beer sold throughout the country is controlled by the regular purchase of samples from publicans, and the subsequent examination of these samples by trained chemists. As a rule, it is found in one out of ten or twelve cases that the beer has been diluted with water, and if the deficiency in alcohol is considerable the publican

who sold the beer is prosecuted. Some persons who indulge in this form of adulteration attempt to conceal the dilution of the beer by adding sugar, but a chemical examination reveals the fraud at once.

Curiously enough, while publicans are prosecuted for selling beer with less than its proper quantity of alcohol, other persons are hailed before the authorities for manufacturing beverages containing too much alcohol. The law of the land has no objection to the presence of alcohol in ginger beer and similar drinks, provided its proportion does not exceed 1 per cent. In order to see that this condition is fulfilled the Revenue officials are constantly taking samples and submitting them for examination by the Government chemists. It is surprising to learn that of about 1000 samples of ginger beer and such like beverages thus taken and tested in 1905, as many as 360 contained alcohol above the legal limit; in several cases there was more than 3 per cent of pure spirit!

Besides satisfying themselves that samples of beer contain the proper amount of alcohol, the Government chemists are constantly testing this beverage also to see whether any arsenic is present. The reader may be surprised that beer could possibly contain this very poisonous substance, but recent experience has warned the authorities to look out

for it. About 1900 a number of cases of poisoning by arsenic occurred in Manchester and were finally traced back to the beer which had been drunk by the sufferers. In the brewing of beer a syrupy substance known as "invert sugar" is employed, this product in turn being obtained by the action of an acid—sulphuric acid, for example—on cane sugar. It turned out that the sulphuric acid used in preparing the "invert sugar" for the Manchester beer referred to, was contaminated with arsenic.

This may very easily happen, for sulphuric acid is often manufactured from iron pyrites, a natural product which invariably contains arsenic. In the Manchester case this poisonous material had passed from the pyrites to the sulphuric acid, from the acid to the "invert sugar," and so into the beer. It is not surprising, then, that since this scare it is considered desirable to examine beer regularly for arsenic.

It is not only in the control and examination of foods and drinks that our public chemist serves the community. The various Government Departments have to purchase large quantities of stores, and in order to prevent waste of public money, it is necessary to make sure that material of the proper quality is supplied. The paints and varnishes, for instance, which are to be employed in public buildings, the oil distributed to our lighthouses, the various inks supplied to Government offices, consignments of

cement, metals, india-rubber, soap, etc., being shipped to India, the drugs and anæsthetics bought for the Army Medical Department, are all examined, samples being sent to the Government Laboratory for the purpose.

The Postmaster-General frequently finds it necessary to call in the assistance of the trained chemist. He must be satisfied that the tarry substance known as creosote, with which the ends of telegraph poles are impregnated before they are buried in the earth, is up to the mark in regard to its preservative power. He submits for examination numerous varieties of waterproof material, so that his postmen may have the best possible equipment for rainy days. The stamps issued by his Department have to undergo a searching examination, so that both the colouring matter on the front and the gum on the back may be certified as harmless.

The detective powers of the chemists at the Government Laboratory have lately been tested in connection with some supposed Old Age Pension frauds. It was suspected that certain entries in old letters, certificates, and family Bibles had been made after the Act was passed, and these articles were accordingly submitted for investigation. In some of the cases a careful examination of the nature of the ink employed showed that the writing was comparatively recent.

The Board of Agriculture, too, has many questions to submit to the expert chemist. There are materials required by the farmer, such as manure, sheep-dips, and oil-cake, the quality of which he cannot tell by mere inspection. In his interests, therefore, it is necessary to have a chemical control of these and other stuffs used in agricultural operations. As an example of the way in which the farmer is liable to be defrauded, some facts bearing on the sale of copper sulphate may be quoted. A solution of this substance, often known as "blue vitriol," is used in dressing wheat and, along with lime, for spraying potatoes for potato disease, and bushes infected with mildew. But the reports of the chemists show that the blue vitriol supplied to the farmer, "agricultural" copper sulphate, or "farmer's friend," as it has been termed, is sometimes grossly adulterated. Sulphate of iron, being a cheaper material, is fraudulently substituted for sulphate of copper. In one case the material sold as copper sulphate was found to contain nearly four-fifths of its weight of iron sulphate, the requisite colour being obtained by the addition of some Prussian blue.

In various ways, then, the analytical chemist is rendering useful service to the community. His scientific vigilance secures the general purity of our food supplies, and checks, to a large extent,

the practice of adulteration in various departments of trade and industry. The effect of his labours is seen in this, that the more serious forms of adulteration, such as were common about the middle of the last century, are now seldom encountered. According to a competent investigator of that period every one of about fifty samples of bread examined contained alum, of twenty-eight specimens of cayenne pepper only four were genuine, while the analysis of coloured sweetmeats showed that more than half of the samples taken contained salts of lead. Things are not so bad as that nowadays, and the credit for such improvement as has taken place must be largely put down to the account of the analytical chemist.

CHAPTER XII

THE INTEREST OF THE INSIGNIFICANT

THE "power of littles" is a hackneyed phrase, and the truth which it embodies is accepted as a commonplace. Nowhere, however, does one come across more striking demonstrations that *quantity* is not the only thing that counts than in the field of chemistry. The properties of a chemical compound are, sometimes fundamentally altered, for

good or ill, by a minute quantity of some other substance, and the course of a chemical change is often profoundly modified by the presence of a trace of foreign matter.

Take the case of iron and steel. To the average person the difference in their chemical composition appears to be insignificant, for steel is merely iron with about one hundredth, more or less, of its weight of carbon added. Yet the difference in the physical properties of iron brought about by this small addition of carbon is very marked indeed, and is of the highest importance in the industrial and technical applications of the metal.

Pure iron is a comparatively soft metal, whereas steel can be obtained in an exceedingly hard condition. If hot steel is cooled suddenly by plunging it into cold water, its hardness is such that it has the power of scratching glass, and when suitably tempered it is adapted for tools of the most varied description. Again, the tensile strength of steel, that is, its power to resist extension, is very high, and it finds a very wide application in modern engineering work, in the building of bridges and in the construction of machinery. All these valuable characteristics of steel are closely related to the small amount of carbon added to the iron.

The presence of traces of foreign matter in a

chemical compound, however, does not always make for improvement. Nitroglycerin, one of the substances which have figured very prominently in the production of modern explosives, is a compound in the manufacture of which the utmost care has to be taken. It is prepared by acting on glycerin with a mixture of sulphuric and nitric acids, and when the action is over and the nitroglycerin has been produced, it is necessary to remove the surplus acids by treatment with water. This dissolves the acids, but leaves the nitroglycerin. It is essential that this process of washing out the acids should be performed with extreme thoroughness, for if the nitroglycerin is left contaminated with even a trace of these, it will decompose. Now the decomposition of nitroglycerin is liable to become a very violent process, and it is therefore absolutely essential that in the manufacture of this dangerous substance the utmost care should be taken to secure a pure product.

