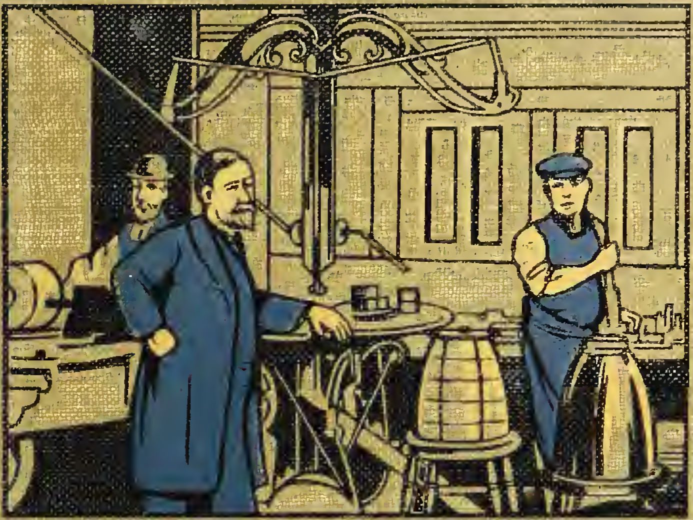
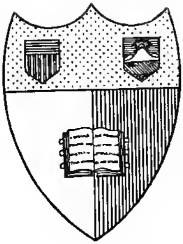


MODERN CHEMISTRY

AND ITS WONDERS

Dr. GEOFFREY MARTIN



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MODERN CHEMISTRY AND ITS WONDERS

A POPULAR ACCOUNT OF SOME OF THE MORE REMARKABLE RECENT ADVANCES IN CHEMICAL SCIENCE FOR GENERAL READERS

BY

GEOFFREY MARTIN, D.Sc., Ph.D.

FIRST-CLASS HONOURSMAN IN CHEMISTRY OF LONDON UNIVERSITY
AUTHOR OF "TRIUMPHS AND WONDERS OF MODERN CHEMISTRY," "PRACTICAL CHEMISTRY," "INDUSTRIAL CHEMISTRY," "THE HALOGENS," "CHEMICAL LECTURE DIAGRAMS," "RESEARCHES ON THE AFFINITIES OF THE ELEMENTS," ETC. ETC.

> Yet I doubt not through the ages one increasing purpose runs,
> And the thoughts of men are widened with the process of the suns.
>
> TENNYSON.

ILLUSTRATED

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PREFACE

MY recently published book *Triumphs and Wonders of Modern Chemistry* met with such an enthusiastic welcome by the chemical reading public, having run through two editions and been translated into Russian in the comparatively short time which has elapsed since publication, that when my publishers approached me with the request to write a companion volume to that work, treating of matters omitted for want of space in the first book, I gladly acceded to their proposal. The present book is the result. The treatment is popular, technicalities being avoided as much as possible. However, in it I suppose the reader to be familiar with the ordinary conceptions of chemistry, such as have already been explained in a popular manner in the first book. The book is not intended for students wishing to study for one or other of the innumerable examinations of our somewhat chaotic educational system. Rather it is intended to interest the cultured general reader in some of the really wonderful achievements of scientific chemistry. The subjects chosen include both technical and pure scientific advances, with which the writer has had special opportunities of becoming conversant.

The reception accorded to the first volume, not only in the reviews but also in the numerous letters which have reached me from practically all parts of the world, has convinced the writer that the work met a real want and that a considerable demand exists for a book of this type. There exists a wide public interested in scientific problems, who have neither the leisure nor the inclination to master the technicalities and enter into the minutiæ of the regular text-book of chemistry—the latter type of book also labours under the disadvantage that only such things can be discussed therein as are likely to have academic examination questions set on them.

In addition to interesting general readers, the book may possibly prove useful to popular lecturers and chemistry teachers in need of interesting illustrative facts for their routine chemical classes.

Popular books on science, although depreciated by professional scientists, yet serve an extremely useful purpose in bringing home to the mass of the people the enormous importance of Science to the State.

The greatest care has been taken to keep the subject matter thoroughly up-to-date. Much of the material here appears in book form for the first time. In every case the most recent authorities, not only English but foreign as well, have been consulted.

No one authority has been slavishly followed, but an endeavour has been made to put every fact in a fresh and original way.

Consequently the reader will find many old problems presented afresh in a novel form and treated on lines different from those usually adopted in the ordinary chemical text-book. By such means I hope to bring the reader into immediate contact with the thoughts of the great leaders of science, whose ideas, usually buried away in the transactions of learned societies, are inaccessible to all but the specialist.

Seeing that this book is being issued during our struggle with the Germans, it will not be irrelevant to mention that for many years chemists have been urging that in any war that we might have with Germany, our enemies would be all the more formidable because of their high scientific education and attainments. The scientists of this country have been advocating that there should be national encouragement and support of the useful kind of scientific man, that our manufacturers should employ men who have scientific qualifications, and that into the ranks of those who govern us there should be introduced a much larger leaven of men of science. Unhappily this advice fell upon deaf ears. A war with Germany is, in a great measure, a contest between chemists, and British chemists believe that if the government would have listened to them, the Germans would have been beaten in the early stages of the great war, and that thousands upon thousands of lives would have been saved; they say that in the Autumn of the year 1914, Germany was saved from a crushing defeat because she had possessed the sense to encourage her chemists. In these pages, the Author hopes that he will be able to reveal the marvels of chemistry, and at the same time to make plain the importance of scientific studies in national affairs.

My best thanks are due to Mr. W. P. Dreaper, Editor of the *Chemical World*, who allowed me to reproduce my article on "Metallic Firestones," which first appeared in that journal under the title "The Pyrophoric Alloy Industry," and also gave me permission to reproduce a picture of the cultivation of Sugar Beet.

To Dr. Lander, Professor of Chemistry at the Royal Veterinary College, London, I am indebted for several curious and interesting facts which do not seem to be generally known.

To Dr. Henry Sand, of Nottingham University College, I am indebted for illustrations of the apparatus used in Electro-chemical Analysis—a subject which has been much advanced by his researches.

To Sir Henry Roscoe, F.R.S., I am indebted for leave to quote from his interesting *Life and Experiences*. To Mr. G. W. Clough, B.Sc., I am indebted for several valuable suggestions. To the late Professor R. K. Duncan and to his publishers, the A. S. Barnes Co. of New York and Messrs. Hodder & Stoughton of London, I must express my best thanks for leave to quote from *The New Knowledge*.

Messrs. Crookes & Reynolds' Diagram of Atomic Weights is reproduced by kind permission of the British Association. The picture of the Pennycraig Explosion is reproduced by kind permission of the South Wales Institute of Engineers from Professor Gallaway's *Colliery Explosions*. The illustration of the "Will-o'-the-Wisp" is reproduced by permission of Messrs. W. & R. Chambers, Ltd., from *The Gallery of Nature*. The two illustrations of Asphalt Digging in Trinidad are reproduced by permission ot the Institution of Mining Engineers. The illustrations of a Malt House and Mash Tuns are reproduced by permission of Messrs. A. Guiness & Co., Ltd. The curve of Atomic Volumes is reproduced by permission of Messrs. Blackie & Son, Ltd., from Caven and Lander's *Systematic Chemistry*. The Chemical Society of London gave permission to reproduce the illustrations of Dr. Sand's apparatus for Electro-chemical Analysis. Professor Joly of Dublin and his publishers, Messrs. Constable & Co., Ltd., kindly gave me permission both to quote from and to use some illustrations of the book *Radio-Activity and Geology*. The Editor of *Cassier's Magazine* gave me leave not only to quote some extracts from the journal, but also to use some of the illustrations. To Messrs. Fred. Bayer & Co. I am indebted for the photograph of the picture entitled "Where German Work-People live."

The photograph of Mendeléeff was supplied by the photographer, Warwick Brooks of Manchester. The illustrations of apparatus used in cutting and welding by the oxy-acetylene flame were supplied by Messrs. Carbic, Ltd. Messrs. Baer & Co. supplied the blocks for illustrating the article on metallic fire-lighters.

Messrs. Charles Griffin & Co. kindly gave me permission to quote certain passages from Dr. Wynter Blyth's book on *Poisons*.

Messrs. Macmillan & Co. courteously gave me permission to quote from Kingsley's *Scientific Essays*.

To all of these I wish to return my best thanks for the assistance rendered.

GEOFFREY MARTIN.

UNIVERSITY OF LONDON.

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MODERN CHEMISTRY AND ITS WONDERS

CHAPTER I

THE WONDERLAND OF MODERN CHEMISTRY

"And Nature, the old nurse, took
The child upon her knee,
Saying 'Here is a story book
Thy father has written for thee.'

'Come wander with me,' she said,
'In the regions yet untrod,
And read what is still unread,
In the manuscripts of God.'

And he wandered away and away,
With Nature, the dear old nurse,
Who sang to him night and day
The rhymes of the Universe."

So sang the immortal Longfellow of the wonders of nature. In the following pages I hope to take the reader with me into part of the Wonderland of Modern Chemistry, and to tell him of facts as strange or even stranger than any ever fabled in a fairy tale—with the advantage of being perfectly true. But first of all I must say a few words about what we mean by the science of chemistry. The reader, with faint memories of his schooldays floating in his mind, may have some sort of idea that chemistry deals with nasty smells, explosions, and such like things. This, however, is a very distorted view to take.

More accurately we may say that chemistry is the science which deals with the different kinds of matter and their various transformations into other kinds of matter. Consequently wood, tea, metals, glass, acids, poisons, perfumes, rocks, air, gases, water—in a word, every substance that you can think of, forms a proper object of study of the science of chemistry. The whole great universe about us, from its uttermost heights to its deepest depths, is built up of matter of some kind or other; and so chemistry must deal intimately with its structure. Our bodies, plants, flowers, and the innumerable products of modern civilisation—be it a railway train or a piece of wall-paper, a palace of marble or a reel of cotton—are all built up of matter, and therefore chemistry as a science must underlie all these things. Ultimately all other sciences rest upon chemistry as a basis, for all such sciences finally deal with matter in some form or other.

This is what makes chemistry so interesting as a study; it is continually giving us glimpses of unexpected wonders. Many of the grandest problems of the astronomer who deals with rushing worlds and blazing suns, of the physiologist who treats of living matter and the mysterious vital processes ceaselessly proceeding in every living organism and producing the most astonishing products and effects, of the physicist who deals with the mysteries of light and heat and electricity and the forces which drive matter into motion, are simply chemical questions; and all these classes of men have at some stage or other to fall back upon the chemist for the elucidation of their deepest problems. Even geology is essentially a chemical science; for the wearing down of rocks and the countless changes undergone on the surface of the earth by the action of wind and water, fire and acids, are essentially chemical changes; indeed, the whole world is but a vast system in ceaseless and rapid chemical change.

Since chemistry is the science which deals with the various kinds of matter, and since all industries use as their raw material matter in some form or other, it is obvious that chemistry must be more closely interwoven with the industries of a country than almost any other science. Indeed, for this reason it has been stated that national pre-eminence in chemical industry ultimately means a national world supremacy.

Chemistry gives us command of matter, and therefore the empire of the world. The country that produces the best chemists must, in the long run, be the most powerful and wealthy. And why? Because it will have the fewest wastes and unutilised forms of matter, the most powerful explosives, the hardest steels, the best guns, the mightiest engines, and the most resistant armour.

It will have at lowest cost the best manufactured articles; its food will be the most nourishing and the cheapest. Its inhabitants will be the most healthy and the best developed, the most free from disease and vice. They will be thrifty, resourceful, intelligent, utilising their country's resources in the best possible manner and opposing the least resistance to favourable evolution.

Their country will be the least dependent upon other lands, the most prosperous in peace, the most terrible in war.

Truly the education of the nation in advanced chemistry and higher physical science is the most paying investment that any country can make. Indeed, one writer goes so far as to suggest that competition between civilised nations is merely a competition in the science and applications of chemistry. Therefore it is greatly to be regretted that in England our higher education and universities are starved—the teachers in great universities often living on pittances such as skilled artisans would refuse,[1] while, still worse, chemical research is greatly

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[1] Let me give some instances of what is now (1915) nothing less than a national scandal. You can purchase the full-time services of a doctor of Science, one who has discovered several new facts and who has possibly written a couple of books, and who has, in a word, brains, ability and ideas in abundance, for—I am ashamed to say it—about £130 a year! This is less than the wages paid to an average clerk of the same age in a bank, far less than that paid to an average civil servant, and even less than that paid to a good fitter in an engineering workshop. The financial position of the scientific worker engaged in research on the fundamental questions of science is pitiable in the extreme. The reader will naturally suppose that, at least, the "teacher-scientists" on the staffs of the great modern universities like those of London, Birmingham, Manchester, Bristol, Liverpool, and Wales, that is to say the *men* who are the *pick* of those who pass through the universities, who do the bulk of the very advanced teaching work of these universities—much of it laborious evening work—all men with brilliant degrees (possessing in nearly all cases the highest scientific degrees attainable, often possessing the doctorate of both an English and a German university), all engaged in researches and making discoveries in science which aid the public in health and sickness, and whose steady but unobtrusive work forms the basis of the great scientific discoveries which from time to time startle the world and lead to the creation of world-wide industries—surely such men at least get a fair wage for their work, a wage as good as that, say, of a clerk in a bank or an employee in the Post or Patent Office, or, at least, as good as a *second division civil service clerk.*

Nothing of the sort. They do not even obtain a living wage, still less a pension! I do not exaggerate. Let me explain. Most of the research work done in England is carried out in our modern universities *by the teaching staff.* Students do little because (as explained below) our university regulations are ingeniously framed so as to make it unprofitable for them to do it. Now the staff of a modern university is very sharply divided into two classes, viz. professors and non-professors. All the latter, some of them men of forty, and more, are known as the "junior staff." A professorship represents the greatest prosperity to which a scientist can reasonably hope to reach. The salary may be put as £600 to £800 a year. Comfortable, you will say. Yes, but meagre compared with that of a *successful* lawyer, surgeon, physician, stockbroker, or man of business.

But what of the junior staff? They start at, say, twenty-two to twenty-five years at anything between £100 and £120 a year. Very, very rarely do they ever get more than £200 or £250 a year at forty years of age. The bulk can *never* obtain professorships, and the few that do ultimately attain to this highest honour seldom do so before they are forty.

These men are sweated at a salary which commences at say £120 and possibly goes up to £200 by the time they are thirty-five or forty. They work often from discouraged by the regulations of the chief British universities, who have made it most unprofitable for an average student to indulge in research of any kind.

Very different is the German system, where the universities turn out, not mere teachers of little boys or

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nine in the morning to ten at night at teaching and researching. After middle age (if they survive !) they may with luck expect some improvement. This, then, is what the brilliant university graduate (and only *brilliant* men are taken on) may expect if he takes up pure science as a profession :—Five or six years' hard work for a brilliant degree, fifteen years' apprenticeship of still more laborious and difficult work at an average salary of £175, and then, with luck, but very doubtful, a possible £600 to £800 a year. This is the country's offer to its best scientific brains. Three months' holiday in the year, I hear my readers whisper. Nothing of the sort. The young scientist in these modern universities has to spend the bulk of his holidays in the stifling air of the laboratory working 12, 13, and 14 hours a day at his subjects—if ever he is to attain that professorship which looms vaguely in the remote distance.

"Poverty" is the excuse put forward by the modern university for sweating 95 per cent. of their teaching staff at this sort of salary. Yet with incredible meanness they forbid them to augment their salary by outside work, and everyone knows that they raise and spend *hundreds of thousands of pounds* for pretentious buildings (what has Birmingham and Bristol spent within recent years on huge buildings?), in spite of the fact that the *average chemical or physical laboratory is as out of date in twenty years' time as is a modern battleship, and that all that is wanted to carry on the work are a few corrugated-iron sheds fitted with working benches with high-pressure water, gas, and electricity laid on.* It is *men* not *buildings* that are the need. Even when money is obtained ear-marked for salaries, a few more assistants are appointed at the same meagre wage, the clerks engaged in purely routine work in the office get a "rise," but no improvement in the position of the junior scientific staff ever takes place. The main problem agitating the university authorities seems to be how to secure incredibly highly qualified scientists at incredibly low salaries. Civil servants are all assured of a living wage by the time they are middle-aged men (say thirty-five or forty) and of a pension afterwards. University teachers, who should rank at least as high as junior second-class civil servants, however, do not attain even this nor do they get pensions. They are told that they must keep "moving on" and that their positions are not permanent. The theory is that they must leave their positions and attain better ones, and the responsibility of the university then ceases—though where they are to "move on" to is left delightfully uncertain. Postmen, clerks in banks, &c., have not this nightmare hanging over them after years of hard and honourable work.

Equally miserable is the pay of technical chemists. Very often they are not paid more than labourers, packers, &c.—in spite of the fact that a long and expensive training is necessary to attain full chemical qualifications.

men crammed with bookwork—as our universities do—but practical men, men *trained in methods of research.* For the German university regulations made it profitable for the student to take up research work, and later these students were absorbed into chemical industry. And the result? Germany turned out chemical products of the annual value of £750,000,000; and in certain chemical products she dominated the world's markets. Meanwhile our universities are merely multiplying examinations and academic distinctions of all kinds, increasing their difficulty and putting all sorts of obstacles in the way of research for students. And yet so long ago as 1877 Huxley remarked:

> "I would make accessible the highest and most complete training the country could afford. Whatever that might cost, depend upon it the investment would be a good one. I weigh my words, when I say that if the nation could purchase a potential Watt, or Davy, or Faraday, at the cost of a hundred thousand pounds down, he would be dirt cheap at the money. It is a mere commonplace and everyday piece of knowledge, that what these three men did has produced untold millions of wealth, in the narrowest economical sense of the word."

Our universities, therefore, should aim at producing not men who *know* a lot—the assimilators of other people's ideas—but *research* men, men of a creative type of thought, who are capable of inventing and producing new things, and are able to harness the forces of nature to their ends. If our university senates see a ghost of a chance they promptly invent some fresh examination for the benefit of the hapless students.[1] They should *diminish*

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[1] In almost any modern English university, for example, before a student can attain its highest Degree in Science or Arts he has to pass no less than four or five separate examinations, each of an increasing stage of difficulty. He is, therefore,

the number of examinations and *increase* facilities for research—as every scientific academic teacher who has had experience in teaching young men and women knows. Make it profitable for your student to undertake research and he will do it with enthusiasm, and boldly plunge into the unknown. Face him with a succession of Chinese-like examinations—as our universities now do—requiring years of study to surmount, and leaving the student jaded and tired to death of mere bookwork at the end of it all, and you find that the average student will never have the energy or freshness left after all those wasted years to face research, which is itself hard and weary work.

In England and Scotland our university research laboratories are empty, but our "knowledge-cramming" classes full. In Germany the research laboratories were full and the "cramming" classes empty—the result of wise university legislation in the latter country.

What has already been achieved by chemical research may be realised when I tell the reader that within the last few years there have been obtained synthetic dyes far brighter and more durable than any natural dyes, artificial fibres far more lustrous than any natural fibres, manufactured scents a thousand times more powerful than any natural scents, wonderful new artificial drugs which have revolutionised dentistry and medicine, abolished pain and disease, and which allow the most astonishing surgical operations to be performed without pain or danger. I might also mention artificial substitutes for bone and ivory, horn and leather, rubber and resins

during the whole of his four or five years of student life kept in a turmoil of examinations, and the only knowledge which appeals to him is that which will help him to answer a probable examination question. The effect of this mental attitude on the teacher may be easily imagined. He dares not touch on anything except those portions of science which adapt themselves to examination requirements—otherwise he loses the interest of his hearers!

(often superior to the natural articles as regards some properties), and tough transparent substances like celluloid and other film-making materials, which have allowed the wonderful development of living pictures and motion photography. Perhaps, however, the greatest achievement of modern chemists is the discovery of explosives of terrific power, which have enabled man to blast his way through mountain and valley, and have rendered possible those truly astonishing modern engineering feats which are rapidly transforming the whole surface of our planet.

When I tell the reader that all these things are but the prelude to far greater achievements, which will ultimately lead to the harnessing of the natural forces of the Universe by man, he will realise that chemical research is no dry and uninteresting subject, but is one which teems with problems, the solution of which will bring into the grasp of the solver prizes of immense value.

At one time—and that quite recently too—terrible epidemics swept across the world, decimating the human race.

The great plague, for example, coming from China swept right across Russia and Europe into England. We are told that grass grew in the streets of London and the dead were so numerous that there were scarcely enough men left to bury them! This was simply an invasion of foreign bacteria, far more deadly than any invasion of human foes; even at the present time such invasions, causing bacterial diseases, levy a frightful toll upon the human race, killing annually millions of men, women, and children. By the manufacture of bacterial killing substances—the so-called "antiseptics"—the chemist has done much to save us from disease; it is safe to state that now it would be impossible for plague to sweep over the world and decimate the whole human race, as it formerly did, not once, but many times. Antiseptics have obviated for ever such a possibility, and the world has to thank chemists for this great advance. At the present time chemical remedies are known for many diseases, and many authorities believe that a time will come when diseases like typhoid and scarlet fever will be as rare as are now fatal mechanical accidents among civilised races. Indeed, many diseases, at one time regarded as very dangerous, are now considered scarcely worse than an ordinary cold.

The chemist also protects us from professional poisoners, who once flourished in Europe to an almost incredible extent, and who still flourish to some extent in many Eastern countries. In past times almost every man of note went in danger of secret poisoners, and medical science was then not sufficiently advanced to decide whether a man died suddenly in a fit or from a swift poison. Now, however, all this is changed, for by the swift and sure means of chemical analysis the chemist can detect poisons in the human body even after the unfortunate victim has been dead for months, and so can bring the guilty ones to justice. Secret poisoning, thanks to chemists, is now almost as deadly to the poisoner himself as to the victim!

Chemistry has revolutionised not only the Arts of Peace but also the Art of War. Whence, for example, has come the knowledge that has made possible the long, slow evolution of the rude bow and arrow of the savage into the great guns of to-day? Surely from the laboratory of the chemist. He has given us our fine steels and our high explosives without which modern armament would be impossible. The modern battleship is but a vast floating engineering shop, whose death-dealing appliances derive their irresistible power from explosive chemicals. Likewise the airship, the aeroplane, the waterplane—where were they invented? Not on the battlefield, but in the shed of the scientific inventor; not until the chemist had discovered how to distil out volatile, explosive components from oil, wherewith to furnish the motive power for their engines, was their advent possible.

All these are practical achievements the value of which can be realised by the average man in the street. But chemists have made discoveries which lead us right into a fairy land of science, discoveries which must appeal to the imagination of every thoughtful person, and which enable us to withdraw awhile from the cares of life and enjoy the calm of science:—

> "The silence that is in the starry sky,
> The sleep that is among the lonely hills."

We all know that the astronomer deals with things of infinite vastness, the grandeur of which, the revealing of series of worlds stretching away in endless vistas into space, strike with awe even the most thoughtless mind. The chemist has revealed equally wonderful things in the domain of the infinitely small; he has directed the arm of reason into regions of almost inconceivable minuteness to weigh and measure the tiny atoms which build up matter—objects so small that they lie as far beyond the vision of the most powerful microscopes as these carry their vision beyond that of the naked eye. Nay, recently the chemist has passed beyond the atom itself and has revealed to our astonished gaze a domain in which the atoms themselves loom as great galaxies built up of still tinier particles. And thus the chemist has given us a truly astonishing vision of universe within universe receding into the infinitely small—just as the astronomer has revealed to us universe within universe stretching away into the infinitely great. The whole vista thus opened out by modern chemistry lays bare hitherto unsuspected depths of complexity in the commonest and most insignificant things about us. Tennyson long ago expressed this grand truth in the lines:—

> "For Knowledge is the Swallow on the lake
> That sees and stirs the surface-shadow there
> But never yet hath dipt into the abysm,
> The abysm, of all abysms, beneath, within,
> The blue of the sky and sea, the green of Earth
> And in the million-millionth of a grain
> Which cleft again for evermore,
> And ever vanishing, never vanishes,
> To me, my son, more mystic than myself
> Or even than the nameless is to me."

And now what of the men who have achieved these wonders—the workers in the rank and file of the great scientific army? What manner of men are they? Well it must be confessed that the majority are very ordinary individuals, certainly not even approximately as distinguished looking as poets or artists or actors or soldiers. They wear neither long hair nor exaggerated neckties, nor have their clothes an extraordinary cut. Indeed, beyond the fact that they are somewhat more shabby than the ordinary business man there is nothing to distinguish the average scientist from the average man in the street. The popular notion that Science is a happy family of mutually admiring absent-minded philanthropists, each striving for the benefit of the human race, is very far from being a picture of the reality. So far from thinking solely of benefiting the human race, most professional scientists, I am afraid, are much more concerned about earning enough money to buy their wives nice hats and bring up their families respectably! In fact, they are just ordinary, everyday men. The scientific world is a very restricted one with prizes few and far between, where the struggle for survival is as fierce as in any natural species, and where bitterness and spite and disappointed hopes are as prevalent as in the industrial or artistic world. As in other branches of activity, the "top" is no limitless plateau with room for all scientists. Rather it is a spiky pinnacle whereon a few eminent professors uncomfortably sit, and occupy most of their spare time in shoving down their junior colleagues who would presume to climb to the same level.

More often than not great scientists pass their lives in obscurity. Yet they have this consolation—their achievements will ultimately be recognised and will spur unborn generations on to fresh endeavours:—

"He is not dead whose glorious mind
Lifts thine on high.
To live in hearts we leave behind,
Is not to die."