An interesting example of the way in which a relatively insignificant amount of a foreign substance may have a notable effect on the properties of a given material is furnished by the history of the incandescent gas mantle. In the competition between gas and electricity as illuminating agents the mantle has played a very important part. It has added so much to the effectiveness of gas light

ing that this older method of illumination has held its own to a surprising extent. Now the ordinary incandescent gas mantle contains about 99 per cent of thoria and only about 1 per cent of ceria. These names are unfamiliar to most people, and a little explanation may be necessary. Thoria is the oxide of the metal thorium, and comes mostly from the United States and Brazil, where it is found in so-called monazite sand. The other constituent of the mantle is the oxide of a rare metal known as cerium.

The peculiar thing about the mixture of thoria and ceria employed in making an incandescent gas mantle is the necessity for adhering to the proportions just mentioned. If mantles were made of pure thoria alone, their power of emitting light when heated in a gas flame would be very low. By adding 1 per cent of ceria, however, the brightness of the heated mantle becomes about ten times as great. With 2 per cent of ceria the intensity of illumination has noticeably diminished again, so that there is a special virtue in the 1 per cent addition. It is interesting to note, in passing, the extraordinary effect which the development of the gas mantle has had on the price of thorium. The cost of thorium nitrate in 1894 was 5os. the ounce; two years later the price had fallen to 8s., while it is about 1s. at the present time.

In comparatively recent times some very interesting observations have been made on the remarkable influence which a trace of moisture may have on the course of a chemical change, or on the properties of a chemical compound. Everybody probably is familiar with the experiment in which a mixture of hydrogen and oxygen, contained in a soda-water bottle, is caused to explode with a loud report by bringing a flame or a spark to the mouth of the bottle. The violence of the explosion gives one the impression that hydrogen and oxygen are only too ready to combine with each other, but, curiously enough, it is found that if the gases are first dried very thoroughly the tube containing them may be heated to redness in a gas flame without any chemical action occurring.

This interesting and striking result has been achieved only by the exercise of much care and patience. In order that the mixture of hydrogen and oxygen may be absolutely dry some phosphoric oxide is put inside the tube containing the gases. This substance is very greedy for water, and most substances when left in contact with phosphoric oxide are deprived of every trace of moisture associated with them. In the case of the mixture of hydrogen and oxygen, it was found that contact for ten days with phosphoric oxide made the gases so dry that they refused to explode when the tube containing them

was heated. But whenever the merest trace of moisture was admitted to the tube, the contents exploded at once on being heated.

These striking experiments demonstrate very clearly how much the behaviour of substances may depend on the presence or absence of some so-called "foreign" material. Examples of this sort of thing might be multiplied, but one more case will suffice. It has reference to the chemical change mentioned above, namely, the combination of hydrogen and oxygen to form water. Generally speaking, the interaction of these two gases is started by a flame or a spark; either a mixture of the gases is exploded, or hydrogen gas issuing into the air is ignited and burns with a pale blue hot flame. In both cases the combination of the two gases takes place at a high temperature.

But some beautiful experiments have shown that hydrogen and oxygen will combine slowly and quietly at ordinary temperatures under the persuasive influence of platinum. This is ordinarily a heavy metal of silvery appearance, but it can also be obtained in water in a very finely divided condition. By passing an electric discharge between the ends of two platinum wires dipping in water, the metal is gradually disintegrated, minute particles being thrown off into the surrounding liquid. These particles remain suspended in the water and impart

a dark brown colour to it; they are so fine, however, that they cannot be removed by filtering the liquid through blotting-paper.

Now this "colloidal" platinum, as it is called, has an extraordinary effect in facilitating the combination of hydrogen and oxygen at ordinary temperatures. A mixture of these gases has merely to be shaken up with colloidal platinum in order to bring about their gradual union to form water. What is further very remarkable, is the extremely small quantity of platinum required for the combustion of hydrogen in this manner. One investigator found that in seventeen days over two gallons of a mixture of hydrogen and oxygen gases were converted into water under the influence of $\frac{1}{16,000}$th of an ounce of platinum. Nor was the power of the platinum exhausted by this performance, for its activity was as great at the end as at the beginning.

Substances which exert a powerful influence in promoting a chemical change without themselves being affected, like colloidal platinum in the case just described, are known as "catalytic agents," and they play a very great part in chemical phenomena. They may fitly be compared with the oil which contributes so much to the smooth working of an engine without actually supplying any of the driving power. A little oil makes a big difference, and a

catalytic agent similarly facilitates chemical changes out of all proportion to its quantity.

It is not merely in pretty experiments that the action of catalytic agents may be demonstrated; they are of the highest value in many technical operations. Take, for instance, the manufacture of sulphuric acid—"oil of vitriol," as it is sometimes called—one of the most important chemical compounds made on the large scale at the present day. For the preparation of this substance three others are required, namely, sulphur dioxide (which is the suffocating gas produced when sulphur is burned), oxygen (or air), and water. The chief difficulty that meets the manufacturer who wishes to make large quantities of sulphuric acid is to persuade the sulphur dioxide and oxygen to enter into chemical combination. It is true that they unite of their own accord when heated together, but with extreme slowness.

Fortunately, however, there are certain catalytic agents under the influence of which sulphur dioxide and oxygen combine rapidly, and thus the manufacture of sulphuric acid on the large scale becomes feasible. Such a substance is platinum, and one of the technical processes at present used for making the acid consists in passing a mixture of sulphur dioxide and oxygen (air) through a heated vessel containing finely divided

platinum. The curious thing is that although the platinum facilitates the union of the two gases in so remarkable a manner it is not changed itself.

When once the difficulty of getting the sulphur dioxide and the oxygen to combine has been overcome, the manufacture of oil of vitriol is an easy matter, for the product of their union, sulphur trioxide, as it is called, dissolves very readily in water to form sulphuric acid. The extraordinary influence of finely divided platinum on this chemical change has been known to chemists for a long time, but it is only within comparatively recent years that this method of making sulphuric acid has been applied on the large scale. Many attempts that were made failed because for some mysterious reason the platinum deteriorated very rapidly and its catalytic power gradually disappeared. After much searching it was found that dust particles and traces of arsenic, which is very often present in sulphur dioxide, have a deleterious effect on the platinum and destroy its power. Nowadays, therefore, the greatest care is taken that the mixture of sulphur dioxide and oxygen is completely freed from arsenic and dust particles before it is passed over the finely divided platinum.

The history of this modern method of making sulphuric acid supplies another example of the great influence which may be exerted by very

small quantities of foreign substances. Generally speaking, a great deal of the chemist's time is taken up in looking for small quantities of undetected compounds. And for this purpose he has some very delicate methods at his disposal.

There is, for instance, the spectroscopic method of analysis. The reader has probably looked at some source of white light, such as an electric lamp or a bright gas flame, through the instrument known as a spectroscope, and observed a band of colour in which the various shades, from red to violet, pass continuously and imperceptibly into one another as in the rainbow. The white light has been split up into its various coloured constituents by the prism in the spectroscope.

Suppose now, instead of an ordinary electric lamp or bright gas flame, we were to take a non-luminous flame, such as is given by the well-known Bunsen burner! This flame could be made intensely luminous by putting into it, by means of a platinum wire, a small piece of sodium chloride (common salt). But examination of this luminous yellow flame with the spectroscope would reveal to us a fundamental difference from the ordinary gas or electric light. Instead of a continuous band of colour we should observe only a bright yellow line. If the nitrate, carbonate, or any other salt of soda were tried instead of sodium chloride the result would be the

same, so that the appearance of this characteristic yellow line in the spectroscope may be taken as proof that the substance introduced into the non-luminous flame contains the element sodium.

Potash compounds are similarly characterised. When they are introduced into a non-luminous flame, the spectroscope shows two lines, one red and the other violet. Each element, indeed, has its own spectroscopic peculiarities, and may readily be recognised by these. This method of recognition, too, is very delicate, for extraordinarily minute quantities of substance are sufficient to answer to the spectroscopic test. It is said that one ten-millionth of a gram of a sodium compound betrays itself in this way.

A striking instance of the detective power of the spectroscope was given in connection with the discovery of the two metals rubidium and caesium by Bunsen and Kirchhoff. These investigators had been examining a certain German mineral water, and had found in the spectroscope some lines which did not correspond with those of any element known at the time. They drew the conclusion that the water must contain some hitherto undiscovered element, and they proceeded to search for it by evaporating down large quantities of the water and testing the residues. Their search was successful, and resulted in the discovery of two new elements which were

named rubidium and caesium. Since 40 tons of the

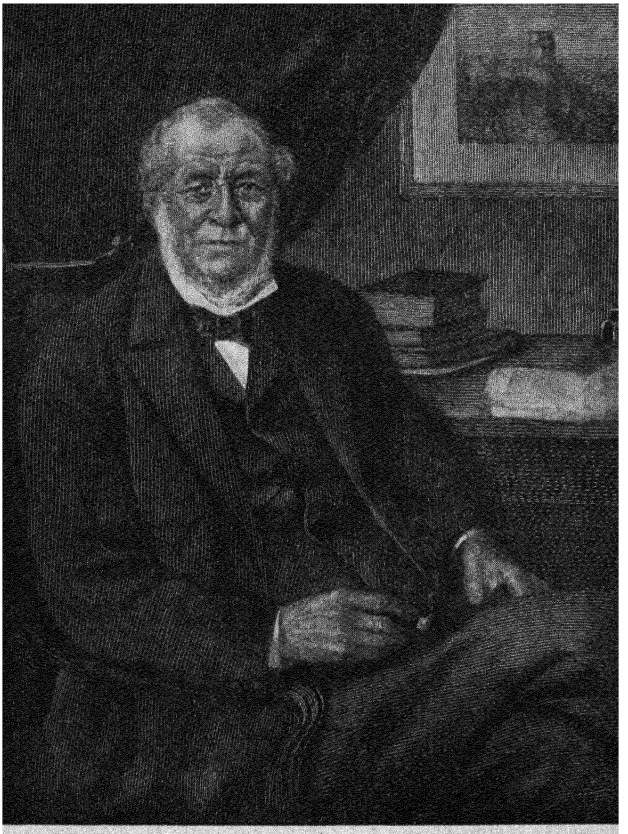


FIG. 39.—Bunsen.

water had to be evaporated in order to get one-quarter of an ounce of caesium chloride, it is evident that the

spectroscope revealed the presence of extraordinarily minute quantities. Indeed, it is highly probable that without the spectroscope rubidium and caesium would never have been discovered.

The question how far one can get in the detection of the very minute is of great interest to the chemist, for he believes that matter, however uniform and homogeneous it may appear, really consists of definite separate particles. He pictures the air, for instance, as constituted of innumerable minute particles, or "molecules" as they are called, rushing about in all directions at a very high speed. This seems very fanciful, especially when one is told that the number of gas molecules in a space equal to a pin-head is probably about 30 million times as numerous as the population of the globe. If this is correct, then the molecule must be almost inconceivably small—somewhere between the millionth and the ten-millionth of a millimetre in diameter.

Now it would be very interesting if one could actually see the individual molecules and so confirm the accuracy of the picture just sketched. But the best microscope fails us long before we reach the molecular order of things. Particles of a diameter less than about one ten-thousandth of a millimetre are not visible under the microscope, and this instrument by itself, therefore, cannot possibly reveal the separate molecules of a gas or a liquid.

Quite recently, however, a remarkable advance has been made in the detection of the minute. The way in which this has come about will be intelligible to any one who has observed a ray of sunlight entering a darkened room through some minute opening. Innumerable particles of dust are seen

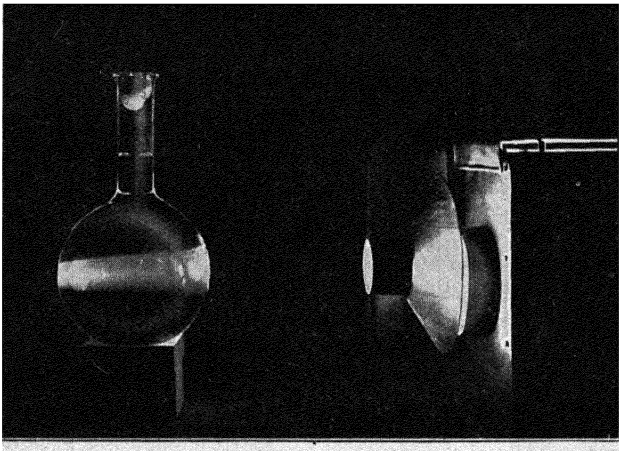


FIG. 40.—A beam of light passing through a flask of slightly turbid water.

floating in the path of the beam. The light is scattered by these dust specks, and it is their presence which reveals the track of the ray. If the room were absolutely free from floating particles the path of the beam could not be detected.

Similarly, if a powerful beam of light is passed through a glass flask containing water, the observer,

looking from the side, can detect the path of the beam only when dust or other particles are floating in it. If the water is ever so slightly turbid the path of the beam is rendered evident by a sort of luminous glow. The particles causing the turbidity in the water may be so tiny as to be quite invisible when it is examined under the microscope in the ordinary way, and yet they render the track of the beam perfectly evident.