How often do we, when engaged in investigating new and unknown regions of science, come across the work of men dead and forgotten scores of years ago; their personality again lives before us in their writings, and we idly wonder concerning their forgotten struggles and difficulties. There is one thing every scientific investigator must bear in mind—and that is accuracy. Facts which are inaccurate and which live in the literature of science for a time, ultimately come home to roost—a Nemesis to the hasty and inaccurate worker. As Goethe put it:—

"Haste not, let no thoughtless deed
Mar for aye the spirit's speed.
Ponder well, and know the right,
Onward then, and know thy might;
Haste not, years can ne'er atone
For one reckless action done."

As a class, successful scientists have one or two small characteristics which differentiate them somewhat from other classes of men.

In the first place, a scientific discoverer owes his success to a highly developed but peculiar mental characteristic—and that is excessive attention to minute detail. His is a mind which frets itself into a frenzy about minute discrepancies which an ordinary individual would regard as too minor for serious attention. Nearly all great discoveries have been made by this attention to little discrepancies.

"Powers of careful observation" is the euphemistic term by which scientists denote this necessary characteristic for discovery. Consequently your successful scientist tends to attach exaggerated importance to little things. He is a "crochety," "finicking" individual. This is why scientists are always quarrelling, disputing about petty details. They are remarkably jealous of each other, usually referring to work other than their own as "very ordinary" if it is a careful, exact piece of research; whereas it becomes "too speculative" if the worker goes in for any degree of originality, and the poor man is always spoken of (behind his back) as "quite unsound." Most eminent scientists in any one branch are deadly enemies. Indeed, it is a most entertaining—if not a dignified—spectacle, to see one eminent professor "slating" another eminent professor's book in hypercritical reviews. Moreover, those professors who write books look down on those who merely do research work, and vice versa. Their ideas are usually distorted as regards the relative value of things, and it is this which has led to the current English notion that a scientist is "unpractical" and a "Fuss pot." I doubt whether scientists could govern a state any more than artists or actors could. Scientists deal with Nature, but Statesmen deal with men, and the qualities which tend for success in the one branch of activity will often be the antithesis of the qualities needed for success in the other sphere of activity.

The average English business man—whose success in life depends entirely upon exercising commonsense—when brought into contact with the new, strange world in which the scientists wander, views with blank astonishment these men disputing, quarrelling, and attacking each other about what seem to him the veriest trifles; he classifies the whole pack as a lot of semi-maniacs. This attitude of mind is largely responsible for the utter lack of sympathy which prevails in England between scientists and the business world, and is the real reason why scientists as a class are so miserably poor.

"The beakers and flasks of the scientific investigator," said the great German chemist, Emil Fischer, "are minute compared with the vats employed by the chemical manufacturer. This relative difference in size also corresponds to the comparative wealth of these two classes of men."

Certainly if scientists as a class had any business ability they would have long ago improved the pittances which are now paid to fully trained men. Scientists simply do not realise their power, and fail entirely to act in a united manner to secure proper recognition of their services. They should be protected from exploitation, especially as the average Englishman thinks that it is the duty of every scientist to be a "martyr to science."

These peculiarities of scientists have been noted for centuries. Thus in the old work entitled *Physica Subterranaea*, published nearly two hundred years ago, we read the following:—

"The chymists are a strange class of mortals impelled by an almost insane impulse to seek their pleasures among smoke and vapour, soot and flame, poisons and poverty, yet among all these evils I seem to live so sweetly, that may I die if I would change places with the Persian King."

Charles Kingsley, who undoubtedly would have made a great scientist if his walk in life had lain in another sphere, speaks some admirable words on the disinterested labours of scientists. They are well worth quoting, although I am afraid they envelop the scientist with an idealistic atmosphere which one better acquainted with this species of the human race would know is far removed from the reality.

In a lecture[1] delivered to the Royal Institution many years ago, he said, speaking of Science :—

"Her votaries have not as yet cared much for purple and fine linen, and sumptuous fare. There are very few among them who, joining brilliant talents to solid learning, have risen to deserved popularity, to titles and to wealth. But even their labours, it seems to me, are never rewarded in any proportion to the time and the intellect spent on them, nor to the benefits which they bring to mankind; while the great majority, unpaid and unknown, toil on and have to find science her own reward. . . . They are engaged in a war—a veritable war—against the rulers of darkness, against ignorance and its twin children, fear and cruelty.

"I can conceive few human states more enviable than that of the man to whom, panting in the foul laboratory, . . . Isis shall for a moment lift her sacred veil, and show him, once and for ever, the thing he dreamed not of; some law, or even mere hint of a law, connecting them all with each other and with the mightier whole, till order and meaning shoots through some chaos of scattered observations. Is not that a joy, a prize, which wealth cannot give nor poverty take away?"

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[1] Kingsley, *Scientific Essays*, published by Macmillan & Co.

Kingsley elsewhere observes of the scientist :—

"He is following a mistress who has never yet conferred aught but benefits on the human race."

And, yet, to this very day, the scientist in the stage play or average novel is always represented as a villain, seeking to murder someone by the aid of mysterious powers!

Tennyson, who had possibly an intimate personal knowledge of scientists, had a decidely lower opinion of them than Kingsley. Tennyson naturally thought, that men who dealt with the mysteries of the universe ought to possess lofty and poetic minds. He found them, however, like ordinary mortals, concerned with petty things and petty spites, and so in "Maud" he described them as having :—

"An eye well-practised in Nature, a spirit bounded and poor."

However this may be, I do not think that anyone can deny the really astonishing achievements of modern chemists, or dispute the truth of Kingsley's words :—

"What physical science may do hereafter I know not; but as yet she has done this: She has enormously increased the wealth of the human race; and has therefore given employment, food, existence, to millions who, without science, would either have starved or have never been born."

It is not the fault of science that Germany has harnessed her to the chariot of death and destruction. Science is potent beyond all belief for good—but she puts terrible powers into the hands of madmen.

Chemists have even dared to leave the inanimate world and have attacked the problem of life itself. In earlier times, even so recently as the first decades of the nineteenth century, men looked with awe upon the mysterious region of vital chemistry. They saw plants and animals produce with ease and in abundance innumerable curious substances which, in the laboratory, men failed altogether to produce ; to mention a few : beautiful dyes, which tinge plants and animals the most exquisite colours, from the soft pink of the rose, through shades of glorious red of the carnation, to wonderful tints of yellow, green, and purple ; sweet tasting sugars, beautiful perfumes, powerful poisons, and wonderful healing drugs, all produced by the strange chemistry of plant and animal life. Yet up to the year 1827 no man had ever produced in the laboratory a single one of these bodies, and chemists hovered awe-stricken at the entrance of this vast chemical domain, fearing to enter, and regarding all these products of the wonderful life-activity of animal and vegetable life as the direct manifestation of mysterious vital forces which prevailed only in living matter and which produced results which no man could imitate. Indeed, not a few persons were of the opinion that even to dare to enter this region, and to endeavour to understand the processes by means of which animals and plants produced these astonishing results, was something in the nature of blasphemy, being in their opinion attempts to spy upon the secrets of the living God and to observe how he brought forth in secret the wonders of the living world.

And so it came about that the whole scientific world was in 1827 thrilled by the announcement that a scientist had actually made a substance artificially which until that time had been brought forth solely in the laboratories of the animal body. For in that year the great German chemist Wöhler succeeded in making in an artificial manner from purely mineral substances the white crystalline substance called urea—a typical vital product. We can well imagine the wonder and delight with which Wöhler first gazed upon artificial urea—a substance now manufactured artificially in tons at a time—and solemn must have been the thought which flashed through his mind that now for the first time in all the ages since the world began, he gazed upon an artificial organic product.

This feat was the forerunner of many other similar ones. Fats were made artificially so far back as two generations ago by Berthelot of Paris.

Artificial grape sugar saw the light twenty years ago at Würzburg. Artificial dyes innumerable are now manufactured in tons at a time, and to-day great industries have arisen in which millions of pounds' worth of substances, formerly only known as the product of vital activity, are annually produced by purely chemical means. It is therefore altogether hard to realise the time when the production of a single artificial organic substance was the cause of endless astonishment.

Now such products are so common that men have ceased to take any notice of them. It is true that only comparatively simple organic bodies have been thus obtained in the laboratory. The immensely more complex organic substances, such as albumen, have not yet been synthesised ; but yet recently a beginning has been made. Thus within the last dozen years Emil Fischer in Berlin has worked out methods for the artificial building up of albuminous substances, and in 1911 showed a small bottle full of the substance thus obtained. This synthetic protein, however, is anything but cheap. The starting materials for its preparation cost about £50, and the labour involved in its preparation must have been much more costly than even this, and so the substance has not as yet appeared on the breakfast table as a food ! It was exhibited simply as a chemical curiosity. But one must remember that the chemical curiosities of to-day are to-morrow world-wide articles of commerce, and so this synthetic protein may be the forerunner of a world-industry of artificial foodstuffs.

The reader must recollect, too, that at the present time the whole human race has to rely for food and warmth upon grains, roots, fruits and fibres, and upon animals to whom organic nutriment is as essential as it is to us. It is true that Science can do much by intensive cultivation and by scientific feeding to increase our planet's stock of foodstuffs. But there is an ultimate limit to the productive powers of the soil of our planet, and although we may increase it greatly by scientific means, yet the population will increase in equal ratio and no doubt will go on increasing long after the reproductive power of the soil has reached its limit.

But what a new vista would open out if Science should discover some means of enabling us to feed on inorganic material such as surrounds us on every side in untold billions of tons! The atmospheric nitrogen, which is about us on every side and of which some seven tons' weight rests on every square yard of the world's surface—sufficient nitrogen for nearly fifty tons of living matter—is even now being fixed by electrical means and converted into manures, and so ultimately into food. But Emil Fischer's synthesis of simple proteins is a stage further than this. It represents the artificial production of actual foodstuffs by purely chemical means, from the purely inorganic materials which surround us on every side in millions of tons. And if Science should so advance as to make the production of this artificial food an easy matter—giving us bread, so to speak, from the air and stones about us—then food would become so inexpensive and so abundant that the human race could multiply into numbers which altogether baffle conception.

The difficulties to be surmounted, however, are stupendous. Nevertheless the very bread we eat, and most of our foodstuffs, may yet be produced on a manufacturing scale by chemical means. Then, indeed, a new epoch will have dawned for the whole human race. Mankind will have reached a new stage in his upward development. And what the end of it all will be we cannot even guess. It may be that we are just in the beginning of the beginning, as Tennyson hinted in the pregnant words:—

"Well—were it not a pleasant thing
To fall asleep with all one's friends
And every hundred years to rise
And leave the world, and sleep again:
To sleep thro' terms of mighty wars,
And wake on Science grown to more,
On secrets of the brain, the stars,
As wild as aught in fairy lore;
Titanic forces taking birth
In divers seasons, divers climes,
For we are the Ancients of the Earth
And in the morning of the times."

On the other hand, it may be that Science will not continue to advance at her present swift rate of progress.[1]

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[1] One great danger to the ultimate progress of Science is the rise into power of the great Scientific Societies, whereby the whole of crystallised scientific thought becomes vested in the hands of a few men, who, like the Theological Societies of old, will crush and suppress any attempt of scientists to break away from established tenets or establish free modes of thought among themselves.

Paradoxical though it may seem, a period of reaction follows the work of every great original thinker, and the mistakes or influence of a Newton or a Helmholtz often paralyse for many years the labours of workers in whole branches of thought which were traversed by these great minds. A great thinker like Aristotle probably put back scientific thought for 2000 years! Now when immensely rich and immensely powerful International Scientific Societies (Science is International) adopt as fairly and irrevocably established certain great theories and methods of investigation, their power to crush free thought and free investigation is enormous, and their motives in doing it will be identical with the motives which impelled the Priesthood to crush free-thinkers in the Middle Ages—namely the firm conviction that in so doing they are benefiting the human race and doing the right thing. The reader must remember that human nature is un-

It may be that a long period of stagnation, lasting for thousands of years, may follow the present epoch of enhanced activity. But of this period of stagnation we can at present detect no sign. Science, aided by thousands of busy brains, is striding onwards so swiftly that no single man can keep pace with her or prophesy into what unknown regions of fact and thought she will next launch us.

As yet we are far from any information which will lead us to expect the artificial making of any piece of living matter in our laboratories. The simplest organism is marvellously complex, the end product of billions of years of evolution in Nature's laboratory.

However "biological chemistry"—as the science which deals with vital processes is called—is already well-established and rapidly advancing. Its progress is fraught with the most momentous consequences to the human race.

In biological chemistry most processes are carried on by means of mysterious substances called "enzymes" which up to this time have never been obtained in a pure condition, but which cause chemical changes to take place without themselves undergoing much change. Now since we are dependent, not only for the assimilation of our very food, but also for a large part of our luxuries and comforts, upon these changes, it will readily be seen that when man acquires the power of guiding them very strange things may come to pass. Most of

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changed, and that the irresistible tendency of all men is to resent any attempt to deviate from the established order of things. Science can *only* advance by allowing *freedom of thought*, and even when men hold opinions which we feel *absolutely certain* are incorrect, tolerance should be extended to such views. Advances are *always* made by *minorities*, whose opinions, gradually gaining ground, finally become *majorities*, only in turn to be assailed by other minorities. The power of the few men who control the English and the German Chemical Societies is, at the present time, simply enormous. They completely sway between them the whole of scientific chemical activity in this country and abroad. Should such men become too conservative they could block and suppress original ideas and make chemistry a stagnant science. See, for example, p. 119.

the countless chemical changes which occur in the animal and vegetable kingdoms—some of them of a truly wonderful nature—are due to the action of these enzymes. Many of the oldest industries of the world's history—the making of wine, beer, and vinegar, the souring and clotting of milk to form cheese, the tanning of hides—are dependent upon the formation of enzymes in the bodies of bacteria or in living tissues. The same is true of the fermentation processes employed in the retting of flax, in the curing of tea and tobacco, coffee and cocoa. Even the coagulation of blood from a wound (which stops bleeding) and the processes of digestion are all dependent upon enzymes. So also are modern processes for disposing of sewage by bacterial oxidation. Now that these results of biological science are being applied in the service of industrial and economic chemistry, the results which will ultimately follow are altogether difficult to foresee.

The influence of these discoveries on our ideas of the mechanism of life itself is very great. Although the fundamental secret of the nature of life still remains, and will long remain, hidden from our eyes, yet it is indisputable that much which was quite recently regarded as vital and inseparable from living matter has been proved to depend upon conditions which can be realised apart from the living organism; it is indisputable that the veil hiding the actual crude material mechanism by means of which the vital processes are carried on, is being rapidly drawn aside by the chemist. But unfortunately this brings us little nearer to the mystery of life itself. For example, what is *Thought* and all the allied mental phenomena? How can any rolling concourse of atoms thrill thought and consciousness into matter? It avails not how complex a system we conceive of flashing atoms and sub-atoms, for our chemistry cannot explain how thought arises from their motions and arrangements. It may be true that the notion of a flower or a picture or even a complex mental resolution all take their rise in definite atomic motions or collisions going on in our brains—but these changes do not constitute or explain the arising thought itself.

A man is but an aggregate of material atoms—whirling, wheeling, colliding—in ceaseless change. And Science, before she can pretend to have solved the problem of life, must explain how such a mere aggregate of so many pounds' weight of carbon, nitrogen, phosphorus, oxygen and hydrogen atoms can evolve thought and consciousness by the mere relative movement of these atoms.

At present Science has no standpoint wherefrom to plunge into such mysteries ; she has no sure anchoring ground from which to venture into the unsounded depths of *Mind*, to conceive of its generation and flight. She has nothing definite to lay hold of in such shadowy realms, nothing to grip and guide her experimentally as in the more material sciences such as chemistry and physics and mechanics, where experiment reigns supreme.

And so, in spite of all the enormous advances of Science within the last few centuries, we are, apparently, as far as ever from the solution of the great mystery of life itself.

Even to-day, after a century of strife, Science still knows not whether Wordsworth was right when he wrote the grand words which represent the intuitive belief of unnumbered millions of the human race :—

"Our birth is but a sleep and a forgetting!
The Soul that rises with us, our life's Star,
Hath had elsewhere its setting
And cometh from afar.
Not in entire forgetfulness
And not in utter nakedness
But trailing clouds of glory do we come
From God, who is our home."

CHAPTER II

THE ROMANCE OF SOME SIMPLE NITROGEN COMPOUNDS

NITROGEN, like carbon, forms an innumerable multitude of compounds. So numerous are they, indeed, that a large book could be written about them alone. These compounds are among the most important known, comprising as they do the bodies which build up living matter, explosives, medicines, drugs and dyes—in a word all those bodies which serve the thousand and one wants of civilised peoples. Interesting as the subject would be, we cannot treat of these substances here. I wish to direct the reader's attention to some quite simple nitrogen compounds, which are of surpassing interest at the present time.

The fate of a world probably rests upon two simple compounds of nitrogen—namely, *nitric acid,* HNO_3, and *ammonia,* NH_3.

This is a fact sufficient to direct attention to these two substances, old friends of our schooldays as they are, and invest them with a fresh interest. Indeed they form the centre of attention of the scientific world at the present time, since it is directly or indirectly from these two bodies that all our effective explosives are made.

Deprive a nation of them, and slowly but surely her offensive power declines and ultimately vanishes, for with them goes her means of manufacturing explosives. Moreover, her supplies of food must dwindle and fall far below the needs of any congested population, because nitrates and ammonium salts are needed by the land for manurial purposes, to supply nitrogen to make crops grow.

Let us, therefore, first of all concentrate our attention on these two substances. Of the two *nitric acid,* HNO_3, has possibly the greater commercial importance, and so we will take that first.

It is a colourless liquid. The pure acid is terribly corrosive, attacking organic material such as paper ,wood, and skin extremely rapidly. Most metals dissolve in it, evolving poisonous nitrous fumes. Moreover, the strong acid is decomposed by light, evolving oxygen gas. Hence if an air-tight bottle of the pure acid is placed in a brightly lighted room, enough oxygen may be gradually formed to cause such a pressure inside that the bottle explodes and hurls the fluid in all directions on to the wooden floors and benches. When this occurs invariably the wood takes fire and burns furiously. Some chemical laboratories have been burnt down in this way. The acid is, therefore, always preserved in dark blue bottles in a dark place. For a similar reason it is very difficult to send pure nitric acid in large quantities long distances by rail. For if the glass vessel in which it is confined should happen to break, then the strong acid pouring over the waggon almost always sets it alight. Consequently the substance, when in large quantities, is sent diluted with water. In the colour industry, however, it is absolutely necessary to have a very strong acid free from every trace of water. The difficulty of transportation was ultimately got over by mixing the strong acid with an equal volume of strong sulphuric acid. The mixture can be sent in iron vessels, and consequently without danger, since the iron becomes "passive" or insoluble in acid, owing to, some authorities say, a thin coating of iron peroxide forming a protecting film over it.

Owing to the terribly corrosive properties of nitric acid many fearful accidents have happened, and of these the most dramatic was that which occurred some years ago in a large German dye-factory. A workman overbalanced himself and fell into a large vat containing a boiling mixture of strong nitric and sulphuric acids, such as is used for dissolving dyes. There was no one in the building to hear his last despairing cry, and when, later, the man was missed, nowhere could a trace be found of him. His vanishing was an absolute mystery which no one could account for. Some people thought that the man had secretly fled the country and gone to America, others that he had met with an accident. The manager of the works suggested that he had fallen into

FIG. 1.—Railway trucks set on fire by nitric acid.

the acid and had been dissolved, hair, flesh, boots, clothes, bones and all. The weeping wife now laid claim to his insurance money, but the assurance officials refused to pay out anything. "Produce us evidence of death," they said, "and we will give you the money. How do we know that your husband has not simply secretly left the country?" So the poor widow was in a sad plight and at her wits' end what to do. She appealed to the manager of the works, and he resolved to solve the problem. Being a chemist, he knew that the human body contains quite a considerable amount of phosphorus, which must be found in the acid (if the man had really fallen into it) in the form of phosphoric acid. So he caused an analysis of the liquid to be made, and sure enough found a large amount of phosphorus present, such as represented the amount known to be in the body of a full grown man. This evidence was then presented, and the end of it all was that it was accepted as conclusive evidence of death, and the poor widow received the payments due to her. Applied chemistry is thus of great use, sometimes, in legal matters, although lawyers are not, as a rule, trained in such matters.

Nitric acid, being one of the most important of modern chemicals, is manufactured in enormous quantities. It is stated that more than 100,000 tons are made annually—enough to form a lake 200 yards square and 10 feet deep. At the present time, owing to the war, far greater quantities than this are being made.

Nitric acid is absolutely indispensable for making dyes and explosives. The aniline dye industry—worth millions of pounds annually—would be non-existent without nitric acid. So also would the explosive industry. Almost every high modern explosive in some stage or other in its manufacture requires nitric acid.

Thus nitro-glycerine—the basis of dynamite, cordite, blasting gelatine and the like—is made (p. 59) by bringing together nitric acid and glycerine. Picric acid (the basis of lyddite, mellinite and the like) and trinitrotoluene, so important as the bursting charge of modern shells, are obtained by allowing nitric acid to react with phenol and toluene—substances contained in coal tar. Ammonium nitrate—a compound of nitric acid and ammonia—is the base of most mining explosives.

Therefore, deprive a nation of its nitric acid and you deprive it of its explosives and of its power of waging war.

Until quite recently practically the only source of nitric acid was Chile saltpetre (sodium nitrate, $NaNO_3$). The acid was—and still is—obtained from this by heating it in iron boilers with concentrated sulphuric acid (oil of vitriol), when the following change takes place:

$$\underset{\text{Sodium nitrate}}{NaNO_3} + \underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\text{Sodium hydrogen sulphate}}{NaHSO_4} + \underset{\text{Nitric acid}}{HNO_3}$$

The nitric acid which distils over is collected in earthenware vessels.

Now, until quite recently, practically the world's whole supply of nitrates came overseas from a rainless and desert strip of land lying along the coasts of Chile and Peru; it was long ago remarked that with all her strength Great Britain could be put out of commission in war times simply by cutting off her supply of nitrates from Chile. The same applied with even greater force to Germany and the Continent of Europe.

In England at the time of writing the same fact holds to-day; but in Germany new factors have come upon the scene, and she no longer depends to the same extent as formerly upon overseas imports of nitrates. Germany has begun to make her own nitrates and nitric acid. In my former book, *Triumphs and Wonders of Modern Chemistry*,[1]

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[1] 2nd ed., p. 196.

I explained how in the atmosphere we have a practically inexhaustible supply of nitrogen—about 4000 billion tons.

Every square yard of land has about seven tons of nitrogen lying over it: but all this nitrogen is "free" and therefore useless for chemical purposes. We have to combine it or "fix it" as chemists say, before we can turn it into useful products.

There are several ways of doing this. In the first place we can *burn* the nitrogen of the air directly to nitric acid simply by causing it to pass through a high tension electrical arc. How this was done was briefly indicated in my former book, but the subject has developed since then and so, for completeness' sake, some additional details are here given.

The various processes now in use for directly burning the air to nitric acid are shown diagrammatically in the accompanying drawing, which is taken from the writer's *Chemical Lecture Diagrams*.

Fig. 1 shows a general view of the plant. A is the air compressor, which forces a steady stream of air into the electrical furnace B (which may be any of the types shown below). Here combination of nitrogen and oxygen occurs, nitric oxide, NO, being formed, thus: $N_2+O_2=2NO$; and the gas at 800–1000° C., mixed with excess of air, passes into the cooling chamber C, and then along a series of pipes, D D, which traverse the interior of a boiler, F, and so heat it sufficiently to cause it to develop enough steam to work the pumps, &c.

The gas, now cooled to about 50° C., enters a large oxidation chamber, G, where the nitric oxide, NO, finally unites with oxygen still present in the air to form nitrogen peroxide, NO_2, thus: $NO+O=NO_2$, and the chamber becomes filled with the brown fumes of this substance. Combination has not occurred before because in C the temperature was too high to permit of the existence of

NO_2, as a high temperature decomposes it, thus: $NO_2 = NO + O$. The nitrous fumes now pass along the pipe H I into the absorption tower K, where it meets with a descending stream of trickling water. This decomposes the nitrogen peroxide, forming a mix-

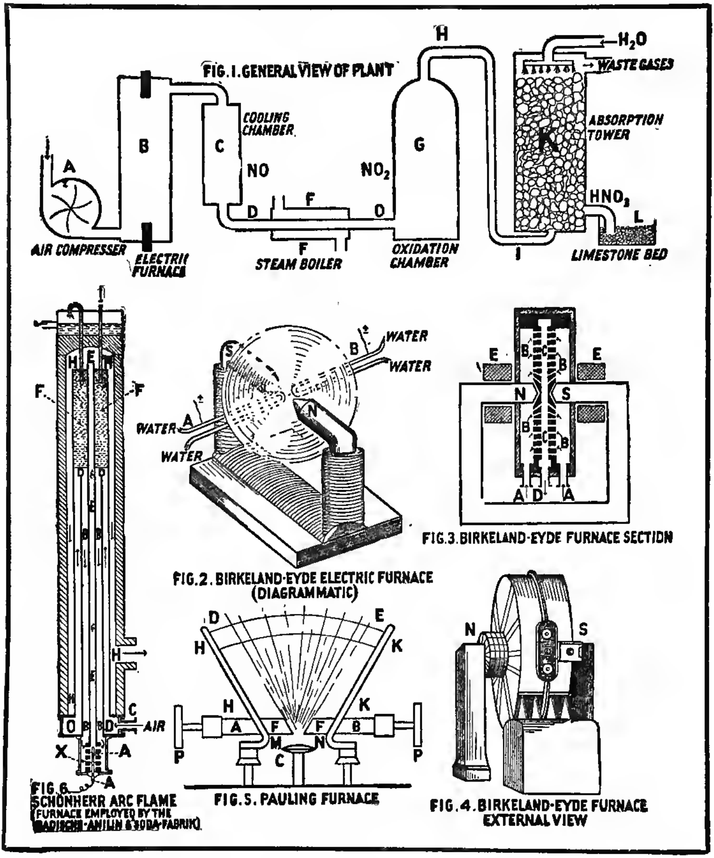

Fig. 2.—Nitric acid from the atmosphere.

ture of nitrous and nitric acid, thus: $2NO_2 + H_2O = HNO_2 + HNO_3$. This liquid can be drawn off and converted into pure nitric acid by driving warm air through it; but more usually the acid liquids are allowed to flow into a series of tanks, L, filled with moist limestone, which is converted into a mixture of calcium nitrate and nitrite. If soda or potash is employed as the neutralising medium, we get sodium or potassium nitrates produced.