If, now, this whole experiment is carried out under the microscope, that is, if a thin layer of the turbid liquid is illuminated by a strong beam of light, and the axis of the microscope is directed at right angles to the beam, the minute suspended particles reveal themselves as discs of light on a dark background. This is the exact counterpart of what is seen when the dust particles in a ray of light appear as bright specks. The discs or bright specks give no direct indication of the *size* of the particles; but each disc corresponds with one particle, and hence the number of the particles may be estimated.

An instrument arranged for making the experiment described in the foregoing paragraph is known as an "ultramicroscope," because it enables us to detect the existence of suspended particles considerably smaller than any we can actually see under the microscope in the ordinary way. Distinct

particles measuring only five-millionths of a millimetre in diameter have been detected with the ultramicroscope. This is not so very much bigger than the molecules are supposed to be, and these observations, therefore, are of the very greatest interest to the chemist.

Further, the very finest suspended particles, the existence of which is revealed only by the ultramicroscope, are seen to be in rapid and unceasing motion, like a swarm of dancing gnats. The smaller the particle, the more rapid is its movement. These striking observations suggest that although we cannot yet study the behaviour of the molecules themselves, the chemist's notions about these minute particles and their movements are not so fanciful after all.

CHAPTER XIII

SCIENTIFIC AND TECHNICAL CHEMISTRY

THE history of chemistry, like that of other sciences, has much to tell us of men who have devoted their lives to the study of Nature's secrets. They have spent laborious days and years in the search for new substances and in the careful investigation of those already known. This they have done entirely for love of the work stimulated

always by the fascinating variety of natural phenomena. Their discoveries may not have had any immediate practical value, and may not have brought them any return in the shape of hard cash, but they had at least the joy of the explorer and the satisfaction of adding to the sum of human knowledge.

To-day also there are many chemists who are working purely for exploration. The man in the street would say that the new substances they are preparing in their laboratories are of no use whatever to anybody, and that the problems to which they are devoting their energies have not the least bearing on practical life. Such a critic points approvingly, on the other hand, to the chemists who are tackling definite technical problems, and applying chemistry on the factory scale. Success in solving their problems secures an immediate cash return, and some narrow-minded people would have us believe that this is the only standard by which we must judge the value of the chemist's work.

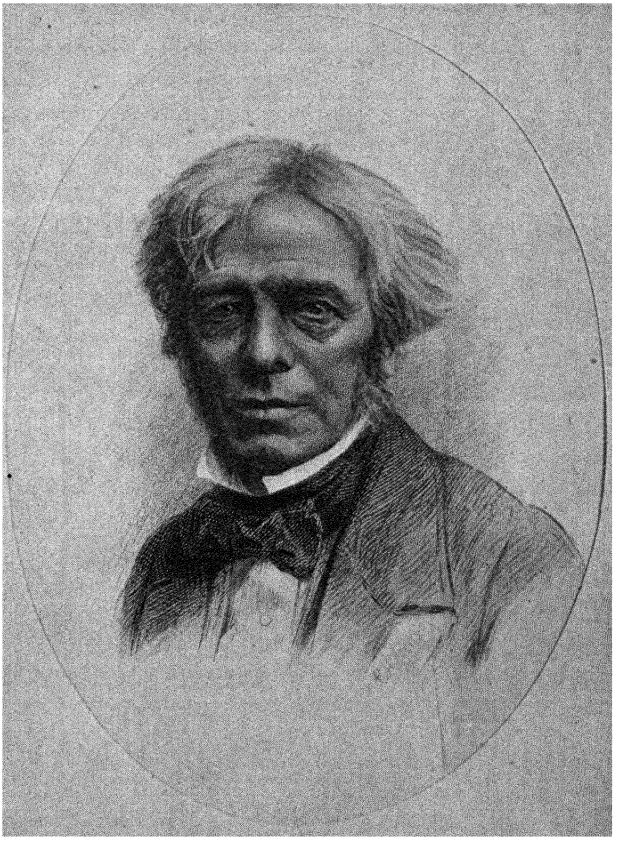
But all contributions to our knowledge of nature and its laws are welcome, even although they do not seem to have any direct bearing on practical life. It must be borne in mind, too, that there are many cases on record in which a discovery in the realm of purely scientific chemistry has afterwards led up to valuable technical

applications. It is therefore very unsafe to predict that because a chemist's work at the present time makes no immediate contribution to the solving of technical problems, it will never have any value in that direction. A glance at the history of chemical discovery serves to emphasise this.

Take the case of Michael Faraday, whose wonderful investigations have won for him an enduring place in the annals of science. He called himself a "philosopher," but in reality he was a born experimenter in the fields both of physics and chemistry. It is interesting to note, by the way, from what a humble origin Faraday rose to be one of the greatest English men of science. His father was a journeyman blacksmith, and young Michael began earning his own living as a bookseller's errand-boy. Later on, as an apprentice, he gathered scraps of scientific knowledge from the books which passed through his hands, and, stimulated by these, he devoted part of his spare time to making simple chemical experiments.

The desire to be engaged in scientific work became steadily stronger in young Faraday, and it received a mighty impulse when, through the kindness of one of the bookseller's customers, he was enabled to visit the Royal Institution and listen to the lectures of Sir Humphry Davy. This led up to Faraday's appointment as Davy's

laboratory assistant, and great was his delight at



being able to exchange the bookselling business for

the more congenial pursuit of scientific knowledge. From that date onward Faraday's progress was steady and assured. His genius and enthusiasm led him to many striking discoveries, and in due time he became Professor of Chemistry at the Royal Institution, the very place where, in his younger days, he had sat at the feet of the famous Davy.

Faraday deliberately preferred the investigation of purely scientific problems to the more lucrative work which was open to him. About 1831, when forty years of age, he realised that if he was properly to follow up his scientific discoveries he must relinquish the professional work which had already brought him a large income, and paid much better than investigations in pure science. Accordingly he gave up the idea of making money at chemistry, and devoted himself with enthusiasm to the search for knowledge.

A study, however, of the subsequent development of applied chemistry shows very clearly that Faraday, while apparently engaged in rearing a purely scientific fabric, was really laying the foundations of several important industries. Take, for example, his experiments on the liquefaction of gases. He succeeded in causing a number of substances ordinarily known as gases—for example, chlorine, carbon dioxide, ammonia and sulphur

dioxide—to assume the liquid condition. The production of liquid chlorine aroused much interest in the scientific world, and was the source of much satisfaction to Faraday himself. It was equivalent to the discovery of a new country.

The method adopted in liquefying these gases was extremely simple. A bent tube was employed, one end of which, *a*, contained a substance capable of yielding the gas when heated. After the substance had been introduced the tube was sealed up. The application of heat to *a* liberated the gas, and the pressure thus generated in the closed tube caused the gas to condense, and to appear as a liquid at *b*. The production of the liquefied gas was facilitated by artificially cooling this end of the tube.



FIG. 42.—Faraday's bent tube.

Such a liquefied gas represents at the ordinary temperature a considerable store of energy. This was evident to Faraday when he cut open one of these bent tubes containing liquid chlorine. The parts flew asunder as if with an explosion and the liquid chlorine disappeared entirely. These explosion effects were much more marked with liquid carbon dioxide. Tubes which had contained some of this material for two or three weeks exploded spontaneously with great violence, and it was therefore necessary to avoid risks by using masks and

goggles while these liquefied gases were being investigated.

It was perhaps these explosions that suggested to Sir Humphry Davy that condensed gases might possibly be used as a source of mechanical power: for instance, in the driving of an engine. Nothing very much, however, has come of this suggestion, and for the really practical application of liquefied gases we must come down to a much later day; so that Faraday's labour in this new field was in his own time of purely scientific interest, and it was left for a much later generation to discover the practical results to which the pioneer work of Faraday and others led up.

A moment's consideration will show the magnitude of these latter-day applications of liquefied gases. The reader is no doubt familiar with the fact that evaporation produces cold, and may have seen an experiment in which a rapid current of air is blown through a little ether contained in a flask. Ether is in itself a very volatile liquid, and, assisted by a current of air, it evaporates very rapidly indeed. The flask containing the ether becomes extremely cold, and any water adhering to the outside is converted into ice.

The same sort of thing, only to a much more remarkable extent, occurs when a condensed gas is rapidly evaporated. A quite intense degree of

cold may be attained in this way, and the artificial production of ice on the large scale becomes a comparatively easy matter. Hence it is that at the present day large quantities of ammonia and sulphur dioxide, both in the liquefied condition, are produced. The most economical way of making these condensed gases and of using them for refrigeration has become a problem for the engineer rather than the chemist. The engineer has devised machinery which permits the refrigeration even of large chambers by these artificial means, so that it is possible to transport fruit, meat, and dairy produce from the ends of the earth, and land them in England in a fresh condition.

Another wonderful sequel to Faraday's pioneer investigations has been the production of liquid air. This is a comparatively recent achievement, and although at first it was merely a scientific curiosity, liquid air is now a commercial article. This provides the means by which oxygen is obtained on the large scale, for when liquid air is evaporated the nitrogen which it contains, being the more volatile constituent, escapes more rapidly and leaves the oxygen ultimately in an almost pure condition. All this shows how experiments originally made for a purely scientific purpose may turn out to be the basis for future industrial applications of the greatest value.

The work of Faraday supplies another striking instance of this. In 1824 he brought before the Royal Society a discovery which has proved to be of the highest importance. While investigating the substances produced when oil is decomposed by heat, he obtained a hydrocarbon, that is, a compound of carbon and hydrogen only, which had not previously been discovered. Faraday called this new liquid "bicarburet of hydrogen," but its modern name is "benzene." It was an interesting find, but the discoverer himself had no idea of the exceptional part his new hydrocarbon was destined to play in the history of applied chemistry.

About thirty years later, Perkin showed how mauve could be obtained from aniline, and this discovery led up to the manufacture of numerous artificial dyes. Now benzene is the parent substance of aniline, so that Perkin's work conferred a new importance on Faraday's hydrocarbon and on coal tar, the source from which it is derived. In 1906, large numbers of chemists, manufacturers, and dyers assembled in London to do honour to Sir William Perkin, the founder of the artificial colour industry. The chief meeting of the occasion was held in the Royal Institution, where Faraday worked and where he had discovered the hydrocarbon which turned out to be one of the main factors in that industry. On the table at which leaders of science and industry

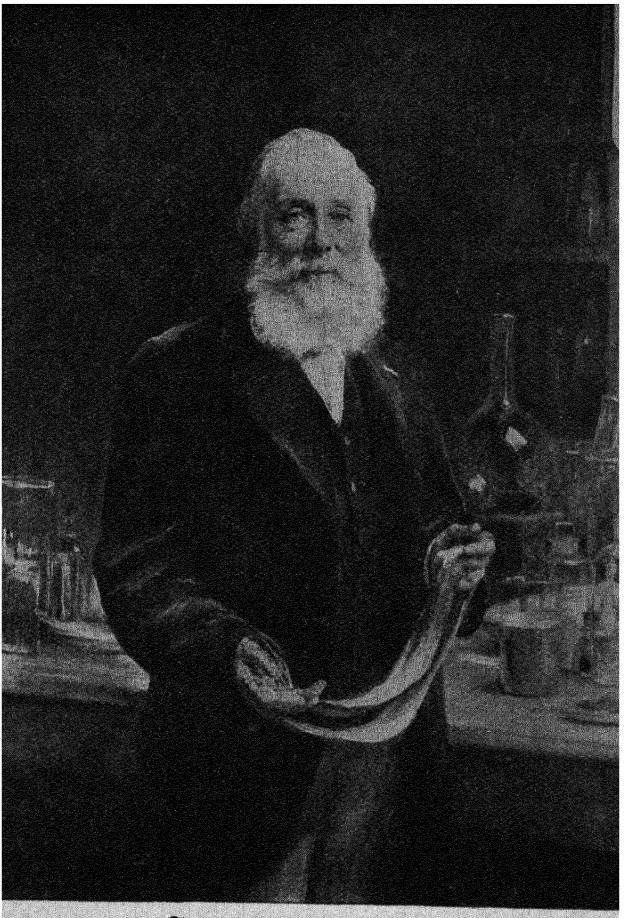


FIG. 43.—Sir William Perkin.

from different countries offered their congratulations to Sir William Perkin there stood a small bottle of

benzene, the very specimen which Faraday had prepared eighty years before.

Perkin's discovery of mauve, the first artificial dye, was itself the result of experiments carried out with a purely scientific object. He was not aiming at the production of a colouring matter at all, but was trying to make the well-known alkaloid quinine, in the laboratory. In the course of these attempts, as Perkin himself has related, aniline was subjected to the oxidising action of chromic acid and was found to give a perfectly black product. When this unpromising material was purified, dried, and extracted with spirits of wine the beautiful colouring matter known as mauve was obtained.

This, as events have shown, was an epoch-making discovery, and one of the first results was that aniline came to the front as a commercial substance of the highest importance. Hitherto this compound, the parent of mauve, had been a material of purely laboratory interest; it was made only in very small quantities, and only when required for the purposes of scientific research. But when Perkin began to make mauve on the manufacturing scale, tons of aniline were required, and new sources of the material had to be found. The procedure adopted then and still followed at the present time was to extract benzene from coal tar, convert the benzene into nitrobenzene, an oily substance with

a smell like that of bitter almond oil, and then finally to prepare aniline by acting on nitrobenzene with scrap iron and hydrochloric acid.