Fig. 2 is a diagrammatic sketch of the Birkeland-Eyde furnace. The electrodes consist of two copper pipes, A and B, kept cool by a current of water. They are connected with a high-tension powerful alternating current, which forms an arc between them. The arc is placed between the poles of a powerful electro-magnet, which then blows it out into a wheel-like disc of flame composed of burning oxygen and nitrogen. The whole is enclosed in a refractory casing, shown in section in fig. 3 and a general view in fig. 4. The section fig. 3 shows how air is blown in to feed the flame. The air enters at A A and passes in through holes in the refractory lining. The electric flame plays down the disc-like space C C, and the burnt gases come out at D and then pass away to the absorption plant, as indicated in fig. 1. E E are the wires of the electro-magnets.

Fig. 4 shows how the Birkeland-Eyde furnace looks when viewed externally.

Fig. 5 shows the Pauling arc flame. The main electrodes A and B are bent into the shape of a V, A H H being a section of one main electrode and B K K a section of the other. The base of the electrodes thus forms at M N a vertical slot, through which are introduced thin "lighting knives" F F. These "knives" can be brought very close together by the screwing arrangement P P, and the arc, thus lighted at the narrowest portion of the spark gap, shows a tendency to rise up between H H and K K, owing mainly to the upward pull of the hot gases, but is interrupted at every half period of the alternating current, only to be reformed at the lowest and narrowest part of the electrodes. Through a nozzle, C, a stream of previously heated hot air is blown upwards into the arc, causing the air to diverge and form between the V-shaped main electrodes a flame of burning O and N, sometimes a metre in length.

Fig. 6 shows the furnace employed by the Badische Anilin und Soda Fabrik, making use of the Schönherr arc flame. A A is an insulated high-tension electrode, the other electrode being the iron piping E E, into which A A projects. An arc is thus formed between the electrode A A and the iron piping; but a stream of air is blown in peripherically at the base of the piping, through a series of orifices, X X, in such a way as to cause a rotating movement in the tube E E, and a whirling flame of burning O and N to run up the tube E E E, which is cooled at the top by the water-cooling arrangement F F. The hot nitrous gases stream away from E E, down the external pipes H H, and so out into the plant for absorbing the nitrous fumes. The air enters the furnace at C, and is heated to a high temperature before being blown into the arc (through the orifices at X) by passing up the tube D D and down the tube B B, both of which are heated by the hot gases streaming away from the furnace.

Now the main disadvantage of all processes of directly burning up the atmosphere is the very poor yield of nitric acid for the power applied. Such processes can only come into extended use in lands where power is cheap—especially in lands rich in water power, which is especially useful for the production of the electric current. Hence such processes have mainly developed in countries like Norway, Sweden and America, where very great waterfalls exist (see chap. VIII.).

Quite recently, therefore, a sensation was made in the scientific world when it became known that nitric acid can be made quite cheaply from ammonia gas, NH_3, and that the latter in its turn can be manufactured quite cheaply from atmospheric nitrogen and hydrogen, as we shall presently see.

The process for turning ammonia into nitric acid was brought to perfection by the famous German chemist Ostwald. It is simplicity itself—although many years of patient research were necessary before it was brought to commercial success. The ammonia gas is mixed with the requisite amount of oxygen gas and the whole is sent through tubes filled with a preparation of finely divided metallic platinum, which here acts as a catalyst. The temperature must be very carefully regulated, and when this is done, we get the ammonia quantitatively converted into nitric acid thus :

$$\underset{\text{Ammonia}}{NH_3} + \underset{\text{Oxygen}}{2O_2} = \underset{\text{Nitric acid}}{HNO_3} + \underset{\text{Water}}{H_2O}$$

Thus Germany's power—due entirely to scientific research—of producing nitric acid quite cheaply from ammonia, renders her independent of the saltpetre beds of Chile for the supply of her explosives. In fact, were it not for the wonderful development of chemical science in Germany, it is quite safe to say that, encircled as she is by a ring of enemies, Germany would have been beaten to her knees in a few months. Her supplies of war necessities would have been utterly unequal to the demand. She could not, in fact, have undertaken the present terrible war at all. It is German science, even more than German armies, which has made her a menace to the neighbouring nations. It has given her such a powerful command over matter, that she can produce most of her own supplies.

But this brings us back to our old friend *ammonia*, NH_3, and we must now say a few words regarding this very important substance.

Ammonia gas is lighter than air and very soluble in water, so that it must be collected by displacing the air out of a vessel as shown in the illustration (fig. 5). It may, of course, be collected over mercury. The gas thus obtained is colourless and invisible but possesses a most powerful smell. A single sniff of it will bring tears to the eyes and almost suffocate one. Indeed death has been known to follow the accidental breathing of the vapour. Ammonia gas is so soluble in water that at 0° C. over a thousand cubic feet of it will be condensed within a single cubic foot of water. The water becomes warm as the ammonia dissolves in it and extends so as to double its bulk. It is very probable that a chemical combination takes place, thus:

$$\underset{\text{Ammonia}}{NH_3} + \underset{\text{Water}}{H_2O} = \underset{\text{Ammonium hydroxide}}{NH_4OH}$$

This solubility of the gas may be shown by inverting a jar of it over water. This rushes up and completely fills it. A striking experiment is founded upon this fact. If a bottle filled with ammonia gas and fitted with a cork containing a tube which projects up inside the jar (fig. 3), be placed over water, the water will run up the jet and on reaching the end will squirt in a fountain into the interior of the jar until it is full of water. If the water be coloured red with litmus solution, this will turn blue within the jar owing to the action of ammonia, and we get a red fountain of water changing its colour to blue in a most striking way. The first drop of water which reaches the inside of the jar absorbs nearly all the ammonia in the neighbourhood and thus creates a partial vacuum inside. The external pressure of the air, pressing down with a force of 15 lbs. per square inch, then forces the water into the vacuous vessel with such force that it squirts up as a regular fountain.

The gas will not burn in air unless heated strongly. Chemically it combines with acids, neutralising them and forming a series of most important compounds known as the ammonium salts, some of which are valuable manures. The solution of ammonia in water is what is termed a "base," because it has these properties and turns red litmus blue.

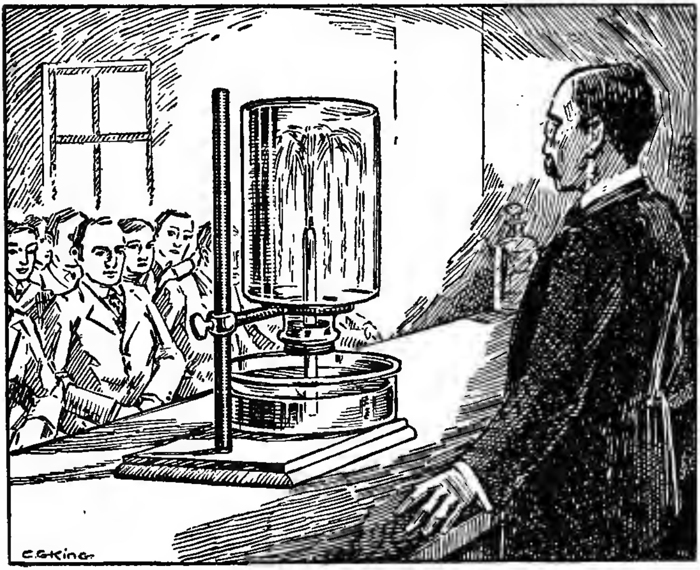

Fig. 3.—Solubility of ammonia in water.

Pressure and cold turn it into a colourless liquid which boils at – 38·5° C. and freezes at – 77° C. to a mass of white transparent crystals.

Liquid ammonia, like water, absorbs much heat when allowed to evaporate, and is now used on a large scale for producing cold and manufacturing ice. This liquid ammonia possesses very powerful solvent properties, dissolving as a rule those things which dissolve in water and in many other ways behaves like water.

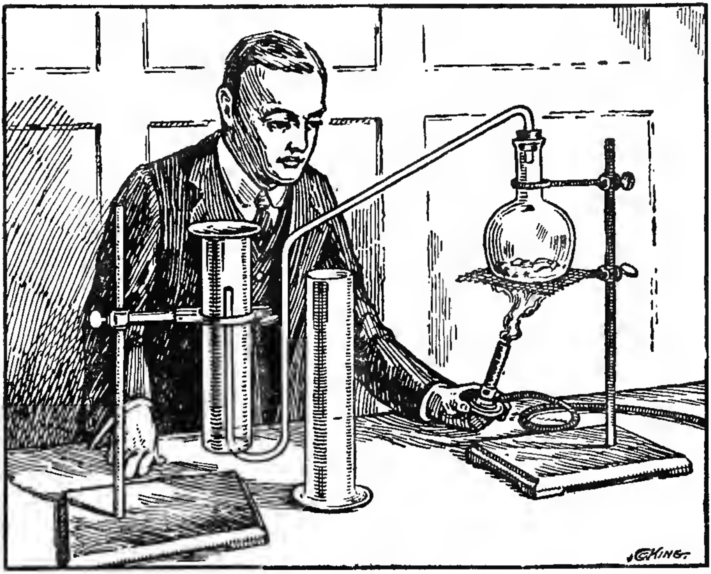

FIG. 4.—Preparing ammonia by heating lime and ammonium chloride.

Ammonia gas is easily prepared by heating together ammonium chloride and slaked lime, when the following change takes place:

$$\underset{\text{Ammonium chloride}}{2NH_4Cl} + \underset{\substack{\text{Slaked lime}\\\text{(Calcium hydroxide)}}}{Ca(OH)_2}$$

$$= \underset{\text{Calcium chloride}}{CaCl_2} + \underset{\text{Ammonia}}{2NH_3} + \underset{\text{Water}}{2H_2O}$$

As a matter of fact, very large amounts of ammonia are manufactured every year in this way from liquors which are formed when coal is distilled for the purpose of making coal gas. The coal contains a considerable amount of nitrogen, and much of this escapes in the form of ammoniacal liquors, which when collected and heated with lime evolve the ammonia as such. Usually, however, the evolved ammonia is absorbed by passing the gas into sulphuric acid, when the valuable ammonium sulphate is produced, thus:

$$\underset{\text{Ammonia}}{2NH_3} + \underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\text{Ammonium sulphate}}{(NH_4)_2SO_4}$$

Thus, even in 1906 Great Britain produced about 290,000 tons of ammonium sulphate, and Germany about 235,000 tons. This substance found its main use, of course, for manurial purposes, as plants need for growth nitrogenous food quite as much as do animals.

However such quantities, large as they may seem, are much too small to meet national needs. They are a mere drop in the ocean of the world's hunger for nitrogenous compounds. Consequently, a great sensation was produced in chemical circles in 1913 when it became known that two German chemists, namely Haber and Le Rossignol, had succeeded in solving the problem of how to make free nitrogen and free hydrogen unite directly so as to form ammonia. Of course it had long been known that hydrogen and nitrogen will directly unite under suitable conditions. A simple experiment can be carried out to prove this.

If we mix hydrogen and nitrogen gases together in the proportion of three volumes of hydrogen to one volume of nitrogen, and then pass a series of electrical sparks through the gaseous mixture, we notice that it will contract and form the strongly smelling ammonia gas:

$$\underset{\text{Nitrogen}}{N_2} + \underset{\text{Hydrogen}}{3H_2} = \underset{\text{Ammonia}}{2NH_3}$$

How electricity achieves this is not known. Perhaps the intense heat of the electrical spark shatters the hydrogen and nitrogen molecules into single atoms which then rush together to form ammonia molecules.

The subject is, however, probably far more complex than this. It is known that under the influence of the electric discharge (which we must picture as a stream of tiny electrons flying like projectiles with a velocity of thousands of miles a second across the space occupied by the whirling gaseous molecules), centres of attraction appear in the gas, being probably composed of molecules or atoms which have captured many electrons. To them come streaming other molecules and group themselves in thousands around the centre to form complicated clusters. It is probably in these clustering groups of molecules that those collisions occur which give rise to the formation of ammonia molecules. Ultra-violet light will bring about the same result, but how or why these strange changes take place remains for the most part wrapt in mystery.

However this may be, it is certain that any such method of producing ammonia is quite hopeless from a commercial standpoint—the yield of ammonia is too bad.

Now Haber and Le Rossignol set to work in another way. They made numerous experiments, and discovered that if they sent hot nitrogen and hydrogen through tubes containing finely divided metallic osmium or uranium the two gases will readily unite and the ammonia can be separated from the gases in quantities large enough to make the process a very profitable one. The metallic uranium or osmium act "catalytically"—that is to say, they cause the union to take place without themselves undergoing any marked chemical change. Many such catalytic actions are known in chemistry, but how these "catalysts" work is not known.

The process has been used technically on a large scale in Germany by the Badische Anilin und Soda Fabrik, and the whole process forms a really wonderful feat of scientific chemical engineering. Stupendous pressures are used—the gaseous nitrogen and hydrogen being compressed to about 200 atmospheres—3000 lbs. on the square inch—and all leakage under this enormous pressure has been eliminated. Many of the details, however, are still kept secret, and it is known that works costing over £2,000,000 were being erected in Germany in 1913 for the production of ammonia on the larger scale.

Owing to the dangerous pressures employed, it is stated that many of the working parts are buried in immense trenches so that the disastrous effects of an explosion will be minimised. The nitrogen is obtained in practically unlimited quantities by liquefying the air and separating the oxygen by fractional distillation, as explained in my former book, *Triumphs and Wonders of Modern Chemistry*, p. 183. The hydrogen is obtained by the decomposition of coal gas or similar gases, or by passing steam over red-hot iron, or by passing water gas over red-hot lime, for in fact by modern methods hydrogen can be obtained in practically unlimited quantities and extremely cheaply.[1]

The following diagram, fig. 5, taken from the author's *Chemical Lecture Diagrams*, will explain the method employed in making synthetic ammonia.

The pump M forces a mixture of nitrogen and hydro-

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[1] The technical processes are explained at length in the author's work, *Industrial Chemistry*, vol. ii.

gen under a pressure of 200 atmospheres along the tube E E E into the vessel H, whence it passes out through X F F W through a drier, C (filled with soda lime), into the strong tube O P, as shown. A is an electric heater, whereby the gas passing along the inner tube S T is raised to a temperature of 800–1000° C., and then passes, while hot, through the contact substance at B (usually finely divided osmium or uranium), which is heated by the hot gas to about 500–600° C. Here combination between the hydrogen and nitrogen takes place, and ammonia is formed. The tube S T is thus kept hot by the gas streaming down it, the temperature being highest at S and decreasing as we proceed towards T. Therefore the cold entering gas, as it comes in by U and passes over the hot tube on its way towards S, naturally gets heated, and at the same time aids in cooling the tube from T to *a*, so that by the time the gas passes from U to S it is almost raised to the temperature of the furnace at S, whereas, as the heated gas passes down the tube S T, it is finally so chilled by the incoming gas at U that it issues at T with a temperature not much higher than the atmospheric. The interchange of heat is thus nearly perfect. The mixture of uncombined gas, together with the produced ammonia, passes along the tube N R, through the pump M, and then along the tube E E into the refrigerator H. H is surrounded by a vessel, L L, kept at a temperature of – 60° C. to – 70° C. by a mixture of alcohol and solid CO_2; and at this temperature the ammonia gas condenses to a liquid form, and may be drawn off at K. The cold, gaseous hydrogen and nitrogen, which remains uncondensed, passes away by X F F, and here meeting the entering gas coming down the interior tube E E chills it so considerably that it enters H at a temperature not far removed from that at which the ammonia condenses. At the same

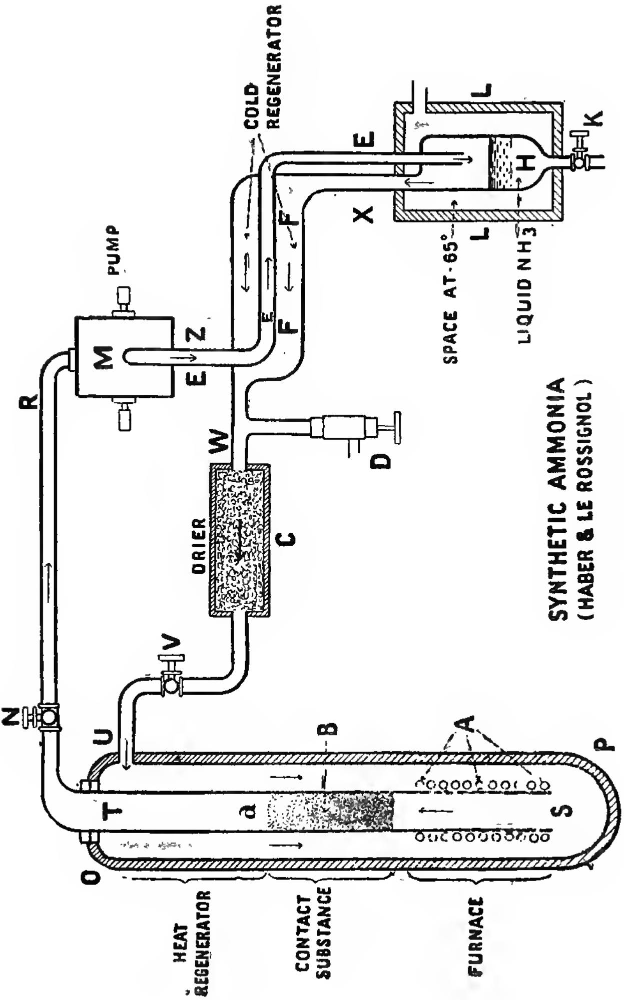
COLD
REGENERATOR
PUMP
M
E
Z
R
N
E
F
E
F
X
L
H
K
L
SPACE AT -65°
LIQUID NH_3
W
D
DRIER
C
V
U
T
O
a
B
A
S
P
HEAT
REGENERATOR
CONTACT
SUBSTANCE
FURNACE
SYNTHETIC AMMONIA
(HABER & LE ROSSIGNOL)

Fig. 5.

time the gas escaping along F F is heated almost to atmospheric temperature by the incoming gas, and so passes away through a drier, C (filled with soda lime), into U almost at atmospheric temperature.

The production of ammonia in this way is fraught with tremendous economical consequences. Ammonium salts will become much cheaper than they have hitherto been, and so the price of nitrogenous manures will fall greatly. This will lead to a revolution in many branches of agriculture, and intensive farming will now be possible on a very large scale. Hence the capacity of the world to produce foodstuffs will increase greatly, so that a long era of prosperity should lie before the world—if cheap and sufficient quantities of food have any influence on such matters. The manufacture of all sorts of expensive nitrogenous compounds, such as explosives, dyes, celluloid, photographic films, and so on, will also be enormously cheapened, and this in its turn will make other industries develop, and these will react one on the other so as to benefit trade and commerce in a way quite incalculable at present. Haber and Le Rossignol's process for producing synthetic ammonia represents the foundation of a world industry, whose evolution and development will profoundly modify the conditions of the human race.

We must now say a few words about the compounds of nitrogen with oxygen—the *Oxides of Nitrogen.*

It has been mentioned in a previous chapter, nitrogen under the influence of an electrical discharge will burn in oxygen, producing oxides. There exist no less than five of these—namely; N_2O, NO, NO_2, N_2O_3, and N_2O_5. The first—*nitrogen monoxide,* N_2O—is a colourless gas easily obtained by heating ammonium nitrate:

$$\underset{\text{Ammonium nitrate}}{NH_4NO_3} = \underset{\text{Nitrogen monoxide}}{N_2O} + \underset{\text{Water}}{2H_2O}$$

It is soluble in cold water but less so in hot. Burning bodies blaze in it almost as brightly as in oxygen gas itself. Its great peculiarity consists in the fact that when breathed it causes insensibility. While coming to, the patient will utter sounds like laughing. Hence the popular name "laughing gas." It is much used by dentists and doctors for minor surgical operations. If mixed with oxygen and breathed for a short time it will not cause insensibility but will intoxicate one like alcohol. Sir Henry Roscoe thus describes its effects on students working in a chemical laboratory:[1]

FIG. 6.—Dentist administering nitrogen monoxide to a patient.

"At the end of the session of laboratory work there

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[1] *Life and Experiences*, p. 35 (1906).

was held by the students what may be termed 'a chemical saturnalia' by the administration of nitrous oxide (nitrogen monoxide) to such of the laboratory inhabitants as desired to take it. I remember very well some ludicrous incidents, interesting in showing what varied effects the nitrous oxide intoxication produces on different individuals. The Famulus of the laboratory was a Quilp-like creature, Williams by name. When under the influence of the gas he simply sat upon the coal box and made the most horrid series of grimaces that one could imagine. Watts (of dictionary fame) on the other hand when under its influence danced about in a high state of exhilaration, clicking his thumbs in great delight. A student of the name of Fox, a Quaker, and of course a man of peace, became terribly pugnacious, and chased us all round the laboratory. I remember fortunately hiding behind one of the doors in the furnace room, but he caught one of the excisemen, and, getting the head of the unfortunate man 'into chancery,' inflicted considerable damage upon his person. It was all over in a few minutes, but it was deadly while it lasted. The astonishment of the peaceable Quaker, when he recovered, at the results of his onslaught was very amusing to all but the exciseman."

The next oxide—*Nitric oxide*, NO—is also a colourless gas, much resembling nitrogen monoxide in general properties. Its great peculiarity is that in air it turns red owing to its combining with oxygen, thus:

$$\underset{\text{Nitric oxide}}{2NO} + \underset{\text{Oxygen}}{O_2} = \underset{\substack{\text{Nitrogen peroxide}\\\text{(A red gas)}}}{2NO_2}$$

It may be prepared by pouring strong nitric acid upon copper strips or shavings, and, being insoluble, may be collected over water:

$$\underset{\text{Copper}}{3Cu} + \underset{\text{Nitric acid}}{8HNO_3} = \underset{\text{Nitric oxide}}{2NO} + \underset{\text{Copper nitrate}}{3Cu(NO_3)_2} + \underset{\text{Water}}{H_2O}$$

The gas is poisonous, combining with the hæmoglobin, the red colouring matter of the blood, to form a compound which prevents it from fulfilling its function of oxygen carrier. The gas is even more deadly than carbon monoxide, which combines in a similar way with the blood.

The substance has been known to explode. Indeed some years ago a quantity of the gas stored up in an iron structure in a chemical works exploded when a workman merely turned a tap, and, blowing the apparatus to pieces, killed the unfortunate man. It was probably resolved into free nitrogen and oxygen.

The third oxide—*Nitrogen peroxide*, NO_2—is, under ordinary circumstances, a red gas. It exists, however, in two forms. Below $-10°$ C. it forms a colourless liquid having the formula N_2O_4. Above this temperature it begins to break down into NO_2, changing colour as it does so, and becoming dark red. The red fumes noticed when nitric acid or nitrates are heated are due to the formation of this substance. It may be prepared by heating lead nitrate.

$$\underset{\text{Lead nitrate}}{Pb(NO_3)_2} = \underset{\text{Lead monoxide}}{PbO} + \underset{\text{Nitrogen peroxide}}{2NO_2} + \underset{\text{Oxygen}}{O_2}$$

The substance is a terrible and insidious poison. Many a man has breathed it without at the time noticing any bad effects, but after some hours or even days a pain may develop in the region of the lungs, a violent inflammation may set in, and death through pneumonia follow. The reason is that the water in the lungs decomposes it, forming nitric and nitrous acids, both terribly corrosive, and these cause wounds in the tissues and set up the inflammation.

$$\underset{\text{Nitrogen peroxide}}{2NO_2} + \underset{\text{Water}}{H_2O} = \underset{\text{Nitric acid}}{HNO_3} + \underset{\text{Nitrous acid}}{HNO_2}$$

This fact is rather interesting, because when modern explosives detonate large amounts of nitrogen oxides are evolved and soldiers breathing such fumes are very liable fatally to injure their lungs. (See p. 78.)

Of the remaining oxides, *Nitrogen trioxide*, N_2O_3, is a very unstable blue liquid, which freezes to green crystals, and above $-20°$ C. it decomposes to NO and NO_2. While *nitrogen pentoxide*, N_2O_5, is a colourless solid, which explodes when suddenly heated, and dissolves in water, producing nitric acid:

$$N_2O_5 + H_2O = 2HNO_3$$

It may be produced by distilling strong nitric acid with phosphorus pentoxide.

For ages in the past a terrible and mysterious poison now called Hydrocyanic or Prussic acid has been known to exist. It was extracted from crushed peach stones or leaves, by allowing them to remain soaked in water for some time and then distilling the liquor. The first part of the liquor which distilled over contained the poison. In ancient Egypt some four thousand years ago it was used for putting people to death. Thus on a papyrus preserved at the Louvre, M. Duteil read, "Pronounce not the name of I. A. U., under the penalty of the peach!" in which dark threat, without doubt, lurks the meaning that anyone who revealed the religious mysteries of the priests would be put to death by waters distilled from the peach. "That the priests actually distilled the peach leaves," says Blyth,[1] "has been doubted by those who consider the art of distilling a modern invention; but this process was well known to adepts of the third and fourth centuries, and there is no inherent improbability in the supposition that the Egyptians practised it. From the Egyptians the knowledge of the deadly drink appears to have passed to the Romans, for, although not expressly mentioned, yet the fact that, in the reign of Tiberius, a Roman knight, accused of high treason, swallowed a poison and fell dead at the feet of the senators, is wholly inexplicable, unless it be allowed that the fatal dose was prussic acid, and that in a tolerably concentrated form." Indeed it is believed that this was the actual poison used by Nero to get rid of his brother Britannicus, for the details of this tragedy have been recorded with some minuteness.