It is very plain, then, that experiments which are in themselves of a purely scientific character may have far-reaching consequences in the world of technical chemistry and practical life. The man in the street is inclined to pooh-pooh the discovery of any new substance unless it has an immediate market value. The sort of question he asks is, "What is the use of this new compound?" "Can it be used in bleaching or dyeing?" "May it be used as a substitute for leather?" "Will its discoverer make a fortune?" If these enquiries cannot be answered satisfactorily the new compound is regarded as so much useless rubbish, and its discoverer is considered to have wasted his time. The history of chemical science, however, warns us that this attitude is quite a wrong one to take up. The compound which to-day is of purely scientific interest may be the valuable commercial product of to-morrow, and the chemist who is wrestling with Nature's problems in his laboratory is preparing the way for the applied science of the future.

Discoveries both in scientific and technical chemistry have often been made in a curiously casual way. The observer, either purely by chance or stimulated by curiosity, has stumbled across

some strange phenomenon which clears up his difficulties, or leads him to the discovery of some important law. Many instances of this sort of thing have been recorded.

Graham, for instance, the famous English chemist, was led to begin his great experiments on the diffusion of gases through a curious observation made by an earlier worker. This man, Döbereiner by name, had occasion to prepare quantities of hydrogen, and one day he accidentally employed as gas-holder a jar which had a minute crack in it. To his great surprise, Döbereiner observed that, contrary to all laws which were then known, the level of the water shutting off the gas in the jar slowly rose.

Graham's attention was directed to this strange phenomenon, and his investigations led him to the explanation. Hydrogen, being the lightest known gas, can pass through minute apertures much more rapidly than any other gas. What happened, therefore, in Döbereiner's gas jar was that hydrogen escaped through the crack more quickly than air could get in, so that the level of the water in the jar rose. Thus the use of a cracked vessel instead of a sound one was the starting-point for Graham's wonderful discovery of the laws of gaseous diffusion.

Another striking illustration of the way in which a somewhat trifling observation may lead to

results of great practical value occurred in connection with the discovery of blasting gelatine by Nobel. Nitroglycerin, the explosive substance employed in the manufacture of dynamite, is by itself a very dangerous substance to handle and to transport from place to place. These risks, however, are very much diminished if the liquid nitroglycerin is soaked into the porous earthy material known as *kieselguhr*; the product obtained in this way is dynamite. The *kieselguhr* is itself a harmless, inert, non-explosive substance, and therefore does not contribute to the explosive power of the dynamite. Nobel had been reflecting on this, and was on the look-out for an absorbent material, which might be used, like *kieselguhr*, to soak up the nitroglycerin, and yet might of itself contribute to the power of the explosive.

The solution of the problem came as the result of a casual observation. Nobel had cut his finger one day and painted some collodion over the wound to form an artificial protective skin. It should perhaps be stated that collodion is prepared by taking a certain substance similar to gun-cotton and dissolving it in a mixture of alcohol and ether: when a little of this solution is exposed to the air, it dries up very quickly, because alcohol and ether are volatile liquids.

When Nobel had finished painting over the

wound, there was still a little collodion left, and it struck him that it would be interesting to see what happened if the collodion were mixed with nitroglycerin. He made the experiment, and found to his delight that when the collodion was added to nitroglycerin a jelly-like mass was produced, that is, the dangerous liquid nitroglycerin was transformed into a product suitable for safe handling and transport. Further, the substance in the collodion which gave the jelly with the nitroglycerin was itself a highly combustible material, and was capable of contributing to the energy of explosion. Thus it was that blasting gelatine, an explosive of an extremely powerful character, was discovered.

These illustrations show what may come of comparatively trifling observations. No one can tell what will be the ultimate practical value of an observation accurately made and followed up carefully.

CHAPTER XIV

CHEMISTRY AND OTHER SCIENCES

WHILST it is convenient to speak of different branches of Science as Geology, Botany, Physics, Physiology, etc., it must be remembered that no single one of these is absolutely isolated from the

others. The field of Science, it is true, is divided up into a number of plots, but these adjoin each other, and between them there are border-lands, where workers from both sides join forces in the search for knowledge.

Chemistry is a science which stands in a close relationship to all the others. Especially so is this the case in reference to Physics, and these two together constitute the so-called Physical Sciences, in contrast to the Biological Sciences. Chemistry has been described as merely "the dirty part of Physics," but, although there is much common ground between them, the chemist has a large field to work which is peculiarly his own. Whilst the physicist studies the laws which govern the behaviour of matter in general, the chemist is more concerned with the different forms which matter may assume, and with the conditions under which they exist.

In recent years, however, the border-land between Chemistry and Physics has acquired such interest and importance that a special name —Physical Chemistry—has been given to it, and many distinguished men have laboured in this field of work. All questions connected with the existence of molecules — those ultimate minute particles of which every form of matter is supposed to be built up—have the greatest interest for the

physicist as well as the chemist. Both have made discoveries which have a distinct bearing on these invisible units. The physicist has long known that the space which a given quantity of a gas occupies is diminished by increasing the pressure, and is increased by raising the temperature, and he has discovered also the very significant fact that the laws which govern this influence of pressure and temperature are the same for every gas. There is, therefore, a very striking *uniformity* in the behaviour of different gases towards changing temperature and pressure.

The chemist, on the other hand, studying the chemical actions which take place between different gases, has found that their relations are characterised by a remarkable *simplicity*. In the union of hydrogen and oxygen to form water, for example, the volume of hydrogen is twice that of the oxygen with which it combines exactly, and the water produced, if kept in the form of vapour, occupies the same space as the hydrogen did before union took place. This is only one example of what the chemist has found to be true generally, viz. that in the chemical combination of gases there is always a simple numerical ratio between their volumes and the volume of the gaseous substance formed from them.

These discoveries have together led to the conceptions which are now generally held as to the nature

of gases—conceptions which interpret the remarkable uniformity in the physical behaviour of gases as well as the simplicity of their chemical relationships. According to these views, as hinted in a previous chapter, the ultimate particles or molecules of a gas are in a state of great activity, rushing hither and thither at a high speed, colliding frequently with each other, and impinging on the walls of the vessel which contains the gas. The pressure exerted by the gas is due to these innumerable impacts on the walls of the containing vessel, and the activity of the moving molecules increases as the temperature rises. Further, in a given space, say one cubic centimetre, there is always the same number of molecules, whatever the gas may be, provided that the temperature and pressure are kept the same. Now all these views are based on the knowledge of facts brought to light both by the physicist and the chemist.