"It was the custom of the Romans to drink hot water, a draught nauseous enough to us, but, from fashion or habit, considered by them a luxury, and, as no two men's tastes are alike, great skill was shown by the slaves in bringing the water to exactly the degree of heat which their respective masters found agreeable. The children of the imperial house, with others of the great Roman families, sat at the banquets at a smaller side table, while their parents reclined at the larger. A slave brings hot water to Britannicus; it is too hot; Britannicus refuses it. The slave adds cold water; and it is this cold water which is supposed to have been poisoned: in any case, Britannicus had no sooner drunk of it than he lost voice and respiration. Agrippina, his mother, was struck with terror, as well as Octavia, his sister. Nero, the author of the crime, looks coldly on, saying that such fits often happened to him in infancy without evil result; and after

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[1] *Poisons: Their Effects and Detection*, by A. W. Blyth, p. 2. Published by Griffin & Co.

a few moments' silence, the banquet goes on as before."[1] In the light of modern science we know that the poison must have been either prussic acid or one of its salts. The effects, indeed, of the poison are appalling in their suddenness. A few drops placed in the eye of a dog kill it in thirty seconds. A man has been known to swallow a quantity of the acid, stagger a few paces, and fall dead without a sound or convulsion. Usually, however, the poisoned person falls to the ground in convulsions, and dies in a few minutes.

This terrible substance is known now to be a simple compound of hydrogen, carbon, and nitrogen, having the formula HCN. The pure acid when free from water is a colourless extremely volatile liquid. It has a very peculiar peach-blossom odour and is a strong acid. Usually it is met with dissolved in large excess of water. It may be prepared by distilling any cyanide with dilute sulphuric acid, and condensing the evolved gas in a suitable glass vessel in water. Yet on account of its terribly poisonous nature (a mere sniff of the vapour having had fatal results) only very skilled chemists should undertake its preparation. It seems almost incredible that the famous Swedish chemist Scheele, who first prepared it pure by distilling potassium ferrocyanide with sulphuric acid in 1782, should have been totally unaware that he was dealing with the most powerful of all known poisons. Thus we read with astonishment that he smelt and tasted it, and did various other experiments with it without ill effects.

Free prussic acid occurs in the unripe berries of certain plants. It there serves as a protective means to prevent them from being eaten while still unripe by birds. The curious part of the matter is that as soon as some of these berries are ripe, the prussic acid disappears,

[1] Blyth, *loc. cit.*, p. 6.

as there is no longer need of protection. In many plants and natural oils, especially in bitter almonds, it occurs not free but combined with a sugar, forming a complex compound called amygdalin. By boiling with acids, or even on prolonged standing with water in the presence of certain ferments or enzymes, the acid is set free.

The salts of the acid form a very interesting and important class of bodies, which, however, we cannot discuss further here.

Before concluding this chapter a few words must be said regarding an interesting gaseous compound of nitrogen called *Cyanogen.* This in some respects is allied to hydrocyanic acid, having the formula C_2N_2, although it is a colourless substance not having any acid properties. It was discovered by Gay-Lussac about a hundred years ago, who prepared it by heating the cyanides of gold, silver, and mercury, thus:—

$$\underset{\text{Mercury cyanide}}{Hg(CN)_2} = \underset{\text{Mercury}}{Hg} + \underset{\text{Cyanogen}}{C_2N_2}$$

The mercury salt is placed in a hard glass tube fitted with a cork and gas-delivery tube. At a dull red heat the gas is rapidly evolved and may be collected over mercury, being somewhat soluble in water.

The colourless gas seen to collect over the mercury possesses a smell somewhat like that of peach-blossoms, and when a light is applied to the mouth of the vessel containing it, it is seen to burn with a magnificent purple flame. It is terribly poisonous, a breath or two of it being fatal. At the very highest temperatures carbon and nitrogen appear capable of directly uniting, cyanogen, for example, appearing in the gases evolved from blast furnaces. It is supposed by some authors that it exists on the sun. In eclipses of the sun Hale has observed cyanogen gas floating immediately above the layer of white hot clouds which girdle the sun. Probably it occurs in far greater masses beneath these clouds, where it is inaccessible to observation. If it thus occurs in the sun it must probably have existed once upon a time in the primeval atmosphere of the earth. It certainly occurs in comets. In the tail of the last comet (Comet Morehouse) the spectroscope discovered traces of this deadly gas, and it has been suggested that the passage of a large comet through the solar system may cause such an irruption of this substance into the earth's atmosphere from external space that the whole human race would be poisoned.[1] Although not, I suppose, inconceivable, such an event is very improbable, the largest comet yet discovered bearing with it a quantity of matter far too small appreciably to affect the earth. However, it is by no means impossible that in space there exist worlds whose atmospheres contain large amounts of this gas, and whose seas are impregnated with prussic acid. The faintest breath of their atmospheres, and the slightest gulp of their waters would instantly prove fatal to any creature built on lines similar to those found upon the earth.

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[1] Several novels have been written in which the supposition is made that in its journey through space the earth dashes into such poisonous vapour, which kills off everything except the heroes and heroines of the story, who have an exciting time exploring the dead world and starting it anew.

CHAPTER III

THE ROMANCE OF EXPLOSIVES

HUMAN civilisation is very old, so old that its very beginnings are lost in the mists of antiquity. Thousands of years before London or even Troy was founded, there existed huge world-cities, with their swarming millions of inhabitants, their long broad paved streets, their countless shops and stately palaces. Such indeed were Babylon, Nineveh, Ur and Nippur, the ancient wonder cities of Mesopotamia, some four thousand years ago. Their remains, buried under the dust mounds of ages, are now being laboriously excavated. Indeed the modern traveller when passing over the desolate and silent wastes of sand which now cover their ruins can scarcely realise that he is standing on a place where thousands of years ago reigned the most intense human activity. He can stand on the very spot where—

"Once Babylon, by beauty tenanted,
In pleasure palaces and walks of pride,
Like a great scarlet flower reared her head,
Drank to the sun, and laughed, and sinned, and died."

But all that he will see of her one-time mighty fortifications and colossal buildings, which towered up into the air to the height of 600 feet, are a few unsightly mounds of earth.

Centuries before Christ, great commercial cities like Tyre, Sidon, and Carthage were built of rows of streets of stately, six-storied, stone houses, while thousands of trading ships rode at anchor in their harbours or were moored along their broad, busy quays.

Civilisation reached a high level in ancient Egypt. Some of the engineering works carried out by the Egyptians still remain unsurpassed, the wonder of the modern world. Crete, thousands of years before our era, was the theatre of a wonderful civilisation, the very memory of which had faded like a dream from the memory of men until, a few years ago, the ruins of great palaces were unearthed, whose charred remains tell us of wars unrecorded and forgotten in which this civilisation perished.

Ages later, and still in the memory of all, arose and spread the splendid civilisations of Greece and Rome. America, too, even in very early times, seems to have from time to time witnessed the periodical rise and fall of native civilisations. A common fate overtook these old civilisations. One after another they perished, overwhelmed by armies of warlike savages. Time after time this has happened, not only in Asia, but also in Europe and America. Every time settled life and progress began in any region of the world, when towns began to grow up, wealth and trade develop, and plenty and prosperity to smile throughout the land, then thriftless savages in neighbouring districts, scorning to obtain by patient labour what might be taken by force of arms, came pouring in upon the bright spot, and usually succeeded in destroying so completely the beginnings of civilisation in these regions, that we are often ignorant to this very day that they ever existed. The world's history—or rather that fragment of it with which we are acquainted—is one vast tragedy. And the reason is simple enough. A civilised man is not and never will be a match physically for savages living under wilder and harder conditions. The very conditions of civilisation set a premium upon a high intelligence and a weak muscle, and the process of evolution in a very short time produces a type of man corresponding to this want. But among savages intellect is at a discount. It is the fighting man, the man with strength and courage, who is esteemed and valued, and consequently produced by the conditions of life under which he exists. Unless, therefore, a civilised state can compensate the physical disadvantages of its warriors by artificial aids such as a superior organisation, powerful fortifications, and offensive death-dealing machinery, sooner or later this state is bound to perish in hand-to-hand conflicts with ruder and less civilised nations; and thus the advances it has made in the art of life are all swept away again. This being so, we may well inquire whether the modern European civilisation will also perish in the same way? We believe not. It is possible that our civilisation will suffer a slow process of internal decay as the result of the spread of some religious mania, such as has happened in the East time after time, and in the West once at least; but violent, abrupt dissolution at the hands of savages is now unthinkable. And the reason is simple. Behind each civilised man now stands a power a million times mightier than the strongest arm that ever drew a sword or hurled a spear—the terrible power of modern explosives. The bravest savage is as defenceless as a rabbit before civilised man with his lyddite shells and quick-firing guns. Uncivilised races can manufacture swords and spears and arrows of the materials found abundantly about them. But the manufacture of explosives and of arms of precision is utterly beyond their power; for their production requires a knowledge of chemistry and of engineering science such as is unattainable by any uncivilised people. Indeed a people arriving at such knowledge must necessarily attain civilisation at the same time. Under modern conditions a civilised race can only be overcome by a civilised race. Nay, more; we may well doubt whether at the present time a civilised race can be overcome even by a civilised race. A nation like Germany, governed by military despots drunk with an imaginary superiority, may try to overrun the world. But her only chance was to take the world by surprise, to deliver a swift, assassin-like blow in the midst of smiling peace, and overwhelm the other nations while these were unprepared for war. Give but a breathing time, and civilisation puts such terrible defensive weapons in the hands of the defenders, and such mighty economic forces into motion, that such efforts are brought to nought. Napoleon took fifteen years to kill a million men; Kaiser William the Mad, in his attempt to wreck a continent, killed two millions of men in twelve months, and into the vortex of the titanic struggle sucked thirty millions of armed men. Such are the forces which modern civilisation opposes to those who try the methods of savages and endeavour to take by force that which is not theirs by right of labour. Modern science has rendered as true now as ever it was, the old, old saying that "he that taketh the sword shall perish by the sword."

Thus we owe our safety to explosives, and indirectly to the chemist who produces them. It was said of old that the pen is mightier than the sword. We can now say with truth that the balance of the chemist is mightier than either. The nation that leads in chemistry leads in all other things, for upon this science there depend not only the means of producing metals for making machinery and tools, but also the production of materials from which are made clothes, books, inks, paint, dyes, medicines, and fire itself—in a word, all that distinguishes our life from that of prehistoric savages.

But here the reader will require to know what we mean by an "explosive." Any body which will suddenly expand and exert great force in so doing may, in a sense, be called explosive. Even such a harmless liquid as water can be made to act as a powerful explosive. The most terrific natural explosions which occur on the earth are caused by it. When water is brought into contact with white- or red-hot material it is suddenly converted into steam which may occupy several thousand times the volume of water from which it was produced, and if restrained from so doing will exert an enormous force.

The terrible volcanic explosions which occur from time to time, and fill the world with awe and terror, are due, as a rule, to water coming into contact with the white-hot matter in the interior of the earth. Whole mountains and islands have by this means been blown into the air with a tremendous crash. Thus at Krakatoa in 1883 a whole mountain, forming more than a cubic mile of solid rock, was hurled into the air. The vast thunder of the explosion was heard nearly 2000 miles away, while windows were shattered by the mighty sound-waves at a distance of 150 miles! In comparison with this, the most awful of artificial explosions produced by modern high explosives seem quite puny. Thus in 1896 some 55 tons of blasting gelatine were being unloaded from a railway train at Johannesburg in South Africa, when it exploded as the result of an end-on collision. The town was startled by the sound of a titanic thunderclap, and looking upwards saw a sheet of flame accompanied by a cloud of flying débris ascending to the sky. Rushing to the spot, the townspeople found that a crater 300 feet long, 65 feet broad, and 30 feet deep had been produced in the soft ground, while every building within a radius of 1000 yards was either blown down or badly shattered.

About 30,000 tons of material had been blown into the air.

In 1893 the Hudson River Palisades were blown up at Fort Lee, and there 2 tons of dynamite, placed in a chamber in the rock, brought down 100,000 tons of rock. In the same year 2½ tons of dynamite, placed in chambers in a dyke at the Dinoric quarries at Llanberis, blew up 180,000 tons of rock; while at Talcen Mahr in 1895, 7 tons of powder poured into two shafts overthrew nearly 200,000 tons of material. Yet what are these results when compared with the explosion which at Krakatoa blew into the air some seven thousand million tons of rock and earth!

All modern explosives are solid or liquid substances which are capable of suddenly liberating large quantities of gas as the result of extremely rapid chemical action. These gases set up a tremendous pressure, and so blow out the bullet from the gun with enormous force in exactly the same way that the compressed air of a boy's air-gun does. The explosion, or the sudden conversion of a solid or liquid into gas, is effected by the application of heat, electricity, or simple percussion.

The explosive best known to us all is *Gunpowder.* This consists of:

Potassium Nitrate, KNO_3 . .	75 parts
Charcoal, C	15 ,,
Sulphur, S	10 ,,

The finely-powdered materials are thoroughly mixed together in gun-metal or copper drums, having blades in the interior capable of working in the opposite direction to that in which the drum itself is travelling. After passing through a sieve the mixture is then ground under heavy metal rollers, subjected to hydraulic pressure, and then broken up into a form suitable for the particular purpose for which the powder is intended.

The explosion is due to the fact that the elements of the potassium nitrate are dissociated by heat, gaseous oxygen and nitrogen being set free. The nascent oxygen combines with the carbon to form the gases carbon monoxide ($2C + O_2 = 2CO$) and carbon dioxide ($C + O_2 = CO_2$). The sulphur should unite with the potassium to form solid sulphide of potassium according to the equation:

$$\underset{\substack{\text{Potassium nitrate}\\ \text{(saltpetre)}}}{2KNO_3} + \underset{\text{Sulphur}}{S} + \underset{\text{Carbon}}{3C} = \underset{\text{Carbon dioxide}}{3CO_2}$$

$$+ \underset{\substack{\text{Potassium}\\ \text{sulphide}}}{K_2S} + \underset{\text{Nitrogen}}{N_2}$$

But as a rule it unites with some oxygen, producing the gas sulphur dioxide ($S + O_2 = SO_2$). The gases formed by the explosion of a given bulk of gunpowder occupy about 300 times the bulk of the powder at ordinary temperatures. The enormous heat produced by the sudden inflammation expands these gases many times further. To this expansion the explosive force is due. The force set up may be reckoned as some hundreds of tons per square inch. Moreover, as the powder burns rapidly this pressure is suddenly applied, and has all the effect of a tremendous blow. The chamber in which the bullet is confined gives way at its weakest point. Hence the bullet yields before the breech, and is hurled with a mighty force from the barrel. This is not always the case: fearful accidents sometimes occur when the ball has been too tightly wedged, or when the metal of the breech is weak.

In the atomic world we must picture the explosion as consisting in millions upon millions of gaseous molecules bursting forth from the flaming surface of the powder and flying swiftly against the bullet, whirling as they fly with incredible velocities. Then, just as one billiard ball imparts motion to another, so also do each of the myriads of molecules imparts theirs to the projectile. The motion imparted by a single molecule may be as nothing, yet the accumulated effect of untold millions of impacts is stupendous. The projectile acquires an ever-increasing motion, until it finally rushes forth from the barrel and flies shrieking through the air on its errand of destruction. The whole complex change, the sudden shattering of countless millions of atomic systems, passes in a flash beneath our eyes. Yet, as I have pointed out in my former book,[1] a single second is a vast interval of time in the atomic universe, during which the atoms have ample time to carry out countless billions of minute evolutions ; consequently the bright flash of an explosion is to an atom no swift change, but in reality betokens the slow and orderly passing of one atomic universe into another.

The old black gunpowder is now rapidly passing away, having been almost entirely superseded by other explosives, as we shall presently see. The smoke which it produces when fired contains more than 50 per cent. of the total weight of the powder, and is thrown out as solid matter to foul the atmosphere, becloud the gunner, and make his situation a conspicuous target for the enemy. The modern smokeless powders are free from these defects.

The effects producible by gunpowder, mighty as they are, fade into insignificance when compared with those producible from certain modern "high" explosives such as dynamite or nitro-glycerine, picric acid, and mercury fulminate. The starting-point in the manufacture of dynamite is glycerine. I suppose that everyone is

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[1] *Triumphs and Wonders of Modern Chemistry*, 2nd ed., p. 60.

acquainted with this clear, oily, and sweet-tasting liquid, and, indeed many of us have eaten it in honey, for it is often used for adulterating this article by unscrupulous dealers. Glycerine is obtained in very large quantities as a secondary product in the manufacture of soap and candles from oil and fats, being produced by the action of high-pressure steam or boiling alkalies upon these substances.

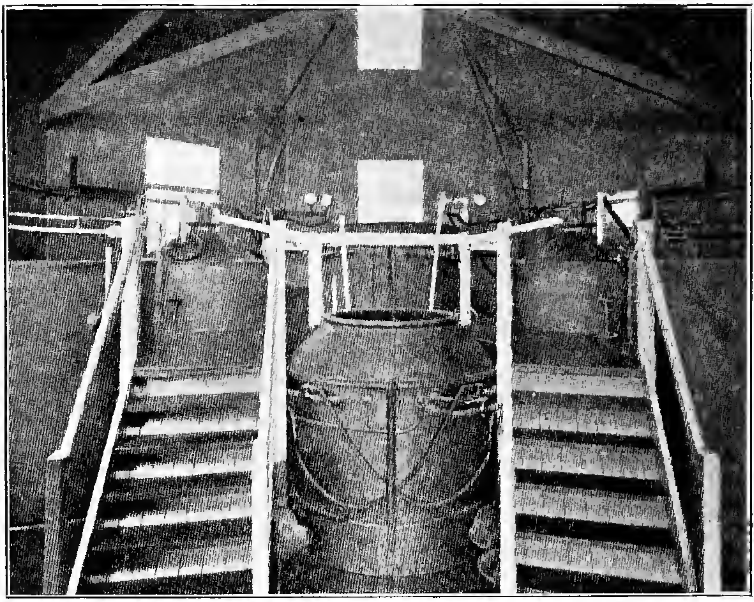
In order to make nitro-glycerine, the glycerine is sprayed in a very fine stream into a leaden tank (called a "nitrator") containing strong nitric acid, rendered more active by being mixed with sulphuric acid, and kept cold by a stream of cold water circulating through leaden coils in the interior of the vessel. In all these dangerous processes stirring is required, and since air is the most easy and frictionless means of agitating a liquid, a stream of this is allowed to bubble up from perforated pipes placed in the tank. There is no apparent change, for pure nitro-glycerine resembles glycerine itself very closely in appearance; nevertheless the following change has occurred:

$$\underset{\text{Glycerine}}{C_3H_5(OH)_3} + \underset{\text{Nitric acid}}{3HNO_3} = \underset{\text{Nitro-glycerine}}{C_3H_5(O\,.\,NO_2)_3} + \underset{\text{Water}}{3H_2O}$$

What has happened is that three hydrogen atoms from the glycerine molecule have been displaced by the introduction of three NO_2 groups from the nitric acid. As soon as the chemical change is ended the nitro-glycerine must be separated from the nitric acid and then washed until it is completely free from adhering acid. This is carried out as follows. The leaden tank in which the reaction takes place is provided with a narrow conical top as seen in our illustration (Plate 1). When the action is over, waste acid from a previous charge is run in at the bottom and displaces the nitro-glycerine upwards, and this overflows by way of an outlet from the narrow top of the nitrator. This top chamber is a closed compartment with a glass window in the narrow overflow face. The nitro-glycerine containing a large volume of water and acid runs over into a first washing vessel, called a "forewash," seen between the two nitrators in Plate 1, the flow being stopped when the waste acid has risen to the sight window. In the first wash tank the liquid is washed with a copious supply of water agitated by a rapid stream of air kept bubbling through it in order to free it from acid. The water is skimmed off by an indiarubber pipe, and the nitro-glycerine is then run into a second vessel containing a large volume of water, seen in our illustration, Plate 1, between the two stairways, and is then washed again. Next it runs away through a gutter and enters the final wash-house, shown in Plate 2.

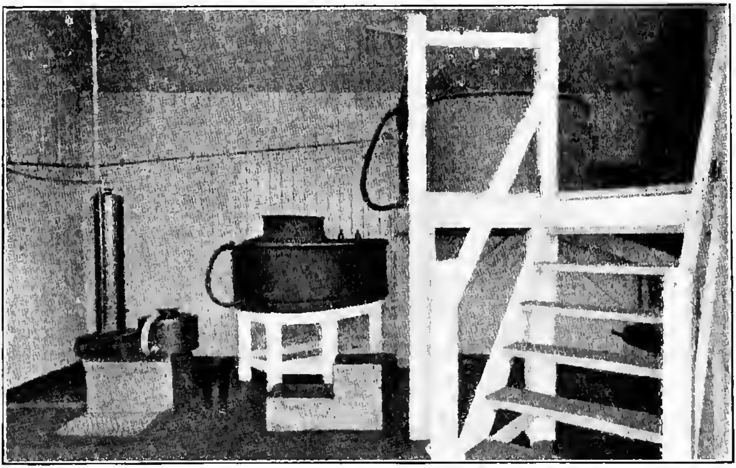
In this the heavy, oily nitro-glycerine is washed with alkaline water, with softened warm water, and with softened cold water, and finally is drained off and collected. The object of this extremely thorough washing is to prevent the prepared stuff from spontaneously decomposing in use, the slightest trace of acid left in it having been known to cause terrible disasters through premature explosion. The nitro-glycerine is then freed from moisture by being filtered through salt, which, being unaffected by the explosive liquid, sucks out of it the last of its moisture, thus serving both as a filter and a dryer. All waste water goes to a large tank in a further house, and is run through a labyrinth to separate any nitro-glycerine that it still contains. The mud which settles in the tank is run with the waste water into a pond at some distance, and at brief intervals a cartridge is fired in the bottom of that pond in order to blow up and destroy any traces of nitro-glycerine which may accumulate there.

A visit to a large explosive works is well worth making.



From Cassier's Magazine.

PLATE 1.—Manufacture of Nitro-glycerine.



From Cassier's Magazine.

PLATE 2.—Interior of the Washing House of a Nitro-glycerine plant.

The most elaborate precautions are taken to avoid disaster. The buildings are separated by wide intervals, and are buried deep in the earth and surrounded by great earthworks in order to minimise the effects of any explosion. The workmen move silently about clad in soft felt shoes, for boots containing nails might cause a percussion and result in a terrible disaster. In each building very few men are employed, so that any culpable carelessness on the part of a workman will result in the loss of only two or three lives at most.

In one room you will see the dangerous nitro-glycerine being produced by the hundredweight. By the side of the tank containing the nitric and sulphuric acids, into which the glycerine is steadily pouring, you will see a workman sitting intently watching a thermometer. By him is an apparatus for signalling alarm to neighbouring buildings. Anything going wrong with the charge in the nitrator will manifest itself in a rapid rise of temperature. The utmost upper limit of temperature allowable is 25° C. (77° F.), and if the rise continues a few degrees above this the whole charge may explode and blow the whole building into the air. So the workman sits with his hand on a lever, ready in an instant, by means of a single movement of it, to turn off the stream of glycerine and discharge the contents of the nitrator into a deep tank of cold water, situated under the foundations of the house. Here it is flooded and all danger is at an end.

How dangerous is the operation of making nitro-glycerine, and how easy the slightest carelessness of the workmen is visited by the supreme penalty of death, may be seen from the case of the explosion at Hayle, which occurred on January 5, 1904, at 10.55 A.M. At the time of the explosion nitro-glycerine was flowing down a gutter from the precipitating house to the washing-house, which were separated by an interval of about a quarter of a mile. What exactly happened will now never be known, but it is believed that the single workman who was in the former building clumsily dropped the heavy leaden lid of one of the tanks. The concussion was sufficient to explode the whole charge, which first blew into fragments the precipitating house, instantly killing the man, and then flashing down the gutter, the explosion entered the washing-house, killing the three men working there, and hurling the building into the air. The thunder of the explosion was heard over an area of 3000 square miles, extending even so far as Exeter, some 90 miles away. The effects of the explosion were visible for several miles around the works, chiefly in the breakage of glass. Thus at St. Ives, no less than four miles away, some £200 worth of glass windows were shattered, many being blown entirely out. And here a curious thing was noticed, a phenomenon which accompanies most terrific explosions. The windows, especially in the houses facing the works, were blown, not inwards *but outwards*. The effect of an explosion at a distance is apparently to project the atmosphere vertically and produce a partial vacuum around, so that the air inside a vacuum-surrounded house simply bursts it open and blows its windows outwards.

But this reminds me of the exciting time which a public school has just come through safely. The crisis came suddenly during the chemistry lesson of one of the higher classes.

One of the boys quietly remarked to the master: "Please, sir, I have made a pint of nitro-glycerine," and he held up proudly for the master to see a beaker filled with a pale yellow liquid.

The class stared at the beaker in horrified amazement. The master paled. There was enough of the deadly explosive to blow the whole school down, and half the town with it. "Good God!" said the master, "how did you make it?" "Oh," said the boy, "I just poured a pint of glycerine into a mixture of strong nitric and sulphuric acid." The master carefully approached the beaker and gingerly carried it to a cupboard. Little work was done during the rest of the lesson. Everyone walked about on tip-toes, and none ventured near the cupboard where the terrible jar reposed. After the lesson the news spread like wildfire. Everyone had visions of the buildings flying skyward like a fiery rocket. At every unusual sound boys and masters jumped. The sudden slamming of a door sent a shudder through the whole school.

Late in the afternoon the chemistry master stole silently from the school, with the beaker in his hand. Gingerly he picked his way up the main-street of the town in a zigzag path to avoid the possibility of collision with passers-by. Arriving at the playing grounds, he distributed the nitro-glycerine in remote parts of the grounds. When he returned the school breathed a sigh of relief, and set up the master as a lifelong hero. Meanwhile the enthusiastic young experimenter was sternly summoned to interview the infuriated head . . . but here we will stop. Instead of dwelling on the painful scene which ensued, let us discuss the properties of nitro-glycerine.

Nitro-glycerine is a heavy, colourless oil which, like the glycerine from which it is derived, tastes sweet. It is very poisonous; in large quantities it acts like strychnine, and causes death in a few minutes; but in small quantities it is a powerful medicine for stimulating the heart. It soaks into most substances in a most extraordinary manner. Indeed if placed on the skin it will soak through into the blood, causing giddiness and severe heart trouble. After a time, however, workmen get used to it, and indeed actually knead the glycerine into other substances by the hand, as we shall presently see.

After the terrible accidents that have happened the reader will be surprised to hear that nitro-glycerine does not readily explode. It is not nearly so explosive as gunpowder. In fact the flame of a match can be quenched in it without danger. If we apply a light to it, the oil will burn quietly with a smoky flame. If poured from an open vessel on to a fire the liquid usually blazes up without explosion. In fact it is only when suddenly heated, or when subjected to a violent shock, such as that caused by the explosion of a small charge of fulminating mercury, that it will explode. But when the substance does explode it goes off with terrific violence, shattering the stoutest structures into fragments. Its explosive force is estimated at eight to ten times that of the same weight of gunpowder.

Nitro-glycerine has several properties which make it dangerous to use as such. For example, it freezes between 4° and 5° C. into a crystalline solid which must be thawed again before using by placing in warm water. When solid it is much more liable to explosion by simple percussion than when liquid. At Hirschberg a mining overseer was killed by the explosion of some frozen nitro-glycerine which he attempted to break into smaller pieces with a pickaxe. Like water, the nitro-glycerine expands in freezing, and may thus burst the vessel containing it in the same way that freezing water sometimes bursts water-pipes. Indeed this was the cause of a terrible accident some years ago. A box of nitro-glycerine was being sent to some mines and was lying in the office of a luggage company waiting to be fetched away. The cold had caused the substance to freeze and burst its packing. In the warm office it again melted and, unluckily for him, one of the office boys observed a yellowish liquid oozing from under the lid. Being of an industrious nature he at once fetched a hammer and nails and began to fasten the lid on more securely, when, with a flash like lightning and a roar like a vast thunder peal, the box exploded, shattering the whole office and causing the great building to reel and almost collapse. When the dust of fallen masonry and the smoke had cleared away, the horrified searchers discovered that some thirty people had been blown to pieces. No trace of the unfortunate office boy was ever found again. This disaster shows that nitro-glycerine is in some respects very dangerous to store and to transport. Indeed when it first began to be manufactured by Mr. Nobel—a Swedish engineer—no railway or ship company could be induced to accept the danger of conveying it. Mr. Nobel was actually on the point of abandoning its manufacture when a fortunate accident revealed to him a method of making it transportable. One day when unloading a waggon containing a number of jars of nitro-glycerine packed in sand to prevent breakage, it was observed that a jar had fractured and that the nitro-glycerine had soaked right into the sand, just as ink soaks into blotting paper. The sand was observed to have the same powerful explosive properties as the pure nitro-glycerine, but was far safer, and being in a compact form, far easier to transport. The old "Kieselguhr Dynamite," in fact, is merely sand soaked in nitro-glycerine. Ordinary sand, however, is not used but a fine sort called "Kieselguhr," which is really nothing else than the skeletons of innumerable myriads of tiny organisms, and will absorb no less than three times its weight of nitro-glycerine. The quantity absorbed, however, must be always less than the capillarity of the cellular diatoms enables them easily to retain without drip or overflow. Kieselguhr fully charged with nitro-glycerine is as dangerous as the unabsorbed liquid itself.

Now kieselguhr (a variety of sand) is in itself an inert substance and so reduces the effective action of the explosive base nitro-glycerine.

A great advance was made when, instead of inert kieselguhr, other absorbants for the nitro-glycerine were used *which are themselves explosives*. One of the most powerful explosives in use is of this nature and is called "blasting gelatine." It is, in effect, a solution of nitro-glycerine in a kind of gun-cotton called collodion cotton (made by soaking cotton in a mixture of nitric and sulphuric acid). It is made by mixing together 7 to 10 per cent. of collodion cotton with 93–90 per cent. of liquid nitro-glycerine at a temperature of 40° C. Solution takes place and on cooling an amber-coloured, translucent, elastic mass is produced. When saltpetre and wood meal are kneaded into the mixture we get the explosive known as *Gelatine dynamite* or *gelignite*. These dynamites have so far displaced the old "kieselguhr dynamite" that the latter formed in 1909 only 0·4 per cent. of the total amount of explosives used in mines and explosives in Great Britain.

And now a few words on what dynamite has done for civilisation. Modern times have been distinguished by the carrying through of gigantic engineering operations; it is quite safe to say that without the employment of high explosives these could never have been achieved. Tunnelling operations have become quite simple, dynamite cartridges enabling men to blast their way right through the hearts of mountains, while dynamite makes the construction of great canals an easy matter; the rocks and earth in the way are simply shattered by dynamite explosions and the debris is then carted away by mechanical appliances. Consequently once any great engineering feat—such for example as the making of the Panama Canal—is decided upon, the price of dynamite and the raw product glycerine from which it is obtained at once goes up with a bound, as the demand for explosives exceeds the supply.

Now these great engineering operations have all one object in view, and that is the speeding up of communication between one part of the world and another; and so dynamite, perhaps more than any other agent, has knit the world into a closely connected civilised whole. Methods of quick transit of persons, inventions, news, and merchandise from one part of the world to another have done more to bring universal peace and prosperity into the world than any other influence, and as this has in the main been made possible by engineers who in their turn could only do their work by using high explosives, the inventor of dynamite probably has been one of the greatest benefactors to humanity.

Thousands of tons of dynamite are made yearly and used for blasting purposes. In using gunpowder for blasting it is necessary tightly to confine it, by what is called "tamping," in a hole prepared for it in the rock. In fact if gunpowder was exploded on an iron plate in the open air the disruptive effect would be nil. It must be confined. But this is not so with dynamite or nitroglycerine. They exert their greatest force in the direction of those points in actual contact with them. Hence if a small amount of dynamite be merely placed on the top of a large boulder rock or on an iron plate, and be absolutely unconfined in any way, then on exploding the dynamite the rock or plate will be shattered into a thousand fragments. Hence dynamite, made up into small tin cartridges for convenience, is merely placed in the drill holes without tamping of any kind. Sometimes the liquid nitro-glycerine itself has been poured into the hole and then a little water poured on top is the only means used to confine it.

This makes nitro-glycerine rather a favourite explosive for burglars who wish to blow open safes. This is especially the case in America. The thieves, after forcing their way into a safe room, next lute up all the crevices between the door and the walls of the safe by soap or some similar lute. Then they pour the liquid nitroglycerine in through cracks in the safe door. A detonator is then applied and the explosion usually succeeds in detaching the safe door from the walls, thus making the contents accessible to the criminals.

In a recent burglary at the London Hippodrome a gang of thieves, who had secreted themselves in the building after the performance, attacked the night-watchman and after gagging and chloroforming him, proceeded to an underground room known as the treasury and blew open the safe with gelignite. This is the account of the night-watchman :—"About 1.30 at night, while patrolling the theatre, I came to the vestibule at the main entrance. I was carrying a bull's eye lantern, and there was a little light coming through the glass doors from the street. Suddenly two men sprang at me and threw me down. One man pinned me down while the other pressed a cloth over my face. There was a strong odour of chloroform, and while I was struggling to free myself I lost consciousness.

"It was about 5.30 A.M. when I awoke. My head was aching badly and I felt very drowsy. My lamp was by my side but it had gone out. I at once thought about the safe, and getting up I ran to the door leading to the underground treasury room. It was open. I ran downstairs and saw the safe, which weighed over a ton, lying on its back. Its door, which had been forced, was all buckled up as if made of tin. All the money (some £500 or so) which was kept in the safe was gone. I at once called in the police." The police soon found that the burglars had turned over the safe, drilled some holes in the cracks of the door, and then forced in a quantity of gelignite (which as put up in cartridges has a creamy consistency). All crevices between the walls and the door were then sealed up by yellow soap, and the charge was exploded by a time-fuse inserted in the keyhole. The explosion would not make much more noise than the discharge of a rifle, and so was not heard in the street.

As an agent used for blasting nitro-glycerine is so vastly superior to gunpowder that it must be regarded as one of the most valuable discoveries of our age. Yet it has no value whatever as a projective agent. Exploded in the chamber of a gun it shatters it to pieces. Now what is the cause of the singular difference in the explosive effect of dynamite and gunpowder? The reason is this: in gunpowder the act of explosion consists mainly in the union of carbon and oxygen to produce gaseous products. But the carbon and oxygen atoms are in *different molecules*. The grains of charcoal and nitrate, although very small, have a sensible magnitude, and consist each of many million molecules. Now the chemical union of the carbon atoms of the charcoal with the oxygen of the nitrate can only take place on the surface of the grains. The first layer of molecules must be consumed before the second can be reached, and so on. Hence the process, although very rapid, must take an appreciable time.

In the case of *nitro-glycerine* and *dynamite*, however, the carbon and oxygen atoms are in the *same molecule* at an almost infinitesimal distance apart. Hence the combustion takes place *in the molecules themselves* and is practically instantaneous; thus:

$$\underset{\text{Nitro-glycerine}}{4C_3H_5(O.NO_2)_3} = \underset{\text{Carbon dioxide}}{12CO_2} + \underset{\text{Water}}{10H_2O} + \underset{\text{Nitrogen}}{6N_2} + \underset{\text{Oxygen}}{O_2}$$

When the substance explodes the oxygen atoms attached to the nitrogen rush for the carbon and hydrogen atoms and unite with them to form carbon dioxide and steam, while the nitrogen atoms are set free and part of the oxygen as well. The whole molecule is thus suddenly shattered and flies apart into gaseous products which occupy more than 1200 times the volume of the original nitro-glycerine, if the gaseous volume is calculated at ordinary temperatures and pressures; but the heat liberated expands the gas to nearly eight times this volume. And all this takes place almost simultaneously among all the vast assemblance of nitro-glycerine molecules. So that the gas is liberated practically *instantly*.

Now all our experiments are made in air, and this air presses with an enormous weight on every surface. Each square yard of surface supports about nine tons weight. Hence if a volume of gas is suddenly liberated it must press back this weight of air in order to find room for itself. In the case of gunpowder the 300 volumes of gas come off slowly enough to lift and displace the air without getting much compressed. In the case of nitro-glycerine, however, the 1200 volumes of gas come off instantly and cannot lift the air suddenly enough to relieve the pressure. Hence an enormous gaseous pressure is suddenly developed around the explosive, which shatters the material in contact with it. The following illustration may help the reader to realise this more clearly. Take a light wooden surface, say one yard square. Move it slowly through the atmosphere and we encounter little resistance because the air flows round it as it moves. If, however, we force it rapidly forward the resistance greatly increases since the air has no time to flow round it. If we increase the velocity of the motion to that of an express train—a mile a minute—we would encounter a resistance which no human strength could overcome. Increase this velocity a dozen times, that is to say make it move as rapidly as sound waves, and the air would oppose such a resistance that our wooden board would be shivered into splinters.

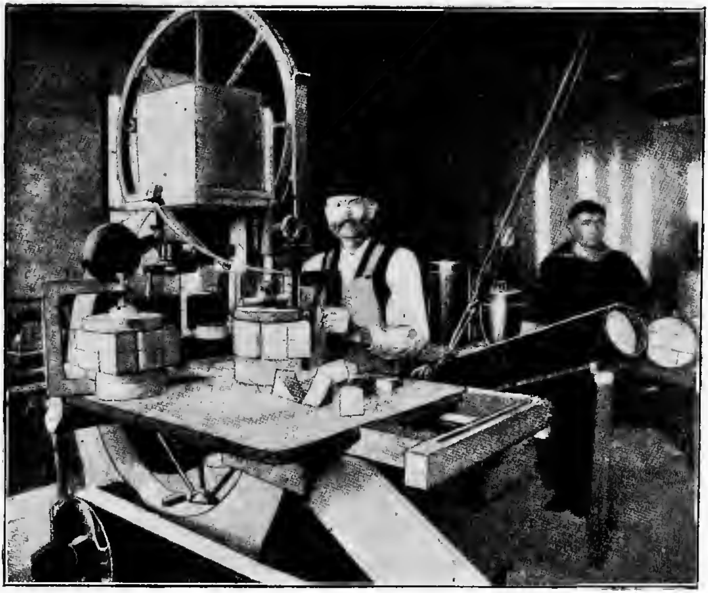
Multiply this velocity ten times and not even a boiler plate could withstand the resistance. Multiply the velocity once more by ten and we reach the speed with which the earth rushes round its orbit, about twenty miles a second. To a body moving with such a vast velocity the air at the surface of the earth presents an almost impenetrable barrier against which the strongest rocks may be dashed to pieces. Indeed this effect often occurs when meteorites rush into our atmosphere with planetary velocities. They are often shattered with a loud explosion.

Now in the case of a piece of dynamite placed on an open rock or iron plate and caused to explode, we get a volume of gas some thousands of times greater than the volume of the dynamite suddenly shooting forth with a velocity of many miles a second. It encounters in an instant an enormous resistance from the air, and so a sudden gaseous pressure of some thousands of tons is generated all round the dynamite; and this instantaneous pressure has all the effect of a tremendous blow on the material on which the explosive is placed. Hence it is easy to understand why the strongest rocks and the most impenetrable of iron plates are shivered into splinters by the force of its explosion in the open air alone. In the case of gunpowder the gas is liberated fairly slowly, and consequently such an enormous pressure against the air is never generated. So that gunpowder placed on an open surface in air and exploded exerts no disruptive effect. It is only when its gases are liberated in a confined space that the pressure becomes great enough to shatter massive structures.

The reader will doubtless consider that such an enormously swift rush of gas as that which causes a dynamite explosion must be quite exceptional in the scale of nature. Certainly, on the earth gases seldom rush so rapidly. Even in the mightiest storms the wind seldom travels more than 40 yards a second, whereas the gas rushing from dynamite has a velocity of many *miles* a second! but we must remember that anything which is abnormal on the earth may be a normal condition in other parts of the universe. And so it is in this case. In myriads of the suns scattered through space the stupendous gaseous velocity which causes a dynamite explosion is vastly exceeded by that of currents of gas in their atmospheres. On the sun, for example, mighty winds of white hot gas rush along with velocities of 700 to 800 miles a second. The pressure and tearing force of such winds must exceed a million-fold the most terrific dynamite explosion producible by us. So that over the whole vast surface of the sun there is continually going on age after age, as a normal condition, the same vast explosive action which we see reigning for a fraction of a second when a dynamite bomb explodes!

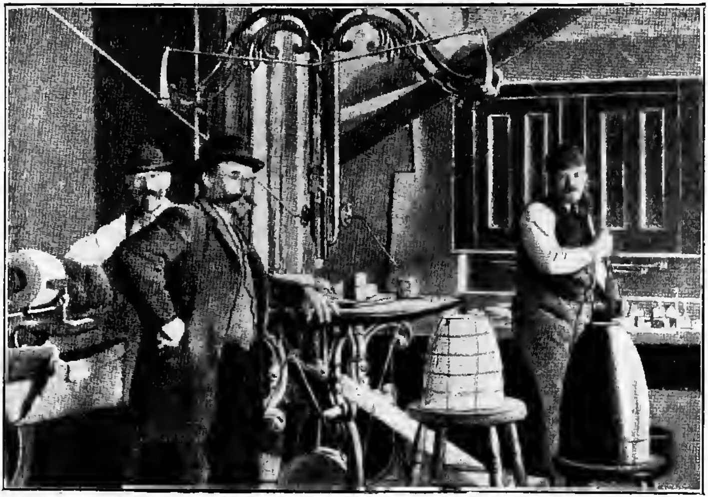
The next explosive that we will deal with is gun-cotton. This has a chemical composition somewhat similar to nitro-glycerine and is produced by the action of nitric acid on cotton. Pure cotton which has been freed from fat and grease by boiling with alkali is immersed in a mixture of concentrated nitric and sulphuric acids (1: 3) for five or six minutes. The cotton is removed and the excess of acids squeezed out. It is next placed in cooled earthenware pots for 24 hours until the process of nitration is completed. The cotton must then be most thoroughly washed in order to remove from it every trace of acid. If this is not done a disastrous explosion may result at a later stage owing to the spontaneous decomposition of the product.

In order to carry out the washing, the cotton is first placed in a centrifugal machine, and the greater part of the acid is there wrung out from it. Then it is plunged into a tank containing a large volume of rapidly chang-



From Cassier's Magazine.

PLATE 3.—Shaping charges of gun-cotton with a band saw.



From Cassier's Magazine.

PLATE 4.—Chiselling and turning blocks of gun-cotton for charging shells.

The brass-nose shell is shown on the right-hand stool, and the charge for this on the left-hand stool and in the lathe.

ing water in which the gun-cotton is kept in agitation by a revolving feathered wheel. Afterwards it is boiled with water which usually contains a small quantity of sodium carbonate. The physical character of the cotton fibre is such that it presents every obstacle to the removal of the free acid, since it is built up of capillaries, but by reducing these tubes to the shortest possible length the removal of the acid from their interiors is much facilitated. The material is therefore placed for several hours in a paper-pulper or rag-engine. There it is passed continuously around under the beater knives until it is chopped into a condition of complete division exactly like paper pulp or corn meal. The pulp is then pumped into other vessels and again washed and boiled with water until no trace of acid can be detected by delicate chemical tests in the wash-water. Gun-cotton before pulping and when dry looks exactly like the cotton from which it was made but has a somewhat harsher feel.

To prepare the pulp for use in filling torpedoes or shells, the pulp from the rag machine is conveyed to a moulding press and the moulded discs or blocks are taken to a final hydraulic press; here they are fashioned into the desired form, just as *papier maché* is. As taken from the press these blocks contain 12 to 16 per cent. of water, but as sent into service they contain about 35 per cent., which is added by allowing the compressed blocks to soak in a trough of fresh water until they cease to absorb more. If, in providing charges for torpedoes and shells, it is inconvenient to mould the portions for the heads and other parts, these are readily and without much danger shaped from blocks by cutting them with a chisel or band saw, or boring with a drill, or turning in a lathe, being careful to keep a stream of water flowing on the gun-cotton during the operation. (See Plates 3 and 4.)

Gun-cotton does not readily explode. If a match is applied to it when unconfined it merely flashes away in a whiff of flame. Wet gun-cotton will not burn at all, and bullets may be fired into bales of the stuff without any bad effects. When dry, however, a sharp blow has been known to cause explosion.

Consequently it is in the drying houses that explosions of gun-cotton usually occur. Indeed after scores of years of manufacture all danger is not eliminated, and quite a bad explosion occurred so recently as Monday, March 3rd 1913, at Nobel's explosive works in Ayrshire, whereby seven men were killed outright and ten seriously injured.

Apparently decomposition occurred among boxes of gun-cotton drying in the heating room, and so violent was the concussion that in a village *half a mile away* the roofs of houses cracked and came crashing down upon their occupants, while chimney stacks were thrown down in all directions, buildings rocking as if smitten by an earthquake. At Glasgow, fully thirty miles away, windows rattled in a violent manner and crockery fell down from shelves and was broken. This occurred in a most scientifically managed works where every precaution was taken for isolation of the explosive and safety of the workers. In fact this disaster shows that those who have in harness great atomic forces always stand in danger of losing control of them. Like fire, modern explosives are excellent servants but very bad masters.

In practice gun-cotton is always set off by means of a detonator charge, which is exploded in the middle of it and thereby gives such a shock to the chemical molecular structure that the whole mass instantly explodes with terrific force, much in the same way that dynamite does. Indeed the tearing effect is much the same in both cases.

The chemical constitution of this highly explosive gun-cotton as used in mines, torpedoes and shells is

$[C_6H_7(NO_2)_3O_5]_x$, being produced from cellulose (of which cotton fibre is made up), which has the formula $[C_6H_{10}O_5]_x$ as the result of the replacement of three hydrogen atoms in the cellulose molecule by three nitro groups, NO_2, from the nitric acid. "Trinitro-cellulose," as the substance is called chemically, is insoluble in ether but soluble in acetone. There exist, however, lower forms of gun-cotton, in which only one or two nitro groups have entered into the cellulose molecule, and these are soluble in ether, their ethereal solution being known as collodion; they form the basis of what is known as celluloid.

Powders are now made of "gelatinised" gun-cotton, *i.e.* gun-cotton which by means of partial solution and subsequent evaporation of the solvent is made into a stiff jelly-like elastic mass. One powder of this sort, which has caused much discussion recently, is the French "B Powder." It is a smokeless powder consisting of two parts of insoluble nitro-cellulose (*i.e.* gun-cotton) mixed with one part of soluble nitro-cellulose (*i.e.* collodion wool), the whole made into a jelly by adding a mixture of alcohol and ether and stirring until the ingredients form a "jelly," after which the alcohol and ether are evaporated.

Such powders formed of "gelatinised" nitro-cellulose or gun-cotton are for some unknown reason much more unstable than the ungelatinised parent substances, although apparently the process of gelatinisation is a merely physical one attended by no chemical change. When kept for some years such powders often gradually decompose with increasing rise of temperature, and then suddenly the decomposition becomes so marked and the rise of temperature so great that the mass may explode with great violence. Consequently the French naval authorities have decreed that all B Powder over four years old shall be destroyed by being sunk in the sea.

This discovery was only made at the cost of human life, owing to a terrible series of disasters to French battleships.

First of all the French battleship *Jèna* blew up with a terrible loss of life, to be followed very shortly by a still more appalling disaster. On Monday, September 23rd 1911, at 5.35 in the morning an unexpected explosion took place on the battleship *Liberté* lying at anchor in Toulon harbour. As the alarmed men swarmed up from below, this explosion was followed by a series of others of fearful violence, culminating in a terrific explosion at 5.55 A.M., which could be heard thirty miles away. The air around was filled with debris, a captain on a training ship two miles away being killed by a flying fragment, while great chunks of massive iron armour, weighing tons, were hurled in all directions around the ill-fated vessel, crashing through the sides and decks of neighbouring warships and killing and wounding men in all directions. In a few minutes no less than 200 lives were lost and the noble vessel was reduced to a mass of twisted and torn scrap metal. Our illustration shows the battleship *Liberté* after the explosion (Plate 5).

Cordite is a mixture of nitro-glycerine, gun-cotton, and vaseline in the proportions: nitro-glycerine, 30 parts, gun-cotton, 65 parts, and vaseline, 5 parts. The combustion of the powder without vaseline causes excessive friction of the projectile in the gun, producing rapid wearing of the rifling; it is chiefly to overcome this that the vaseline is introduced, for on explosion a thin film of greasy matter is deposited in the gun, and acts as a lubricant. In order to prepare this substance the nitro-glycerine is poured over the gun-cotton and well mixed by hand; then acetone is added and the whole mingled in a kneading machine for 3½ hours. The acetone does not enter into the constitution of the powder, but since it dis-

Photo by Meurisse.

PLATE 5.—The Battleship *Liberté* after the explosion of B-powder on 23rd Sept. 1911.
The noble ship was reduced to a mass of scrap-iron, 200 lives being lost within a few minutes.

solves both the nitro-glycerine and the gun-cotton it allows them to be thoroughly mixed and incorporated into a homogeneous mass. The acetone is afterwards removed during the drying process. Vaseline is now added and the kneading is continued for some hours. The cordite paste is first subjected to a preliminary pressing, and is finally forced through a hole of the proper size in a plate by hydraulic pressure or by hand. The thick fibrous paste, if of a small diameter, is wound on drums, whilst if of a large diameter, it is cut off in suitable lengths. The most tedious process is the drying out of the solvent acetone. If the drying is done quickly, the surface of the cords is hardened, and the solvent cannot escape from the interior. Large cordite may thus require as many as seventy days in which to dry completely. This drying is effected in steam-heated stoves, and the drying of the exterior surface must proceed only as quickly as the interior will give up its solvent to the more outward portions. It is for this reason, among others, that a large store of cordite is necessary to meet possible demands, because the substance cannot be made in a day or a week, and any hurry in drying would cause the rods to split and alter their rate of burning and so spoil their ballistic properties. Cordite is a splendid ammunition for guns, and forms the basis of what is now known as smokeless powder. It is perfectly safe, a rifle bullet fired into a mass of it only causing it to burn quietly, while a detonator cannot be made to explode it. *Balliste* consists of nitro-glycerine 37·5 per cent. and nitro-cotton 62·5 per cent.

It is impossible in the course of an article such as the present to pass in review all the numerous explosives that are known.[1] We should however mention *Picric Acid*, $C_6H_2(NO_2)_3OH$, which is prepared by dis-

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[1] For further details the reader should consult the author's book, *Industrial Chemistry*, vol. i., "Organic," where a full account of the subject is given.

solving phenol, C_6H_5OH (carbolic acid), in nitric acid. It or its salts are used for shells under the names "Lyddite," "Mellinite," &c. Trinitrotoluene, $C_6H_2(NO_2)_3CH_3$, is now very largely used and is stated to be superseding picric acid.