There are, however, many other border-land problems in attacking which there has been alliance and co-operation between the two great branches of physical science. Take the very simple phenomenon with which every one is familiar—the process of dissolving sugar (or salt) in water. The sugar plainly disappears, but it has long been a question why it should do so and what becomes of it. Is the sugar unaltered in the solution or has it

undergone some fundamental change? How are the properties of the water affected by the addition of the sugar?

These and similar questions have been the subject of discussion and investigation by men of science for generations, but the latter part of the nineteenth century and the beginning of the twentieth have witnessed a remarkable revival of interest in the problem of solutions. It would be going much too far to say that the problem has now been solved and that all difficulties have been cleared away, but it is the case at least that recent investigations have added immensely to our knowledge of what takes place when a substance dissolves in water, and of the properties of the solution obtained in this way.

In this modern attack on the problem of solutions physicists and chemists have taken the chief part, but it is especially interesting to note that one of the early stages was initiated by a botanist. This was Pfeffer, Professor of Botany in Basle, who was studying the ascent of sap in trees, and in the course of his experiments was led to measure the force of attraction between a solution and its solvent. Since Pfeffer's work was epoch-making and laid the foundation for much that was to follow, it is worth while to understand exactly what he tried to do.

If some strong sugar solution is put at the bottom of a tall glass jar, and water is then carefully poured in up to the top, matters do not remain in this condition. Although nothing obvious takes place in the jar, a spontaneous intermixture of the sugar and the water proceeds all the time, and after a long interval there is as much sugar at the top of the jar as at the bottom. This process is known as "diffusion," and its occurrence may be taken as evidence that there is some force of attraction between water and sugar.

The existence of this force might be rendered evident in another way. Suppose there were stretched across the jar and just at the top of the strong sugar solution a membrane which allowed the water to diffuse through, but blocked the passage of the sugar! Under these conditions diffusion of the ordinary kind could not take place. The force of attraction between water and sugar, however, would still be active, and would make itself felt in the only way open to it, namely, by water being drawn through the membrane into the sugar solution. The same thing would happen if a weak sugar solution occupied the upper part of the jar instead of water. Across such a membrane as has been described, water would always pass from the weaker to the stronger solution. If the membrane were a delicate one, this entrance of water into the space

shut off by the membrane would very soon burst it. If, on the other hand, the membrane were both strong and rigid, the entrance of a very little water would cause such a pressure as would prevent the passage of any more.

Membranes with this peculiar property of allowing water to pass through them, but refusing passage to various dissolved substances, such as sugar, are described as being "semi-permeable," and were discovered shortly before Pfeffer made his investigations. The results of separating water from a sugar solution by such a membrane were found to be just those described above, and the one-sided diffusion of water observed in this case was termed "osmosis." Pfeffer, however, not only studied this phenomenon, but showed also how it could be made the basis of a method for measuring the force of attraction between solvent and solution —the "osmotic pressure," as it is commonly called. And the measurements made by this botanist have been the starting-point for the numerous, more recent investigations which both physicists and chemists have made on the properties and nature of solutions.

It turns out that many of the most prominent characteristics of a solution are closely connected with the osmotic pressure which Pfeffer first taught us to measure. Thus, for example, it has been

long known that the freezing-point of a solution of sugar is lower than that of pure water, and that its boiling-point is higher than that of water. Not only so, but it has now been found that the extent to which the freezing-point is lower, or the boiling-point higher, is directly related to the osmotic pressure and can be calculated from it; or, *vice versa*, the osmotic pressure of a solution can be calculated from its freezing-point or boiling-point.

All this indicates the significance of Pfeffer's original work. The measurement of osmotic pressure, however, is not the only instance of a notable contribution made by a botanist to chemical and physical science. Nearly a century ago, an English botanist named Brown made a very striking observation, which, after a period of oblivion, has been put on record again and is found to have a most important bearing on some modern investigations of a physico-chemical kind.

Brown found that if the milky fluid obtained by grinding up a little gamboge with water is examined under the microscope, hosts of little solid particles are seen, and they are in a state of constant movement. One might think that perhaps this movement is temporary, observed only when the drop of milky fluid has been freshly put on the microscope slide; but this is not so. Provided that the particles are small enough their movement is,

unceasing, and it seems, therefore, as if this feature were fundamentally associated with matter in a very finely divided condition. Modern research confirms this view, and Brown is to be regarded as the forerunner of those who, in recent times, with the aid of the ultramicroscope, have shown that the idea of the invisible molecules of a substance being in a state of constant motion, is almost certainly correct.

Botanists then have made some notable contributions to the advance of physical and chemical science, but on the other side of the account there is the valuable assistance rendered to botanical science by the physical chemist's work on solutions. Much light has thus been thrown, for example, on the curious behaviour of plant cells when they are immersed in solutions of various substances. The plant cell, it should be remembered, consists of a more or less rigid cell wall enclosing the protoplasm, in which again there may be several spaces, so-called "vacuoles," containing the cell-sap. In the normal healthy condition of the cell, the outer layer of the protoplasm lies close up against the supporting cell wall, just as the bladder of a football, when it is fully blown up, presses against the leather case. This is seen when the cells are examined in a drop of water under the microscope, especially well if the cell contents are coloured.

If, now, some of these plant cells with coloured

contents are immersed for a time, not in water but in a series of sugar solutions of gradually increasing strength, and are then examined under the microscope, it is seen that the cells from the weaker sugar solutions present the same appearance as the normal healthy cells in water. Those, however, which have been immersed in the stronger solutions have undergone a notable change. The protoplasm no longer lies close up against the cell wall, but has drawn itself away at one or more points. There is a definite strength of sugar solution which is just able to bring about this phenomenon, and for each of many other substances, *e.g.* common salt, which produce a similar result, there is also a certain strength of solution which is just effective. This curious change in the appearance of plant cells produced by immersion in strong solutions of various substances is known as "plasmolysis," and it is a phenomenon which has an interest for the botanist and chemist alike.

For it appears that the layer of protoplasm next the wall of a plant cell behaves like a semi-permeable membrane, allowing free passage to water, but preventing the passage of various dissolved substances, which are on either side. In such a case, as already shown, osmosis must occur, and an exchange of water will take place between the contents of the cell and the surrounding solution.

If the sap is stronger than the solution in which the cell is immersed, water will tend to pass inwards; and if the protoplasm were not supported by the rigid cell wall, the cell would burst; all that actually happens, however, is that the protoplasm is pressed if possible still closer to the cell wall.

If, on the other hand, the solution in which the cells are immersed is stronger than the sap, water will pass outwards through the semi-permeable protoplasmic layer, and the contents of the cell will therefore shrink. Hence the protoplasm draws itself away from the cell wall, which, being both rigid and permeable, undergoes no change.