Picric acid assumes the form of a crystalline solid, composed of a mass of very beautiful bright yellow plates or prisms. In fact it was (and still is to some extent) used as a yellow dye.

Picric acid under ordinary circumstances is quite safe to make. In fact, students in chemical laboratories are allowed to make the substance as an exercise; it can be melted without danger, and even be allowed to burn without explosion. Although so safe under ordinary circumstances, yet when exploded with a mercury fulminate detonator it goes off with fearful violence, being even more powerful than gun-cotton or dynamite.

When picric acid explodes it belches forth extremely poisonous gases. Among these we may mention the suffocating carbon dioxide and nitrogen, the blood-poisoning carbon monoxide and nitrogen oxides, the latter of which when breathed causes pneumonia and a suffocating death, while the former is the active agent of gas poisoning in mine explosions; last but not least there are evolved vapours of the deadliest of all poisons—namely, prussic or hydrocyanic acid (p. 48)—a single breath of which can kill a man with the suddenness of the knife. In addition to this, the intense heat of an exploding shell converts part of the picric acid charge into very bitter and irritating vapours, which dye all objects in the immediate neighbourhood a deep yellow colour.

We can, therefore, readily imagine the really terrible effects produced by the explosion of great shells weighing nearly a ton, especially if the explosion takes place in a somewhat confined space, such as the hold of a battleship. First there is the terrific thunder and blaze of light of the explosion itself; then comes a sudden increase of air pressure, and the men not annihilated by the explosion itself are hurled in all directions; lastly come torrents of intensely poisonous gases evolved as a result of the decomposition of the picric acid. Men gasp and die suddenly, killed by the prussic acid and nitrogenous fumes. Such men will appear black and livid in the face, and are often stained yellow by vapours from unexploded picric acid.

In fact by the aid of the enormous guns constructed by modern science the very strongest land fortifications can be reduced to ruin in a few hours. We are told, for example, that some of the Antwerp forts were literally blown into the air by shell fire, so that what was once a fort was transformed into a deep cavity.

The great 15-inch shells of the English Navy hit with precision at 12 miles and pound to dust everything within a hundred yards, while ranks of men are hurled down by such shells when more than a quarter of a mile from the place whereon the projectile falls.

Byron's words, written over a hundred years ago:—

> "The armaments that thunderstrike the walls
> Of rock-built cities, making nations quake
> And Monarchs tremble in their capitals."

seem almost literally descriptive of the overwhelming nature of modern shell fire when directed on fixed land forts.

Picric acid for military purposes is usually fused and poured while in a molten condition into the shell. The disadvantage of its use, however, is that it is an *acid*, and so combines with metals to form salts called "picrates," some of which are very explosive and unstable bodies.

There is, therefore, always the danger that the metal forming the shell and the picric acid charge inside may unite to form some of these unstable explosives, and so cause a disastrous premature explosion.

For these reasons another nitro-derivative, viz.,—*Trinitrotoluene*, $C_6H_2(NO_2)_3CH_3$, has recently come into extended use, although it is not quite such a powerful explosive as picric acid. It is made by treating toluene (which is contained in coal tar) with nitric and sulphuric acid. It crystallises in yellow masses, and is really an extraordinarily safe explosive.

For example, it can be burnt, hit with a hammer, bullets can be fired through it, and all sorts of other rough mechanical treatment meted out to it without causing it to explode.

As much as one ton weight of the substance has been known to burn away quietly without explosion. Moreover, it has no acid properties, and so it will not (like picric acid) combine with metals to form unstable explosive compounds. By means of a detonator of mercury fulminate it can be caused to explode with very great violence—although not so violently as wet gun-cotton. The fragments of shells filled with this substance are large enough to do much damage at a considerable distance, whereas picric acid and gun-cotton tend to pulverise shells and so localise their effect.

One curious effect of the outbreak of war, therefore, is to make supplies of a number of products derived from coal tar of great military importance. Thus coal tar contains both phenol and toluene, from which are made picric acid and trinitrotoluene respectively. Even benzene becomes valuable from the military standpoint, because from benzene we can make phenol and so make picric acid. The very first thing, therefore, that a Government does on the outbreak of war, is to commandeer huge supplies of benzene, toluene, phenol and similar coal tar products. Great care, too, is taken to prevent the export of such chemicals to foreign countries, where they could be used for making ammunition for sale to the enemy.

Mercury fulminate, $C_2N_2O_2Hg_2$, is a most dangerous and sensitive explosive much used for making percussion caps, detonating fuses, and the like. It may be prepared by dissolving mercury in nitric acid and then adding alcohol to the solution. A violent action soon begins, dense clouds of white and then orange coloured vapours are evolved, and the mercury fulminate is precipitated in small, gray, beautifully formed crystals, which are washed with water and stored wet in guttapercha vessels. A slight blow will cause it to explode with a loud detonation, and the easy method of preparation has caused it to be much used by anarchists in their bombs.

Last of all we will mention a curious explosive called *Nitrogen Chloride*. In the year 1811 it occurred to a famous French savant called Dulong, to pass chlorine gas into a strong solution of ammonium chloride (sal ammoniac). To his surprise he noticed that a peculiar yellow oil began to collect at the bottom of the vessel. He collected a small amount of it and began to examine its properties more closely, when all of a sudden it exploded with terrific force, blowing out the unfortunate man's eye and shattering into a pulp three of his fingers. This compound is now known to be nitrogen chloride, and is, perhaps, the most dangerous explosive known. Its formation may be represented thus:

$$\underset{\text{Ammonium chloride}}{NH_4Cl} + \underset{\text{Chlorine}}{3Cl_2} = \underset{\text{Nitrogen chloride}}{NCl_3} + \underset{\text{Hydrochloric acid}}{4HCl}$$

Wishing to preserve others from a like accident, Dulong kept his knowledge to himself and so it came about that a similar accident happened in 1813 to Faraday and Davy. Faraday was holding a small tube containing a few grains of this yellow fluid between his finger and thumb, when he was stunned by a bright flash followed by a violent thunderlike explosion. On returning to consciousness he found himself standing with his hand in the same position, but torn by the shattered tube, and the glass of a thick mask he was wearing cut by the projected fragments. The substance is, in fact, terribly explosive. The slightest touch of an oiled feather, a beam of sunlight falling upon it, or some slight vibration like that caused by a door slamming in the distance, may cause it to explode.

Nitrogen chloride is composed of two elements, both of which are gaseous at ordinary temperatures, and they are held together in the liquid form by very weak chemical forces. The explosion is simply the sudden resolution of the oily liquid into its component gases, nitrogen and chlorine, thus:

$$\underset{\text{Nitrogen chloride}}{2NCl_3} = \underset{\text{Nitrogen}}{N_2} + \underset{\text{Chlorine}}{3Cl_2}$$

A substance like this, however, is far too dangerous to be of any practical use as an explosive.

After all the various accidents and disasters which have been related in the preceding pages, the reader will be rather surprised to hear that commercial explosives are comparatively safe substances *when properly handled.* So safe are they, in fact, that this often actually leads to disaster by the indifference with which workmen handle them. There are cases on record where workmen have melted frozen nitro-glycerine *in a frying pan* over an ordinary fire! While in mining districts the miners will often carry about in their pockets dynamite cartridges, which if exploded would blow them to pieces.

Indeed only a short time ago a rather curious case happened near Nottingham. It chanced that two miners, accompanied by a friend, were taking a walk on a Sunday afternoon on a waste bit of ground in the neighbourhood. They wished to show this friend the effect of an explosion, and so one of them pulled out a cartridge from his waistcoat pocket, applied a light to the fuse, and threw the cartridge to a safe distance.

Now every miner has a dog, who takes an intelligent interest in all that his master does. No sooner did the little animal see an object whirling through the air than he immediately thought that this was something thrown for his especial benefit, and that he was required to fetch it, *and raced in pursuit.* He caught the cartridge in his mouth and then came running back towards the men. These, horror-stricken, fled wildly, with the dog pursuing them. Although the miners developed a record speed, the dog soon caught them up. Luckily the dog had, by seizing the fuse, put it out, and so the situation was saved.

And now I should like to say a few words about a subject on which a great deal of misapprehension exists. If in the case of modern high explosives we have command of powers so vast that mountains can be rent asunder and steel twisted and shattered as if made of paper, why cannot we apply these same powers for driving engines? Would not these same powers placed in the cylinders of engines of suitable construction drive them with far greater power than the ordinary propellant-agent powers, such as gas, steam, oil and electricity? The answer is that there is far more *work* to be obtained out of, say, 1 lb. of coal or petroleum, than out of the same weight of dynamite, and that explosives are only valuable technically *because they liberate their energy in a very short time.* For instance 1 kilogram of liquid petroleum when burnt develops the amount of heat represented by 12,000 calories, and average coal about 8000 calories, whereas 1 kilogram of dynamite (with 25 per cent. kieselguhr) will only develop 1300 calories.

So that the amount of energy liberated by burning 1 kilogram of petroleum or coal would cause an engine to do eight or nine times the amount of work that could be obtained by causing the engine to be set into motion by the power liberated by decomposing the same weight of dynamite. Also the actual utilisation of the energy liberated by explosives compares very unfavourably with that of a high-class engine of the Diesel type, where the efficiency may rise to 37 per cent. of the theoretical, whereas in an engine driven by explosives the efficiency is only 15 to 20 per cent. of the theoretically possible. Consequently the employment of high explosives as motive agents has little prospect of success.

All explosives are substances in a state of strain, from which they release themselves when they explode. They may be compared to compressed springs which contain energy stored up in them which they give out when they perform mechanical work. All explosives, therefore, contain energy stored up in them, and this energy manifests itself when they decompose in the production of heat and the increase of volume which is so characteristic a concomitant of explosions. Explosive compounds must have this energy put into them at the moment of their formation. In other words, they must be formed from their elements with the absorption of heat. It is the heat which thus disappears in them when they are formed which reappears again when they explode, and which gives them their awful power. And experiment confirms theory. It is found that the heats of formation of explosive compounds are negative. In other words, they are formed from their elements with the absorption of heat.

Now it is quite incorrect to assume that very high temperatures decompose all chemical compounds into their elements. The science of thermo-dynamics teaches us that with rising temperature those compounds tend to be formed whose production is attended with the absorption of heat. Thus, in the electric arc at 3000° C. oxygen and nitrogen unite together, heat being absorbed in the process. Further, the well-known compounds benzene and acetylene are formed from their elements, carbon and hydrogen, at the very highest temperatures, with the absorption of heat. Moissan has shown that at the enormous temperature of the electric arc carbon unites directly with many elements to form compounds called "carbides." A large number of these are formed from their elements with the absorption of heat and will explode when struck at ordinary temperatures, then evolving the heat they had absorbed in their formation at high temperatures. In general the higher the temperature at which a reaction takes place the greater is the quantity of heat that is absorbed by it. A similar law prevails for the influence of pressure. An increase of pressure favours the formation of products which have small volumes. In other words, a very high temperature combined with a very high pressure will tend to produce compounds containing a very large amount of heat stored up in them, and possessing a very small volume. Such compounds, therefore, should exhibit explosive properties. For when they decompose they liberate all the large quantities of heat stored up in them, and at the same time they will form products of a greater volume than themselves and thus generate a sudden pressure.

Arrhenius[1] has been led by these considerations to put forward some interesting theories to account for the stupendous explosions which take place on the sun, and,

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[1] *Das Werden der Welten*, pp. 82–84. 1908.

doubtless, on all the visible stars. He believes them to be due to the action of explosive compounds which are produced in the interior of the sun under the enormous temperatures and pressures there prevailing. When these compounds are brought up near the surface again by the violent movement going on all over and inside the giant mass, they explode with enormous power, shooting aloft a column of molten and gaseous debris thousands of miles long and billions of tons in weight. A dynamite explosion can scarcely ever hurl a projectile more than a few thousand feet a second, but these celestial explosives hurl millions of tons of matter aloft at the rate of hundreds of miles a second. They have an energy millions of times greater than any explosive ever made by man.

Arrhenius pictures the gases of the upper levels of the sun's atmosphere rushing downwards into the mighty depths of his body, just as we see them doing in sunspots. As they plunge downwards towards the interior the pressure keeps on increasing enormously, the increase being about 3500 atmospheres per kilometre descended. At the same time the temperature rapidly rises, flaring up to the giant heat of many millions of degrees centigrade. Under these conditions they unite to form compounds. Yes, the very gases which, in consequence of the high temperatures and low pressures prevailing in the outermost levels of the sun (outside the clouds of the photosphere), fall apart into atoms, enter into chemical combination in the depths of the sunspots. But what strange compounds are these! They are utterly unlike any that we know upon the earth. They require enormous quantities of heat for their formation, quantities which transcend those required for the formation of earthly chemical compounds in the same degree that the temperatures in the sun transcend those at which chemical processes proceed upon the earth. We must therefore picture to ourselves that deep in the interior of the sun there exist compounds which when brought to the surface suddenly flash with an appalling roar into their elementary atoms again, liberating as they do so the enormous quantities of stored up heat, and vastly increasing in volume. Such compounds must be regarded as the mightiest of all explosives, in comparison to which all earthly explosives are mere playthings. We indeed can form no conception of their titanic energy. We see their effects when billions of tons of gases come bursting through the photospheric clouds which surround the sun and go rushing upwards for hundreds of thousands of miles, often with velocities that are to be measured in hundreds of miles a second. These velocities exceed a thousand-fold those of our swiftest gun projectiles, and consequently the explosives in the interior of the sun must be over a million times more powerful than earthly explosives, for the energy increases with the square of the velocity produced. That there can really exist substances so rich in energy is shown by the case of radium. This, as shown by Rutherford, will liberate before decomposing a thousand million calories per gram mass—a quantity of heat which exceeds that produced by the burning of an equal weight of coal nearly 250,000 times.

These ideas of Arrhenius are interesting because they give us a glimpse into a hitherto undreamt of region of chemistry, which only comes into existence under the stupendous temperatures and pressures prevailing in the stars, and which we can never hope to attain in our earthly laboratories.

CHAPTER IV

RADIUM AND THE NEW CHEMISTRY

NEARLY three hundred years ago there appeared a vision to the immortal William Shakespeare when at the summit of his mental activity, and he wrote it down as follows in the phraseology of his age:—

> "And like the baseless fabric of a vision
> The cloud-capped towers, the gorgeous palaces,
> The solemn temples, the great globe itself,
> Yea, all which it inherit, shall dissolve,
> And, like this insubstantial pageant faded,
> Leave not a rack behind."

It was not, however, until quite recently that men discovered that this picture of a world fading away is probably a literally true one of what is actually taking place in Nature to-day. Modern discovery has made it extremely probable that the elements are not eternal, as we once thought, but are themselves in change, withering away with age like all other things. Even the very atoms, those foundation stones of the universe, are now thought to be born, grow old, and die.

This immense revolution in human thought all arose from a chance observation of the great French physicist, Becquerel, in 1896. It appears that he was examining compounds of a heavy element called Uranium, when he made the startling discovery that even in the dark it affected a photographic plate like sunlight.[1] At the same

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[1] Niepce de Saint-Victor appears to have been the first who discovered this fact many years ago. Le Bon claims to have anticipated Becquerel in some of his work.

time the air all around the uranium compounds was found to have acquired the power of conducting electricity and soon discharged the most carefully insulated electroscope.

A great impetus was given to these researches when a lady, Madame Curie, traced many of these results to the presence of a mysterious new element which she called "Radium." The ray-emitting power of this new element was perfectly astonishing; it possessed nearly two million times the activity of an equal quantity of uranium. What distinguished this element from any other one previously known was that it was continually shooting out into space with incredible velocities tiny electrified particles which, falling upon a photographic plate, produced the effect of sunlight. The flying particles, moreover, rendered all the air around electrically conductive and so caused the discharge of any electrified body in the neighbourhood. The wonder increased when it became known that, weight for weight, radium was by far the most dangerously poisonous of all the known elements. It even poisons at a distance, in that the tiny electrified particles shot off from it become embedded in the flesh of animals and cause virulent sores and ulcers which take months to heal. Indeed I suppose that if ever it is found possible to collect a ton of the element together into one place it will be found to be certain and agonising death to approach to within a yard or two of it, even if actual contact with the element is avoided altogether.

In addition to being the most poisonous element known, radium also enjoys the distinction of being the most expensive[1] substance at present purchasable upon the earth's surface. In 1913, for example, the market value of radium was about £16,000 a gramme, or in English measures, £450,000 an ounce, £7,200,000 a pound!

This enormous costliness has, and is now, driving mineral prospectors all over the world into the most unlikely and wild regions in the hope of alighting on some great sources of radium, hitherto undetected on account of the inaccessibility of the country. Weird have been the stories told of dangers and escapes of these bold pioneers of civilisation. Indeed some have even perished miserably in their search, one of the saddest cases being that of Mr. J. H. Warner, who, in 1913, with two natives penetrated into unexplored parts of Papua (New Guinea). He was killed and eaten by the ferocious natives of that part, his two companions escaping.

But another and more astonishing fact was soon discovered. It was this: unlike anything else previously known, and apparently in contradistinction to all known laws and theories, radium was found to be hourly emitting very large quantities of heat, without itself undergoing any noticeable amount of change, either physically or chemically. And this heat evolution continued, without noticeable signs of diminution, hour after hour, day after day, century after century, for thousands of years. Curie and Laborde found that in a single hour a piece of radium emitted enough heat to raise an equal weight of water from its freezing point to its boiling point. One ton of radium enclosed in a suitable boiler would cause one ton of water to boil within one hour, and would keep it boiling continually for more than a thousand years.

The energy given off by 12 pounds of radium, if fully utilised under the boiler of a perfect steam engine, would develop one horse-power continuously.

The reader can easily calculate from this that 32 tons of radium in the furnaces of a great liner like the *Mauretania* would propel the ship by developing the same power as is now generated by the daily combustion of some hundreds of tons of coal under her boilers. However, 32 tons of radium would, in the first place, be unattainable; and in the second place, even if obtainable, this amount of radium would cost at present prices some £500,000,000,000. The annual interest on this vast capital expenditure would be at least £20,000,000,000, a sum which in itself would more than pay for all the coal consumed by all the ships in the world, for I do not know how many thousands of years to come. The prospects, therefore, of employing radium for driving steamships do not look particularly rosy. Moreover, even supposing the discovery of some vast deposits of radium in the future in some wild country should solve the problem of supplying tons of radium at a moderate cost, nevertheless, our difficulties would not be overcome. For, as already mentioned, radium is by far the most poisonous substance known, emitting vapours and effluvia which are perfectly deadly; consequently the isolation of the radium in such masses so as to render the escape of all deadly rays and effluvia impossible, would be a decidedly difficult engineering feat.

However this may be, I think that it will be quite clear to the reader that this new element is spontaneously emitting simply enormous amounts of energy. Consequently men quickly realised that they were in the presence of an altogether new order of phenomena, unlike anything that had ever been perceived upon the earth before. And soon the most advanced thinkers were at work, explaining these remarkable properties of the new element.

The present writer was, I believe, the first to suggest the correct explanation, namely, that the radio-active elements are decomposing elements.[1]

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[1] My attention has been called to the following passage, which occurs in the preface of Mr. Soddy's interesting book, entitled *The Interpretation of Radium* (1909);—"The present day interpretation of radium, that it is an element under-

This conclusion was later confirmed by Rutherford and Soddy, who actually isolated the elementary products of the decomposition of the elements. And so it was

going spontaneous disintegration, was put forward in a series of joint scientific communications to the *Philosophical Magazine* of 1902 and 1903 by Prof. Rutherford . . . and myself."

I should like to point out here that Messrs. Rutherford and Soddy were not the first to suggest that the radio-active elements are dissociating elements. So far as I am aware, the first definite statement to that effect occurs in the *Chemical News* of May 2, 1902, in a paper by myself entitled *The Radio-active Elements considered as Examples of Elements undergoing Decomposition at Ordinary Temperatures, together with a Discussion of their Relationship to other Elements.*

In my paper the following very definite statement occurs:—"For many years there has been a general disposition to revive the ancient notion that all matter is composed of a common 'protyle,' and that the elements have been formed from it by a successive series of condensations. And undoubtedly powerful experimental evidence has been furnished by the spectroscopic researches of Sir Norman Lockyer, who believes that the terrestrial elements are more or less completely dissociated into substances of a simple constitution at the high temperatures prevailing in the sun and stars. But what has hitherto been wanting is some experimental evidence that the elements do actually dissociate at temperatures attainable in the laboratory. But it appears that we now have this evidence, for the radio-active elements appear to be actually decomposing at ordinary temperatures." It is also definitely stated that "radio-activity" is a general property of matter—a conclusion now generally accepted. The paper attracted attention in America, and Prof. Baskerville, in his Presidential Address to the Chemical Section of the American Association (see *Nature*, Feb. 25, 1904, p. 403), did me the honour of referring to my paper as follows:—"Many have theorised as to the ultimate composition of matter. The logic of Larmor's theory (*Phil. Mag.*, December, 1897, p. 506), involving the idea of an ionic substratum of matter, the support of J. J. Thomson's experiments (*Phil. Mag.*, October, 1897, p. 312), the confirmation of Zeemann's phenomenon, the emanations of Rutherford, Martin's explanations (*Chemical News*, 1902, lxxxv., 205), cannot fail to cause credence in the correctness of Crookes's idea of a fourth state of matter." Messrs. Rutherford and Soddy, therefore, cannot be credited with being *the first to put forward the theory that the radio-active elements are slowly decomposing.* What they have done is to confirm by their brilliant experimental work my main thesis as regards the nature of the radio-active elements. Their first paper, "The Radio-activity of Thorium Compounds" (*Journ. Chem. Soc.*, 1902, lxxxi., 321), contains no statement of this theory. Their second paper (*loc. cit.*, p. 837) contains on p. 859 a statement of the theory in cautious language; this paper, however, was only published in June, 1902, *after the appearance of my paper.* Messrs. Rutherford and Soddy's first communication to the *Philosophical Magazine* "On the Cause and Nature of Radio-activity" was published only in September, 1902.

that the dreams of a whole generation of the most advanced thinkers, of Faraday, Brodie, Crookes, Herbert Spencer, and Lockyer, were realised at last, and it was proved that men had in radium nothing more nor less than a decomposing element! The radium atom was conceived of as consisting of an enormous number—a quarter of a million—of electrons whirling round with the speed of over a hundred thousand miles a second. As they whirled, the atom was supposed to radiate away energy, and finally to burst like a bubble, shooting out into space with enormous speeds the tiny particles which compose it. It was these tiny flying electrons that were supposed to give rise to the rays which affected a photographic plate. Careful examination showed, however, that these rays were of no simple nature. At least three different sorts were evolved, which are now known respectively as the α, β, and γ rays. Besides these it was found that a peculiar radio-active gas, called an *emanation*, was given off which obeyed Boyle's law, but was chemically quite inert and much resembled the inert gases of the atmosphere, namely, Helium, Argon, Krypton, Xenon, and Neon. Sir William Ramsay and Soddy have considered it to be an unstable element of atomic weight over 200, which breaks down rapidly, throwing out rays as it does so, and after a month it has lost practically all its radio-activity. Among the products of change are Rutherford's A, B and C varieties of radium and gaseous helium.

The α-rays are small particles shot out from the radium atom with velocities ranging up to 12,000 miles a second. They are charged with positive electricity, and when they strike a screen made of zinc blende the molecular impacts cause a sea of scintillating points to occur. It has been supposed that these particles are helium atoms, for their mass has been shown closely to correspond to those of helium atoms, and helium is known to be a product of the decomposition of the radium emanation.

The β-rays are tiny particles possessing a mass of scarce the thousandth part of that of a hydrogen atom. They are negatively charged and fly off from the radium atoms with tremendous velocities. Some of the particles possess an initial velocity of over 160,000 miles a second!

The γ-rays are extremely penetrating, passing through a screen of aluminium 8 centimetres thick before their intensity is halved. They travel with a velocity greater than that of the β-rays, but their true nature has not as yet been ascertained.

The existence of these terrific motions inside an atom teaches us that within the atoms of matter there is a fund of energy so incalculably vast that it is altogether difficult to obtain any clear idea of it.

It has been calculated that a single ounce of radium, were its internal motions fully available as motive power, would lift ten thousand tons a mile from the earth. Hydrogen and all other elements probably contain equal stupendous reservoirs of power, and it seems certain that all the energies previously known to us, which manifest themselves in the heat and light and electrical excitement of chemical combination, are merely overflow tricklings from the immeasurable ocean of intra-atomic energy. And now a solemn thought arises: Astronomy has long taught us that we inhabit but a dead ember swimming wide in the void of space,—a grain of dust flung at random into a fathomless abyss; we are lighted up from 90 millions of miles away by a more horrible hell-fire than ever the morbid mind of mediæval priest conceived; afar off and all around us other dead embers, other flaming suns, wheel and rush through the apparent void often at the rate of a million miles a day; the nearest sun is far beyond our reach, the farthest so remote that the mind fails in its endeavour to conceive of the distance. And so, alone in space, the world rushes forward far swifter than any rifle bullet into the unknown, spinning dizzily as it flies, surrounded on all sides by gigantic fires and terrific forces. Surely, if we come to consider it, the world is a strange, if not appalling place of residence. Shipwrecked mariners, though they cling but to a wave-swept boom, would seem safe compared to mankind on its bullet. And yet, so unconscious are we of the motion, to us our planet appears as a green, commodious home; and the gigantic flames which rear aloft from the sun do but ripen fruit and flower, and warm mildly our smiling summer landscapes; and we unconcernedly go to work, think our little thoughts, do our petty deeds, while all around us in the darkness the universe wheels and roars like a gigantic machine. Yes, safe, very safe, appears our little earth to us. But now radium has revealed a new and startling possibility. Are we not bestriding an explosive a million times more powerful than any explosive ever made by man? If atoms can explode—as radium atoms explode—and fly to pieces with a speed of a hundred thousand miles a second—as radium atoms do—could not some sudden shock let loose this terrific energy residing in all matter atoms, much as a detonator explodes dynamite or gun-cotton, and so cause the whole world to disappear in one enormous flash of light? Such things could conceivably happen, and the glare of the catastrophe would be heralded to the distant worlds of space but by a new star shining briefly in their skies.

New stars appear and disappear, and some writers have supposed that matter can thus, under suitable conditions, explode into a mist of flashing ultra-atomic particles. Truly, the recent advances which science has made have revealed to us possibilities undreamt of by our forefathers, or even by the scientists of a few decades ago.

A most interesting observation has been made by Prof. Bragg. He has shown that the alpha particles shot off from the radio-active elements go *clean through* matter atoms, knocking off electrical particles in their passage and so making the air around a conductor of electricity. He proved this by sending a stream of these alpha particles through a thin metal screen, which robbed each particle of some of its energy, but did not bring a single one to rest. The number of particles in the stream remained unchanged until their velocity had diminished to some 5000 miles per second, after which their subsequent history could not be traced. Now as each particle must have plunged right *through* some hundreds of thousands of atoms before emerging, we have in this the proof that the alpha particles have passed in their wild flight *clean through* the metal atoms, much as a rifle bullet will pass clean through a man.

The vista opened up by this fact will be brought home to the reader when I tell him that now for the first time since science began we have been able to pass anything through an atom. When two molecules of a gas collide they approach within a fairly definite distance, and the approach is followed by a recession under new conditions of motion. Each molecule, however, has a domain into which no other molecule can penetrate—which is roughly the volume swept out by the radius of the molecule. But the defences which guard the molecular domain break down before the onslaught of particles flashing forward at the rate of 12,000 miles per second, and so the alpha particles crash right through the atoms, and their collisions are rather with one or other of a number of circumscribed and powerful centres of force which exist quite inside the atoms and act with great power when approached within distances small in comparison with the atomic radius. Hence we can pass right through the atom an alpha particle, which is simply an atom of helium, and then see what has happened to it when it has come out again, and from the treatment which it seems to have received we can try to understand what it has met with inside.

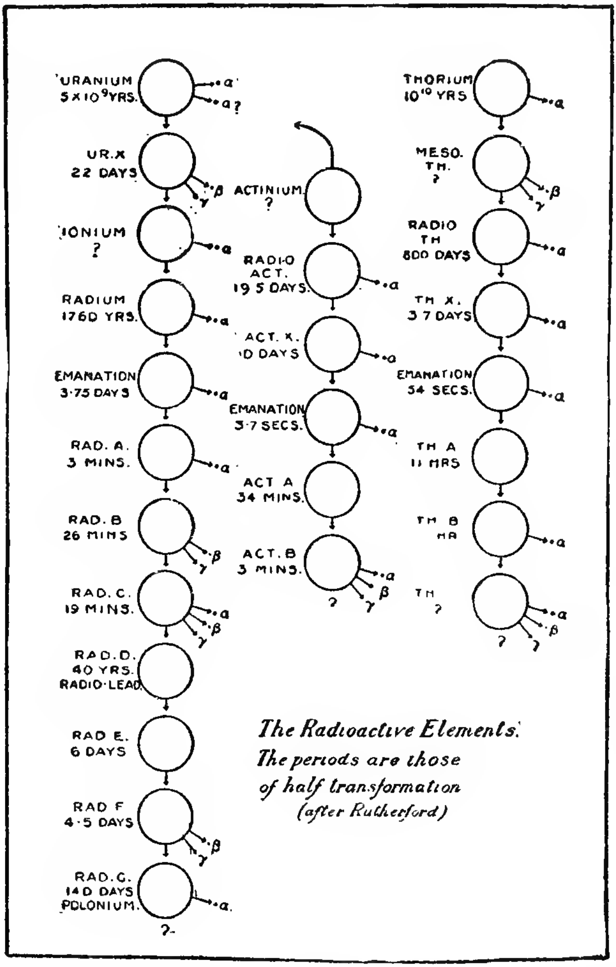
Not only can this be done with the alpha rays, but also with the beta particles (which are electrons) and the gamma rays (X-rays), and so we have at once a powerful instrument for leading us into the mystery of atomic structure itself.

And thus it is that we have presented to us possibilities of obtaining a glimpse of a world beyond the atom, and of discovering the arrangement of the interior of the atom.

The chemical examination of radium showed that it was an element belonging to the calcium, strontium and barium group of elements, but of a greater atomic weight than either of these. Very careful determinations of this constant by M. and Mme. Curie gave it an atomic weight of 226·2 (O = 16). The heat evolved from radium was also found to be a secondary effect, the particles shot out by the exploding atom causing molecular shocks to the neighbouring molecules, thus generating a molecular movement in the neighbourhood which registers itself as heat. Curie and Laborde found that the temperature of a specimen of pure radium bromide remained constantly 3° C. higher than that of the surrounding air.

A really wonderful feat which has recently been performed is the actual counting of the number of alpha particles hurled forth per second by the decomposing radio-active elements. When it is recollected that each of these particles rushes forth from the radium atom at the prodigious speed of about 12,000 miles per second, and that from one gram of radium 1·36,000,000,000 of these helium atoms are expelled per second, the reader will realise what a remarkable feat this actual counting is. And yet it was done in the simplest possible manner by two distinct methods. First of all is a method depending upon the fact that when an alpha particle (that is to say an atom of helium) is expelled from an atom of radium and crashes against a sheet of zinc blende, at the point where the helium atom strikes the blende a tiny blaze of light appears. So that if we bring an extremely small amount of radium near such a sheet of zinc blende in the dark and examine the surface of the mineral by means of a lens, we see flashes of light coming and going, appearing like stars in the sky; and by counting the number of stars which thus appear per second and knowing the quantity of radium producing this effect, it is possible to find out the number of atoms of helium thus expelled from the radium per second. The other method depends upon the fact that each atom of helium as it flies through the air after being shot off by the atom of radium renders the air in its path conducting. Now matters are so arranged that the particle in its flight is allowed to pass between two highly charged metallic surfaces, which are insulated from each other by rarefied air, and are connected to a galvanometer. As the particle flies between them the air becomes conducting and an electrical discharge takes place from one to the other, causing the galvanometer to give a little movement. When the next particle comes flying along there is another movement of the galvanometer, and by simply counting the number of kicks the galvanometer makes in a minute we can count the number of alpha particles flying off from the radium.

Some people have doubted the existence of atoms, but here we have, for the first time in history, the direct effect of single individual atoms; so that, indirectly, the



The Radioactive Elements.
The periods are those
of half transformation
(after Rutherford)

FIG. 7.

subject of radio-activity has given a fresh confirmation of the atomic theory.

Radium itself is a comparatively short-lived element. Rutherford has shown that its period of transformation—that is the period required for one-half of any given quantity of the element to transform into the next element in the line of descent—is under 2000 years. When we consider that the world is known to have been in existence for hundreds of millions of years, it is clear that unless the radium is continually being produced from some source as fast as it decomposes it must all have vanished millions of years ago. It has now been shown that it is probably being produced from uranium through the intermediate formation of a new unstable element called ionium, and that the radium itself then undergoes further changes resulting in the formation of other short-lived radio-active elements, known as Radium A,B,C,D,E,F,G, as indicated in the following table (pp. 102, 103).

This table gives the descendants of the various radio-active elements, as well as their periods of half transformation and the nature of the rays they give out.

As matters now stand we are acquainted with at least three distinct families of radio-active substances, namely, those which are referable to uranium as the parent or originating substance, those which appear to be derived by the break up of thorium, and those derived from actinium. A very brief study of the facts will show the reader that radio-activity is probably a general phenomenon of matter, which is most pronounced among elements of a high atomic weight. Thus thorium and uranium are both radio-active, and are seemingly continually breaking down into elements of lower atomic weight. Indirect evidence of the constant ratio of uranium to radium, as well as the direct evidence of the formation of the intermediate element ionium, which is known to produce radium as a product of further change, leaves no doubt whatever that uranium (atomic weight 240) is slowly producing radium (atomic weight 226), and that possibly lead, silver, and gold are being similarly produced in the earth. More recently Campbell has shown that the element potassium also appears to be very slightly radio-active. If this is so it seems almost certain that the whole body of elements is changing, so slowly that in most cases we cannot detect the change at all, and that the radio-active properties of radium and thorium are only exaggerated cases of a process which is taking place excessively slowly in all elements alike.[1]

It seems certain that all our views as to the duration of geological and astronomical time will have to be revised in accordance with the new knowledge. For example, the presence of radium in the earth's crust has been held to be capable of maintaining almost indefinitely the internal heat of the earth, while the presence of 2·5 parts of radium in one million will account for the present copious emission of heat and light from the sun, and opens out a vista of almost limitless time for the process of stellar evolution.

But especial interest has been roused by the discovery that the amount of radium disseminated through the earth's crust is very considerable. Joly shows that in the sea alone there exist no less than 20,000 tons of radium in solution, while scattered over the ocean floor, and imbedded in it, are no less than a million tons! All this radium has accumulated in the sea and in the sedimentary deposits on its floor as the result of the break up and washing away into the sea of igneous rocks which contain uranium, the parent of radium. The radium especially accumulates in sedimentary deposits, where its

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[1] This view was first suggested by the writer in the *Chemical News*, 1901, **83**, 130; see also articles by the writer, *Chemical News*, 1903, **88**, 197; 1904, **89**, 47, 118,

No. 2. TABLE OF RADIO-ACTIVE SUBSTANCES

ELEMENT	RADIATION	HALF-VALUE PERIOD	ATOMIC WEIGHT
URANIUM	α	6×10^9 years	238
↓			↓
Uranium X	$\beta+\gamma$	24·6 days	234 (?)
			↓
Uranium Y	β	1·5 days	234
↓			↓
Ionium	α	greater than 20,000 years	230 (?)
↓			↓
Radium	α+slow β	2000 years	226
↓			↓
Ra-Emanation	α	3·85 days	222 (?)
↓			↓
Radium A	α	3 minutes	218 (?)
↓			↓
Radium B	$\beta+\gamma$	26·8 minutes	218 (?)
↓			↓
Radium C C_1	$\alpha+\beta+\gamma$	19·5 minutes	214 (?)
			↓
Radium C C_2	β	1·4 minutes	214 (?)
↓			↓
Radium D *Radio-lead*	slow β	16·5 years	210 (?)
↓			↓
Radium E	$\beta+\gamma$	5 days	210 (?)
↓			↓
Radium F *Polonium*	α	136 days	210 (?)
			↓
Radium G (lead ?)	——	——	206 (?)
ACTINIUM	No rays	?	
↓			
Radio-Actinium	$\alpha+\beta$	19·5 days	
↓			
Actinium X	α	10·5 days	
↓			
Emanation	α	3·9 seconds	
↓			
Actinium A	α	0·002 seconds	
↓			
Actinium B	slow β	36 minutes	
↓			
Actinium C	α	2·1 minutes	
↓			
Actinium D	$\beta+\gamma$	3·47 minutes	

TABLE OF RADIO-ACTIVE SUBSTANCES—*continued.*

ELEMENT	RADIATION	HALF-VALUE PERIOD	ATOMIC WEIGHT
THORIUM	α	3×10^{10} years	232·4
↓			
Mesothorium 1	no rays	5·5 years	
↓			
Mesothorium 2	$\beta+\gamma$	6·2 hours	
↓			
Radiothorium	α	2 years	
↓			
Thorium X	$\alpha+\beta$	3·64 days	
↓			
Emanation	α	54 seconds	
↓			
Thorium A	α	0·14 second	
↓			
Thorium B	slow β	10·6 hours	
↓			
Thorium C { C_1	α	60 minutes	
Thorium C { C_2	α	very rapid (?)	
↓			
Thorium D	$\beta+\gamma$	3·1 minutes	

heating effect in time causes the upheaval of mountain ranges on the floors of the sedimentary deposits. In Joly's words, "There is no more striking feature of the part here played by radio-activity than the fact that the rhythmic occurrence of depression and upheaval succeeding each other after great intervals of time, and often shifting their position but little from the first scene of sedimentation, becomes accounted for. The energy, as we have already remarked, is in fact transported with the sediments—the energy (radium) which determines the place of yielding and upheaval, and ordains that the mountain ranges shall stand round the continental borders. Sedimentation from this point of view is a convection of energy. When the consolidated elements are by these and by succeeding movements forced upwards into mountains, they are exposed to denudative effects greatly exceeding what affects the plains. Witness the removal during late Tertiary times of the vast thicknesses of rock enveloping the Alps. Such great masses are hurried away by ice, rivers and rain. The ocean received them; and with infinite patience the world awaits the slow accumulation of the radio-active energy beginning afresh upon its work. The time for such events appears to us immense, for millions of years are required for the sediments to grow in thickness, and the geotherms to grow upwards; but vast as it is, it is but a moment in the life of its parent substance, whose atoms, hardly diminished in numbers, pursue their changes while the mountains come and go, and the rudiments of life develop into its highest consummations." [1]

As the result of very careful investigation of the amounts of radium scattered through the rocks forming the crust of the earth, Joly comes to the somewhat alarming conclusion that the internal temperature of the earth must be increasing steadily, and that ultimately the whole earth may again become molten.

"A celestial body possessing any considerable store of long-lived radio-active elements will not cool as an ordinary body, simply parting with its stored up heat, and falling in temperature gradually from its surface inwards. . . . The quiet accumulation of radio-active energy proceeding throughout the mass will, near the surface, make good the radiation loss, but in the interior, where no means of escape exists, must collect during the passing geological periods. There can be but one result:—general surface vulcanicity and reversion to temperature conditions which may involve the repetition of the entire sequence of events. If such has been the past history of our globe, and such the origin of our geological age,

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[1] *Radio-activity and Geology*, pp. 111–112. (Constable & Co., Ltd., London.)

we find the existing earth-heat to be more or less completely radio-active in origin. . . . We have no reason to find in the advent of radio-activity into cosmic and geological sciences any new difficulties, but rather the clearing away of old ones. The duration of solar heat finds a plausible explanation, and the prolonged duration of geological time without the corresponding cooling of the earth's surface becomes accounted for. But it cannot be said that it enables us to foretell the destiny of our globe. Unless other lines of evidence exist, we are left to the imagination as to what has been the history of the past, and what may result in the future. But wonderful possibilities are brought before us. Peaceful cooling may await the earth or catastrophic heating may lead into a new era of life. Our geological age may have been preceded by other ages, every trace of which has perished in the regeneration which heralded our own. Whatever be the future or the past of our world, we have the untrammelled regions of space in which such varied destinies must surely find their accomplishment. The planets may now be in varying phases of such great events. And when a star appears in the heavens where before we knew of none, may not this be a manifestation of the power of the infinitely little over the infinitely great—the unending flow of energy from the unstable atoms wrecking the stability of a world? . . . With an interest almost amounting to anxiety, geologists will watch the developments of research which may result in timing the strata and the phases of evolutionary advance; and may even—going still further back—give us glimpses of past æons, beyond that day of regeneration which at once ushered in our era of life, and, for all that went before, was 'a sleep and a forgetting.'"[1]

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[1] Joly, *Radio-activity and Geology*, pp. 170, 172, 250 (1909). (Constable and Co., Ltd., London.)

Thus the reader will see that the discovery of the radio-active elements has indeed opened up a new and wonderful vista of possibilities, in the light of which we must remodel all our views regarding the structure of the universe.

For example, it is certain that Kelvin's estimate of the earth and sun's ages, founded on the physical method of treating the earth and sun as if they were simply cooling bodies, has been dealt its death-blow by the discovery of radium in the earth. The old hypothesis is that the earth was flung off in a molten condition from the sun, then a vast incandescent nebulous mass, and, after separation, the world slowly cooled to its present condition—and is still cooling. Now, assuming the world to have hung in space as a molten red-hot globule splashed off from a vaster mass of incandescent liquid, then it is certain that the amount of radium now in the earth would not evolve sufficient heat to retard greatly the cooling of the earth up to the point when it became surrounded by a solid crust. When the solid crust of the earth has cooled to its present temperature the rate of heat loss by radiation into space is exactly compensated by the heat evolved from the elementary disintegration of the radio-active elements in the earth's surface rocks, as explained above ; and so a balance will be struck and the present temperature of the surface will be maintained quite stationary—for a time. But deep below, in the interior of the earth, heat is being continually evolved by radio-active substances which cannot escape, and so there comes a time, as suggested by Professor Joly, when disaster ensues. But not from without by collision with some wandering star—as was once taught—but from within, by the flooding of her surface with irresistible out-pourings of white-hot molten lava, is the destruction to come that will reduce the world to her former incandescent condition, and begin again her life-history perhaps for the thousandth time.

Similarly, it is supposed that our sun will in like manner cool to a certain surface temperature whereat the heat evolved by the elemental disintegration of the radio-active material in the surface layers will balance the heat loss by radiation from the surface, until after some ages of cooling, darkness and death will overtake the solar system, and the planets, hidden by night, will continue to circle ghost-like around our burnt-out sun. And this will be the fate not of our own, but of other suns as well, as described in Peter McArthur's words:

> "The thronged suns are paling to their doom,
> The constellations waver, and a breath
> Shall blurr them all in eternity;
> Then ancient Silence in oblivious gloom
> Shall reign where holds this dream of Time and Death
> Like some brief bubble in a shoreless sea."

But only for a time. Age after age the heat of the decomposing elements accumulates in the sun's interior, and at last causes eruptive outburst after outburst of accumulating violence, culminating in some vast uprush of incandescent fiercely heated matter, which will give the dark sun again its original intensely hot surface, the glare of whose uprising flames will, after ages of darkness, light up afresh the surrounding planets wheeling in silence millions of miles afar, and awaken them to life and activity once more by its beneficent heat and light; and so the dead planets again become covered with busy populations, complicated civilisations, and great cities. This stage is once more followed by slow cooling of the central sun and ultimate darkness, when both planets and sun roll through space as dead worlds enshrouded in darkness save where their volcanoes glow red through the eternal night. Then again follows a fierce blazing up into incandescence; and so cycle after cycle is repeated, time after time, until all is ended by some gigantic collision with a wandering star.

All this may occur not only in our own planetary system but also among the countless millions of suns of space with their attendant planets. These amazing possibilities of the re-birth of dead worlds were unknown to Tennyson when he wrote the despairing lines:

"Many a hearth upon our dark globe sighs after a vanished face,
Many a planet by many a sun may roll with the dust of a vanished race,
Raving politics, never at rest—as this poor earth's pale history runs,—
What is it all but a trouble of ants in the gleam of a million million of suns?
What is it all, if we all of us end but in being our own corpse-coffins at last,
Swallowed in Vastness, lost in Silence, drowned in the deeps of a meaningless Past?
What but a murmur of gnats in the gloom, or a moment's anger of bees in their hive?"

In view of the wonderful revelations of science during the last few years we must decide that the pessimistic attitude of Tennyson is unwarranted by the facts now known to us.

It will be seen, therefore, from what we have stated that the determination of the actual age of the earth is immensely complicated by radio-activity. Seeing that there are possibly independent cycles of incandescence and darkness of both sun and earth, even if we can make an estimate (and there are several ways of doing this) of the time which it has taken for our world to cool from a molten condition to its present surface temperature, we cannot exactly tell what was the sun's state during that time. From present evidence, however, it seems very probable that the sun shone brightly long before the earth came into existence ; it is, however, also possible that the incandescence of the sun arose after the earth's crust had solidified, and that the earth for long æons of ages rolled through space, cold and dark, a dead planet, waiting only for the incandescence of a dark sun to awaken her surface to life activity.

However this may be, the subject of radio-activity allows us to make estimates of the age of the earth by an independent method.

The principle of the method will be understood when we recollect that radium is an element descended by a slow series of changes from uranium, the changes continually proceeding down a series of radio-active elements until a stable element, probably lead (see table 2, page 102) is reached. The process of degradation is excessively slow, but the time-rate of each change has been definitely calculated from laboratory measurements. Also the number of helium atoms (*i.e.* Alpha particles) thrown off during each change is definitely known.

Now two workers, Prof. Joly of Dublin and the Hon. R. J. Strutt of London, assume that all these discharged helium atoms have accumulated in a given mineral *in situ* in any geological formation, and that, consequently, all we have to do in order to estimate its age is to determine in a specimen mineral the ratio of the occluded helium to the still remaining radio-active element, whence we can calculate the age of the geological formation from which the mineral has been taken.

The results, however, have not been very satisfactory, for it has been found that material which must have been formed about the same time gives ages which differ very considerably. The error probably lies in the fact that the helium in the course of time has escaped to some extent from the geological formation in which it was produced ; and this is likely enough when we recollect the changes of temperature and pressure to which the mineral must have been exposed during the long ages which have elapsed since the formation of the mineral, to say nothing of the solvent action of percolating waters.

Professor Boltwood has attacked the problem from a different standpoint by assuming that lead is the ultimate product of the disintegration of uranium, and so from measurements of the uranium-lead ratio of a given mineral, and knowing the rate of transformation of uranium into lead, it is quite an easy matter to calculate the age of the mineral, and so make estimates of the age of the geological strata from whence the mineral was taken.

The age of the earth on these assumptions works out between 200 and 1300 millions of years. The evidence of radio-activity is to give the earth an age greater than that adduced by any other methods.

We thus see what a vista of possibilities the subject of radio-activity has opened out. It has destroyed the pitiably cock-sure attitude so characteristic of scientists only a few years ago, when it was thought that the constitution of matter and of the universe were tolerably well known, and that only a few minor points remained to be cleared up. Some of the greatest thinkers of the Victorian age went down to their graves derided by these cock-sure scientists. But the thoughts of such men as Herbert Spencer and Johnstone Stoney regarding the Universe were considerably nearer the mark than the more conservative assumptions of their antagonists, who loaded them with ridicule. Radio-activity has, indeed, revolutionised the mental outlook of scientists. It has opened up a realm of possibilities previously unthought of save by some old-world thinkers. It has taught us that we cannot doubt that there are still greater truths to be discovered than any which have before illuminated the world.

Although we may see, by means of radio-active explosion,—

> "Atoms or systems into ruin hurl'd,
> And now a bubble burst, and now a world."

and can thus explain much that was previously inexplicable to us, yet we must not forget that

> "Beyond the bright search-lights of Science
> Out of sight of the windows of sense,
> Old riddles still bid us defiance,
> Old riddles of why and whence.
> There fail all the pathways we've trod,
> Where man, by belief, or denial,
> Is weaving the purpose of God."

The omniscience of Science, in fact, has received a shock by the discovery of radio-activity in recent years. She must now confess with Tennyson—

> "So runs my dream ; But what am I ?
> An infant crying in the night ;
> An infant crying for the light ;
> And with no language but a cry."

CHAPTER V

THE MYSTERY OF THE PERIODIC LAW

It was the immortal Wordsworth who sang of

> "Truths that awake,
> To perish never;
> Which neither listlessness, nor mad endeavour,
> Nor man, nor boy,
> Nor all that is at enmity with joy
> Can utterly abolish or destroy."

And I think we may confidently state that the principle which we are going to discuss in this chapter is one of these grand truths. Its cause lies hidden deep down in the roots of the universe, beyond our ken and strength. Its origin is bound up in those primordial forces which brought the material universe into being, evolving from the womb of time, in magnificent succession, element after element, until all space was filled with them. It is the mighty principle which connects together all the multifarious atoms of which all things are built up. Was ever so stupendous a problem set the intellect of man as the solution of the cause of this great law, this mighty hieroglyphic written in unknown characters across the whole domain of chemistry? It links together in one harmonious whole the stupendous mass of matter scattered throughout this wonderful universe of ours, and proclaims the common origin of the very matter of which our own earth is formed and that which builds up the innumerable worlds of space. I think, therefore, that the reader will be interested if I attempt to explain in simple language what this great law is, and what attempts, imperfect and far from the mark as they admittedly are, have been made to explain it.

The enormous number of apparently unconnected facts is the feature of Chemical Science which most deeply impresses the intelligent reader commencing its study for the first time. As he reads element after element rises into view on his intellectual horizon, each the centre of a vast galaxy of compounds, the whole forming a bewildering maze of complex properties, in the midst of which the unaided intellect stumbles helplessly in its attempts to fix and retain them in orderly array. During the first decades of the nineteenth century chemical science advanced rapidly and discovery after discovery kept piling fact upon fact until the huge edifice was a confused jumble constructed without apparent plan or order.

But it was not long before some of the more original intellects were at work, delving behind the facts, collecting and arranging them, in the hope that some simple but grand law would be found governing the bewildering masses of detail, joining them together as by a golden thread.