Interesting questions arise when one compares the strengths of different solutions which are just able to produce plasmolysis. In many cases these limiting concentrations are proportional to the weights of the molecules of the dissolved substances, but on the other hand there are many chemical compounds which are more effective in producing plasmolysis than this rule would lead us to suppose. That is, unexpectedly small quantities of these substances are effective. Common salt is an example of this.

It is just here that the physical chemist comes to the assistance of the botanist, for he has accumulated a lot of other facts showing that common salt and similar substances are exceptionally active in

some respects when dissolved in water. Take, for example, their influence on the freezing-point of water. It has already been stated that the freezing-point of a sugar solution is lower than that of water, and if instead of sugar we were to dissolve in the water an equivalent quantity of alcohol or glycerin, the effect would be the same, and the freezing-point of the water would be lowered to the same extent. If, however, we were to dissolve in the water an equivalent amount of common salt or nitre the freezing-point would be lowered to almost double the extent. Similar results are obtained when one compares the influence of sugar and salt in raising the boiling-point of water.

Now the chemist has further observed that just those substances which have an extra big effect on the freezing-point and boiling-point of water are able to make water a conductor of the electric current. This is an extremely interesting fact, and the numerous experiments which have been made in this connection have suggested an explanation for the special activity of salt and similar substances as compared with sugar. It seems very probable that when salt is dissolved in water its molecules are mostly split up into smaller units, half of which carry a charge of positive electricity, while the other half are negatively charged. These "ions," as they are called, may act as carriers of the electric

current when required, and the greater number of them, as compared with the molecules, explains why salt is more active than sugar in lowering the freezing-point of water and in raising its boiling-point. The botanist, too, finds here an intelligible explanation of his observation that salt is more effective than sugar in producing the plasmolysis of plant cells.

The botanist is not alone in deriving assistance from the physical chemist's investigations. The physiologist also has made a number of discoveries which would be difficult to explain were it not for the facts which are now known about solutions. As one instance of this we may take the interesting observations which have been made on the behaviour of red blood corpuscles when they are immersed in solutions of various substances.

The blood of mammals consists really of a colourless fluid in which are floating innumerable small bodies, containing a red colouring matter, hæmoglobin, and known as the red blood corpuscles. A corpuscle is a droplet of solution enclosed in a thin, flexible membrane, which is freely permeable to water but does not usually allow the passage of dissolved substances from within or from without. It may, in fact, be described as a semi-permeable membrane, and the blood corpuscle is in some respects comparable with the plant cells to which

reference has already been made. There is, however, this important difference, that the blood corpuscle has no rigid wall to give it support, and it is therefore easily ruptured.

When, for instance, a drop of blood is introduced into water, the corpuscles are burst or "laked," the colouring matter inside escapes and imparts a reddish tinge to the water. The same result is observed when a drop of blood is added to weak sugar solutions, whereas in strong sugar solutions the corpuscles remain intact and gradually sink to the bottom, the liquid above being free from colour. When experiments of this kind are made with sugar solutions of different strengths it is found that there is a certain strength of solution above which no laking of the corpuscles takes place.

Similarly for other substances, if each of a series of solutions of graded strength is tested with a few drops of blood, it is found that there is in each series one solution just strong enough to protect the corpuscles. Now the physiologists have found that the concentration of common salt and similar substances required to prevent laking of the corpuscles is unexpectedly low, a result which reminds one of the observations made by the botanists in connection with plasmolysis.

The two sets of phenomena have really much in common. It is the passage of water across

a semi-permeable membrane from the weaker solution to the stronger which explains alike the laking of the blood corpuscles and the occurrence of plasmolysis. When a blood corpuscle is immersed in a solution the strength of which is less than that of the contents of the corpuscle, water enters and the resulting increase of bulk stretches and then bursts the delicate membrane which surrounds the corpuscle. If, however, the blood is added to a solution which is stronger than the contents of the corpuscles, water will pass out and the corpuscles will accordingly shrink a little. The fact, also, that salt is exceptional as compared with sugar is rendered intelligible by the chemist's discoveries about the behaviour of these two substances when dissolved in water.

Besides these problems which have just been discussed, and on which the work of the physical chemist has had such an important bearing, there are many other questions in botany and physiology about which chemistry has much to say. For in the laboratory of the plant or animal body there is produced an infinite variety of substances which are of the highest interest, not only because of what they are in themselves but also because of the ways in which they are made by the living organism.

As has already been stated, there was a time in the history of chemistry when it was supposed that

none of the characteristic substances found in the plant or the animal could be produced apart from these organisms, and such substances were therefore described as "organic," in contrast to the "inorganic" or dead matter with which the chemist operated in his laboratory. Innumerable discoveries, however, have clearly shown that this is a false distinction, and that a great many of the substances occurring in plants and animals can be built up in the laboratory from purely inorganic compounds.

There are many processes, however, employed by the living organism, either for building up or breaking down compounds, which the chemist has not yet learned to imitate. His methods are sometimes very clumsy and tedious in comparison with the operations that go forward so smoothly in the tissues of animal or plant. Take, for instance, the conversion of starch into grape-sugar. If this change is to be brought about in the laboratory it is necessary to *boil* the starch with dilute sulphuric acid. In the living organism, however, the same process occurs with the greatest ease under the influence of curious bodies known as "enzymes." When moist barley, for instance, is allowed to germinate, one of these enzymes, "diastase" by name, is produced, which has the power of converting starch into sugar both easily and rapidly

Human saliva, too, contains an enzyme which attacks the starchy constituents of food and begins their conversion into sugar.

Altogether these enzymes have an extraordinary power of inducing chemical changes to take place quietly, which otherwise would require the application of strong reagents and high temperatures. Naturally they have been the subject of much investigation, but they are very elusive, and the chemist finds it a difficult matter to obtain enzymes in anything like a pure state. Another line of investigation, however, has been opened up by regarding enzymes as belonging to the class of catalytic agents, referred to in a previous chapter. Enzymes undoubtedly resemble catalytic agents in many respects, as, for example, in the smallness of the quantity which suffices to bring about some particular change. It has been estimated that one part of diastase is able to bring about the conversion of about 5000 parts of starch into sugar, and other examples might be quoted, illustrating their extraordinary effectiveness.

One of the most striking chemical changes occurring in the living organism is the building up or synthesis of such complicated substances as starch, sugar, and cellulose from carbon dioxide and water. In the mysterious laboratories of the plant leaf, these two simple compounds are continu-

ally being converted into others which form an important part of the food of all living organisms. And yet this fundamental chemical change is very imperfectly understood, so that there is still ample room for research and discovery in this border-land of bio-chemistry.

In all sorts of unexpected fields, then, chemical forces are at work, and the chemist is able to give material help to workers in the sister sciences. In connection also with the life of the community as a whole, the achievements of chemistry are a valuable contribution to progress.

THE END

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