Oliver Wendell Holmes in his delightful style classifies men into "One-story intellects, two-story intellects, three-story intellects with skylights. All fact collectors who have no aim beyond their facts, are one-story men. Two-story men compare, reason, generalise, using the labours of the fact collectors as well as their own. Three-story men idealise, imagine, predict; their best illumination comes from above, through the skylight." Without absolutely accepting Holmes' classification, it may be said that men of all three classes are to be met with among the devotees of chemistry, but that men of the first class are especially numerous. This perhaps was the reason why, when the great generalisation was at last revealed, first dimly and imperfectly by de Chancourtois in 1862, then clearly and boldly by Newlands in 1864, and finally in all its grandeur by Mendeléeff and Lothar Meyer between the years 1869 and 1871, that their brother chemists troubled very little about their labours until they were forced to their notice in a truly sensational way. This happened as follows: Between the years 1875 and 1885 three interesting new elements were discovered, now called Gallium, Germanium, and Scandium, after the countries of the respective discoverers. In the midst of the excitement which always attends the discovery of new elements, a Russian chemist, Mendeléeff by name (see Plate 6), announced that many years before he had not only predicted the existence of these elements, but had actually described their properties. A reference to his writings showed that this was really so. Led by certain theoretical considerations Mendeléeff had described in 1871 three elements, under the names eka-silicon, eka-boron, and eka-aluminium, whose properties agreed to an astonishing degree of exactitude with those attributed by their discoverers to gallium, germanium, and scandium. This may be seen from the following table, in which the predicted properties and those actually observed are arranged in parallel columns:

Eka-boron	*Scandium*
A hypothetical element whose properties were foretold in 1871 by Mendeléeff	An element discovered by Nilson in 1879
Atomic weight, 44	Atomic weight, 43·8
Oxide, Eb_2O_3, Specific gravity, 3·5	Oxide, Sc_2O_3, Specific gravity, 3·86
Sulphate, $Eb_2(SO_4)_3$	Sulphate, $Sc_2(SO_4)_3$
Double Sulphate not isomorphous with alum, $Al_2(SO_4)_3,K_2SO_4.24H_2O$	$Sc_2(SO_4)_3.3K_2SO_4$—slender prisms not isomorphous with alum.

Photo, Warwick Brooks, Manchester.

PLATE 6.—Mendeléeff.

Eka-aluminium	*Gallium*
Hypothetical element predicted by Mendeléeff in 1871	An element discovered in 1875 by Lecoq de Boisbaudran.
Atomic weight, 68. Specific gravity, 6·0	Atomic weight,69·5. Specific gravity, 5·96.

Eka-silicon	*Germanium*
Hypothetical element predicted by Mendeléeff in 1879	An element discovered by Winkler in 1887
Atomic weight, 72. Specific gravity, 5·5	Atomic weight, 72. Specific gravity, 5·47
Oxide, EsO_2, Specific gravity, 4·7	Oxide, GeO_2, Specific gravity, 4·7
Chloride, $EsCl_4$, liquid, boiling slightly below 100° C., Specific gravity, 1·9	Chloride, $GeCl_4$, liquid boiling at 86° C., Specific gravity, 1·887
Ethide, $Es(C_2H_5)_4$, liquid, boiling at 160° C., Specific gravity, 0·96, slightly less than water	Ethide, $Ge(C_2H_5)_4$, liquid boiling at 160° C., Specific gravity, slightly less than water
Fluoride, EsF_4, not gaseous	Fluoride, $GeF_4.3H_2O$. White solid mass.

Could anything be more wonderful than this forecast? It was as if Mendeléeff was describing elements actually in his hands, so closely and accurately was the forecast fulfilled in each case. And yet at the time he wrote not only were the elements not discovered, but, as he tells us in one of the characteristic footnotes in his *Principles of Chemistry* (vol. ii. p. 25), "When in 1871 I wrote a paper on the application of the periodic law to the determination of the properties of as yet undiscovered elements, I did not think I should live to see the verification of this consequence of the law, but such was to be the case. Three elements were described, eka-boron, eka-aluminium, and eka-silicon; and now, after the lapse of twenty years, I have the great pleasure of seeing them discovered and named after those countries where the rare minerals containing them are found, and where they were discovered—Gallia, Scandinavia, and Germany."

"We see in this successful three-fold prediction," says Duncan when discussing this subject in his recent work entitled *The New Knowledge*, "the scope and power of the periodic law as an instrument of research. We see convincingly that the law must be the expression of a fact. Suppose that an astrologer informed you that your horoscope led him to believe that you would meet, sometime in your life, three men; and that with the utmost particularity he told you their weights, the colour of their hair, the size of their noses, and, in a word, all the habits of mind and body sufficient to differentiate them positively from all other men; and suppose, moreover, that you met these men possessed of qualities identical with the description predicted. You would believe in astrology. Astrology cannot do these things, but chemistry *can* because of the periodic law. Therefore we believe in the periodic law."

It can therefore easily be imagined that this feat of Mendeléeff awakened a surprise and wonder in the scientific world very similar to that caused by the verification, by the discovery of Neptune, of Adams and Leverrier's remarkable prediction of a new planet, as yet unseen by mortal eye, which swung in a mighty orbit outside Uranus. Naturally the attention of the scientific world was directed to the methods employed by the great Russian in arriving at such wonderful forecasts. And then it was found that, many years before, a law had been discovered by various workers, independently of each other, which connected all the elements together in a remarkable way, and regulated their properties. This was called the "Periodic Law" by Mendeléeff in 1871, and has ever since borne that name. Let me now explain its nature. By referring to the table of elements given in any textbook of chemistry the reader will see that some eighty odd ones are there named and arranged in alphabetical order. But now let the reader arrange the elements, not in alphabetical order, but in the order of their atomic weights. Let him, for example, starting with lithium, write the succeeding elements in the order of increasing atomic weight, thus:—

Li	Be	B	C	N	O	F	Na	Mg	Al	Si	P	S	Cl	K
7	9	11	12	14	16	19	23	24	27	28	31	32	35½	39

Then if the reader will study the properties of these elements carefully a remarkable fact will soon appear. It is this :— The series of elements thus arranged does not present one continuous, progressive modification in the chemical and physical properties of its several members with increase of atomic weight, but that the same properties *occur over again* with slight modifications, at intervals down the series. As Huxley aptly put it, the whole series does not run

a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, &c.

But

a, b, c, d, A, B, C, D, α, β, γ, δ, &c.

Thus in the above series of elements, Li (lithium) resembles Na (sodium) and no other intermediate element. Similarly, carbon (C) resembles silicon (Si) and no other intermediate element, fluorine (F) resembles chlorine (Cl) and no other intermediate element, &c.

John Newlands, a young man practically unknown in chemical circles at the time, was the first who pointed this out. Writing to the *Chemical News* in 1864–5 he asserted that when the elements were thus arranged in the order of the magnitudes of their atomic weights "the eighth element, starting from a given one, is a sort of repetition of the first, or that elements belonging to the same group stood to each other in a relation similar to that between the extremes of one or more octaves of music."

No.	No.	No.	No.	No.	No.	No.	No.
H 1	F 8	Cl 15	Co and Ni 22	Br . . . 29	Pd 36	I . . . 42	Pt and Ir 50
Li 2	Na 9	K 16	Cu . . 23	Rb . . 30	Ag 37	Cs . . 44	Tb . . 53
G 3	Mg 10	Ca 17	Zn . . 25	Sr . . . 31	Cd 38	Ba and V 45	Pb . . 54
Bo 4	Al 11	Cr 19	Y . . . 24	Ce and La 33	U 40	Ta . . 46	Th . . 56
C 5	Sc 12	Ti 18	In . 26	Zr . . 32	Sm 39	W . . 47	Hg . . 52
N 6	P 13	Mn 20	As . . 27	Di and Mo 34	Sb 41	Nb . . 48	Bi . . 55
O 7	S 14	Fe 21	Se . 28	Ro and Ru 35	Te 43	Au . . 49	Os . . 51

NEWLANDS' ORIGINAL TABLE OF THE ELEMENTS AS IT APPEARED IN THE *CHEMICAL NEWS* IN AUGUST 1865 (Vol. xii. p. 83).

Note.—When two elements happen to have the same equivalent, both are designated by the same number.

"If the elements are arranged in the order of their equivalents, with a few slight transpositions, as in the accompanying table, it will be observed that elements belonging to the same group, usually appear in the same horizontal line."—NEWLANDS, *Chemical News*, August 1865.

This has since been called Newlands' "Law of Octaves," and was a tolerably clear statement of the periodic reappearance of properties when the weights of the atoms are taken as the basis of classification of the elements. In 1866 the same chemist brought the relations which he had observed to the notice of the Chemical Society of London, arranging the elements in a table so that those belonging to the same group usually appeared in the same straight line. The reader will now suppose that when Newlands explained this new discovery of his to that learned body, the home of all the best chemical talent in the country, it received his communication with the attention that it deserved. But, alas, I am sorry to say, it did nothing of the kind. It required a powerful and imaginative intellect to soar beyond the accumulation of petty detail which then obscured the chemical horizon, and grasp the threads of the great generalisation underlying them. It must be confessed that Chemistry so overwhelms a lesser mind with disconnected facts that, in the words of the proverb, "the wood cannot be seen for the trees"; and insensibly there is produced a mental attitude so pithily described by Tennyson:

"An eye well practised in Nature, a Spirit bounded and vain."

At any rate the body of the Chemical Society at that time was largely composed of the "one-story" intellects of Holmes' classification, mere collectors of facts—careful and accurate analysts, indeed, but devoid of that scientific imagination necessary for grasping the capabilities of such a generalisation as Newlands now brought before them. And so it came about that his paper was received with open ridicule; one prominent chemist[1] actually got up and inquired sarcastically whether the author had ever

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[1] Professor G. C. Foster.

tried to see if a simple law would appear when the elements were arranged in the order of the initial letters of their names—a sally of wit which was greeted with roars of laughter. Newlands' paper was not accepted for publication, and he withdrew, dismayed, from the dangerous regions of theoretical chemistry into the sugar trade. But the whirligig of time brings its revenges. The Chemical Society in 1866 laughed at Newlands and his "Law." But twenty-one years later the Royal Society awarded him the Davy medal for his discovery.

Newlands, therefore, received some tardy acknowledgment of his work during his lifetime. But a predecessor of his, namely de Chancourtois, did not even meet with this encouragement. He, too, between the years 1862–3, had suggested a classification of the elements on the basis of the magnitude of their atomic weights, but his conclusions were so utterly forgotten that it was only long after his death, when the Periodic System had been firmly established, that they were unearthed, and to some extent recognised.[1]

The moral to be drawn from this is—*Persevere.* If Newlands had only borne in mind the teaching of Davidson's lines,[2]

"Dethrone the past;
Deed, vision—naught
Avails at last
Save your own thought."

and had boldly gone forward, undismayed by ridicule and neglect, to deepen and widen his law by a more accurate study of the elements, he could hardly have failed to discover the periodic law in its entirety.

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[1] Hartog, "A First Foreshadowing of the Periodic Law," *Nature*, 1892, 41, 186.

[2] *Fleet Street and Other Poems*, published by Grant Richards, London.

...	...	...	Ti = 50	Zr = 90	? =180
...	...	...	V = 51	Nb = 94	Ta =182
...	...	...	Cr = 52	Mo = 96	W =186
...	...	...	Mn = 55	Rh =104·4	Pt =197·4
...	...	...	Fe = 56	Ru =104·4	Ir =198
...	...	Ni=	Co = 59	Pd =106·6	Os =199
H=1	...	...	Cu = 63·4	Ag =108	Hg=197
...	Be = 9·4	Mg =24	Zn = 65·2	Cd =112	...
...	B =11	Al =27·4	? = 68	Ur =116	Au=197?
...	C =12	Sc =28	? = 70	Sn =118	...
...	N =14	P =31	As = 75	Sb =122	Bi =210
...	O =16	S =32	Se = 79·4	Te =128?	...
...	F =19	Cl =35·5	Br = 80	I =127	...
Li=7	Na=23	K =39	Rb = 85·4	Cs =133	Tl =204
...	...	Ca =40	Sr = 87·6	Ba =137	Pb =207
...	...	? =45	Ce = 92	...	...
...	...	? Er=56	La = 94	...	...
...	...	? Yt =60	Di = 95	...	...
...	...	? In =75·6	Th=118?	...	...

MENDELÉEFF'S TABLE OF THE ELEMENTS, 1869.[1]

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[1] *Zeitschrift für Chemie*, 1869, p. 405.

I	II	III	IV	V	VI	VII	VIII	IX
...	B 11	Al 27·3	...	—	...	? In 113·4	—	Tl 202·7
...	C 12	Sc 28	—	—	—	Sn 117·8	...	Pb 206·4
...	...	...	Ti 48	...	Zr 89·7	...	—	...
...	N 14	P 30·9	...	As 74·9	...	Sb 122·1	...	Bi 207·5
...	...	...	V 51·2	...	Nb 93·3	...	Ta 182·2	...
...	O 16	S 32	...	Se 78	...	Te 128?	...	...
...	...	...	Cr 52·4	...	Mo 95·6	...	W 183·5	...
...	F 19·1	Cl 35·4	...	Br 79·75	...	I 126·5	...	...
...	...	...	Mn 54·8	...	Ru 103·5	...	Os 189·6?	...
...	...	...	Fe 55·9	...	Rh 104·1	...	Ir 196·7	...
...	...	Co=	Ni 58·6	...	Pd 106·2	...	Pt 196·7	...
Li 7·0	Na 22·9	K 39	...	Rb 85·2	...	Cs 132·7	...	...
...	...	...	Cu 63·3	...	Ag 107·7	...	Au 192·2	...
? Be 9·3	Mg 23·9	Ca 39·9	...	Sr 87	...	Ba 136·8	...	...
...	...	...	Zn 64·9	...	Cd 111·6	...	Hg 199·8	...

MEYER'S TABLE OF THE ELEMENTS.[1]

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[1] *Liebig's Annalen*, Supplement, vi. and vii., 1870, p. 354.

As it was, this was left for other minds to do, and a few years later the question was taken up abroad in a wider and more serious spirit. In March 1869, Professor D. Mendeléeff communicated a paper to the Russian Chemical Society in which he set forth an arrangement of the elements in the order of their atomic weights and showed that when thus arrayed the elements showed a periodic recurrence of properties. Mendeléeff was more than the two-story man of Holmes' classification. His, indeed, was a three-story intellect, one that could not only generalise, using the facts of others, but who could idealise, imagine, and *predict.* With a genius amounting, almost, to inspiration, he employed the law not only to correct the atomic weights of many elements, but, as we have already seen, actually to predict the existence and properties of elements unknown at the time. In December 1869, some nine months after Mendeléeff, Lothar Meyer, then Professor of Chemistry in the Polytechnicum at Carlsruhe, published a paper entitled *The Nature of the Chemical Elements considered as a Function of their Atomic Weights,* in which he gave a table of elements substantially the same as that of Mendeléeff, and he likewise remarked that the properties of the elements are periodic functions of their atomic weights. In this scheme the same or similar properties recur when the atomic weights are increased by a certain amount, which at first is about 16, then about 46, and afterwards between 88 and 92.

Meyer also pointed out that the combining capacity of the atoms rises and falls regularly and equally in the first two series of the elements, thus:

Univalent	Divalent	Trivalent	Tetravalent	Trivalent	Divalent	Univalent
Li	Be	B	C	N	O	F
Na	Mg	Al	Si	P	S	Cl

In other words, while lithium (Li) or sodium (Na) can combine with only one atom of an element like chlorine, beryllium (Be) and magnesium (Mg) can combine with two, carbon (C) and silicon (Si) with four, &c.

But Meyer afforded a still more complete and triumphant vindication of the principle of periodicity by plotting the relation of the atomic weights to the atomic volumes, as shown in the accompanying diagram (fig. 8).[1]

Duncan, in graphic language, thus describes the phenomenon which then appears.[2]

"Just as the pendulum returns again in its swing, just as the moon returns in its orbit, just as the advancing year ever brings the rose of spring, so do the properties of the element periodically recur as the weights of the atoms rise. To demonstrate this fact, take some one specific property, for example, the atomic volume, and arrange a table on a piece of engineering paper in which the atomic weights read from left to right (the abscissae), while the atomic volumes read from bottom to top (the ordinates). Now construct a curve by pricking out the positions of the different elements in accordance with both their atomic volumes and atomic weights, and you will find yourself in possession of a table such as fig. 8. We see at once from this curve that the atomic volume is a periodic function of the atomic weight. As the atomic weight increases, *the atomic volume alternately increases and decreases*. The periodicity proclaims itself in the regularly recurring hills and valleys which constitute the curve. Elements which occupy similar positions on the five hills and valleys have markedly similar properties. Thus, you will notice at the summit of each of the five

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[1] The atomic volume is the volume occupied by a weight of the element proportional to its atomic weight, the element being supposed to be in the solid state. It is the atomic weight divided by the specific gravity.

[2] *The New Knowledge*, by R. K. Duncan, p. 23. 1906. Hodder & Stoughton, London; the A. S. Barnes Co., New York. Quoted with permission of the publishers.

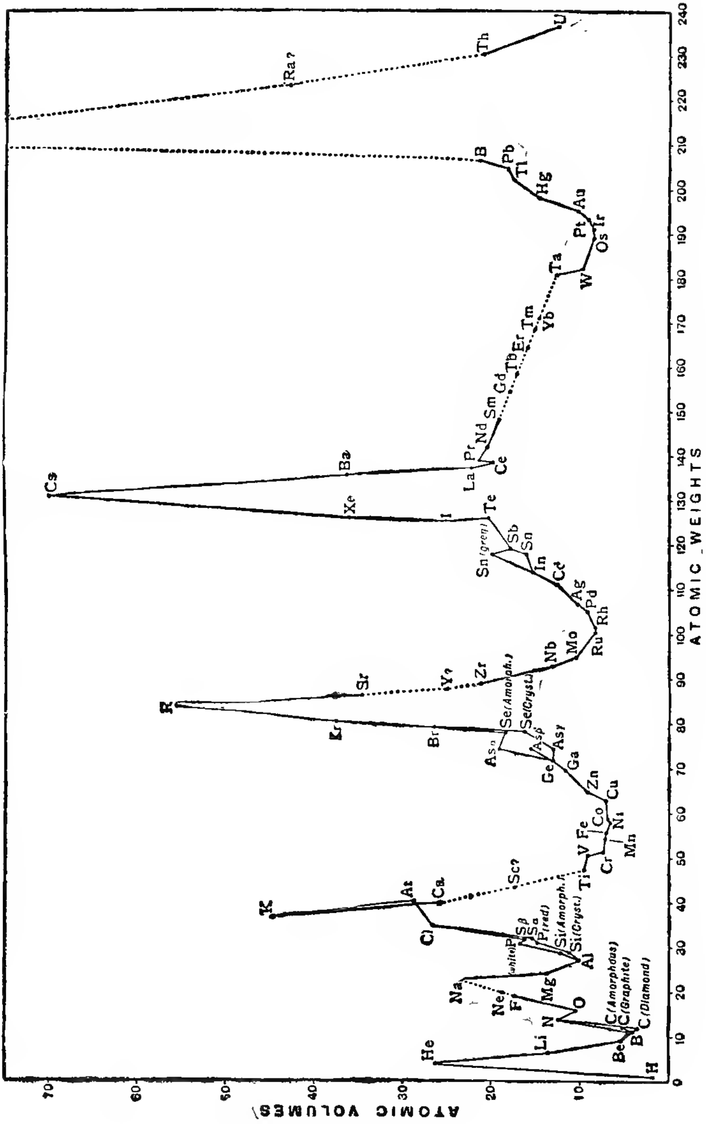

FIG. 8.—Curve of Atomic Volumes.

hills, the symbols of the elements lithium, sodium, potassium, rubidium and caesium, all of these elements possessing amazingly similar properties. Or, again, find the little dot marked S (signifying sulphur) on the slope of the third hill, and you will then notice a little dot marked Se (selenium) and another Te (tellurium) in a correspondingly similar position on the two other hills respectively. These elements have strikingly similar properties. Take now another property altogether, let us say the melting point of the elements, and make a similar diagram. You get a curve remarkably like the first one, with this exception, that the elements which were at the top of the first curve are now at the bottom. The melting point curve is as strictly periodic as the atomic volume curve, and of the same general shape. . . . Similar curves can be constructed for many other properties. Can we imagine, then, that these atoms, these little invisibilities, in which we all live and move and have our being, are separately created, arbitrarily made, unrelated individuals? Hardly so, for they are obviously created in accordance with some scheme. Would that we might understand this scheme all and in all. It would be a veritable glimpse behind the veil of existence. But if we cannot read from Alpha to Omega, we may spell out what we can, leaving future letters to future men; perforce content that if in this cryptogram of the universe we know indubitably that there is a cryptogram to be read, we have at least come to the beginnings of knowledge."

In August 1871 Mendeléeff drew up a complete exposition of the periodic law, and of the deductions which may be made from it. Here for the first time appeared the table which is now to be found in the pages of nearly every text-book of theoretical chemistry, and which is employed as the most generally received basis of the

Series.	Group I. R_2O.	Group II.	Group III. R_2O_3.	Group IV. RH_4 RO_2	Group V. RH_3 R_2O_5.	Group VI. RH_2 RO_3.	Group VII. RH R_2O_7.	Group VIII. RO_4.
1	H=1	...	...	...	...	...	...	...
2	L=7	Be=9·4	B=11	C=2	N=14	O=16	F=19	...
3	Na=23	Mg=24	Al=27·3	Sc=28	P=31	S=32	Cl=35·5	...
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56 Co=59 Ni=59 Cu=63
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	...
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104 Rh=104 Pd=106 Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	I=127	...
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	...
9	(—)	—	—	—	—	—	—	...
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195 Ir=197 Pt=198 Au=199
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	...	...	...
12	—	—	—	Th=231	—	U=240	—	...

MENDELÉEFF'S TABLE OF THE ELEMENTS, 1871.

In this form it appeared for over twenty years in the pages of almost every text-book of theoretical chemistry.

classification of the elements. Mendeléeff's latest formulation of his system, drawn up a few years before his death, is as shown on page 129. It will be seen that this scheme differs from its old classical form by the addition of the new elements contained in the atmospheric air, which were discovered by the recent epoch-making researches of Sir William Ramsay. These elements appear to be unable to combine with other elements, and so Mendeléeff places them in a special group 0 containing elements without valency. He also introduces two hitherto undiscovered elements, which he terms X and Y, and places them in the non-valent group. To both of these he attributes an atomic weight less than that of hydrogen. The element Y is believed to be identical with a very light element called coronium which occurs in the sun's atmosphere, floating high up and flashing out a brilliant green light. He attributes to it the atomic weight 0·4 or less.

The element X he calls Newtonium, in honour of the great physicist, and calculated that its atomic weight was about 0·000001, or about five hundred times lighter than electrons. Mendeléeff further supposed that this element formed the substance of which the luminiferous ether is built up.

The periodic system as it comes from the hands of Mendeléeff still suffers from many imperfections. The properties, for example, do not always correspond to the atomic weights. Argon, with an atomic weight of 39·8, occurs before and not after potassium with an atomic weight of 39·1. The same applies to tellurium (127·6), which should have an atomic weight intermediate between that of antimony (120) and iodine (126·9).

Again, in different grades of combination elements assume entirely different properties. Divalent iron, for example, differs very much in properties from trivalent

Series.	Group 0.	Group 1.	Group 2.	Group 3.	Group 4.	Group 5.	Group 6.	Group 7.	Group 8.
1	X Y	H 1·008	...	...	...	...	...	...	...
2	He 4·0	Li 7·03	Be 9·1	B 11·0	C 12·0	N 14·04	O 16·00	F 19·0	...
3	Ne 19·9	Na 23·05	Mg 24·1	Al 27·0	Si 28·4	P 31·0	S 32·06	Cl 35·45	...
4	Ar 38	K 39·1	Ca 40·1	Sc 44·1	Ti 48·1	V 51·4	Cr 52·1	Mn 55·0	Fe 55·9 Co 59 Ni 59 (Cu) —
5	—	Cu 63·6	Zn 65·4	Ga 70·0	Ge 72·3	As 75·0	Se 79	Br 79·95	...
6	Kr 81·8	Rb 85·4	Sr 87·6	Y 89·0	Zr 90·6	Nb 94·0	Mo 96·0	—	Ru 101·7 Rh 103·0 Pd 106·5 (Ag) —
7	—	Ag 107·9	Cd 112·4	In 114·0	Sn 119·0	Sb 120	Te 127	I 127	...
8	Xe 128	Cs 132·9	Ba 137·4	La 139	Ce 140	—	—	—	— — — (—)
9	—	—	—	—	—	—	—	—	...
10	—	—	—	Yb 173	—	Ta 183	W 184	—	Os 191 Tr 193 Pt 194·9 (Au) —
11	—	Au 197·2	Hg 200	Tl 204·1	Pb 206·9	Bi 208	—	...	...
12	Rad.Emanation 222	Actinium	Ra 226	—	Th 232	Ur X_2 (Brevium)	U 239	...	...

MENDELÉEFF'S MOST RECENT ARRANGEMENT OF THE PERIODIC SYSTEM OF THE ELEMENTS, 1903.

It differs from the old classifical form of 1871 by the introduction of a "non-valency" group 0 to include the inert gaseous elements discovered by Sir William Ramsay in the air. It also contains some of the newly discovered radio-active elements.

iron, divalent lead from tetravalent. Consequently corresponding compounds must be taken for comparison, and this too greatly increases the difficulties of classification. There are many other difficulties which we cannot discuss here.

Many other plans have been devised for exhibiting graphically the relations thus discovered by Newlands, Mendeléeff and Lothar Meyer. We will mention here one, shown in the diagram (Plate 7), constructed by Professor Emerson Reynolds and subsequently modified by Sir William Crookes. Speaking of this, Crookes, in his Presidential Address to the British Association in 1886, says:—

"The more I study the arrangement of this zig-zag curve the more I am convinced that he who grasps the key will be permitted to unlock some of the deepest mysteries of creation. Let us imagine if it is possible to get a glimpse of a few of the secrets here hidden. Let us picture the very beginning of time, before geological ages, before the earth was thrown off from the central nucleus of molten fluid, before even the sun himself had consolidated from the original protyle. Let us imagine that in this primal stage all was an ultragaseous state, at a temperature inconceivably hotter than anything now existing in the visible universe; so high indeed, that the chemical atoms could not have been formed, being still far above their dissociation point. In so far as protyle is capable of radiating or reflecting light, this vast sea of incandescent mist, to an astronomer in a distant star, might have appeared as a nebula, showing in the spectroscope a few isolated lines, or forecasts of hydrogen, carbon, and nitrogen spectra.

"But in the course of time some process akin to cooling, probably internal, reduces the temperature of the cosmic

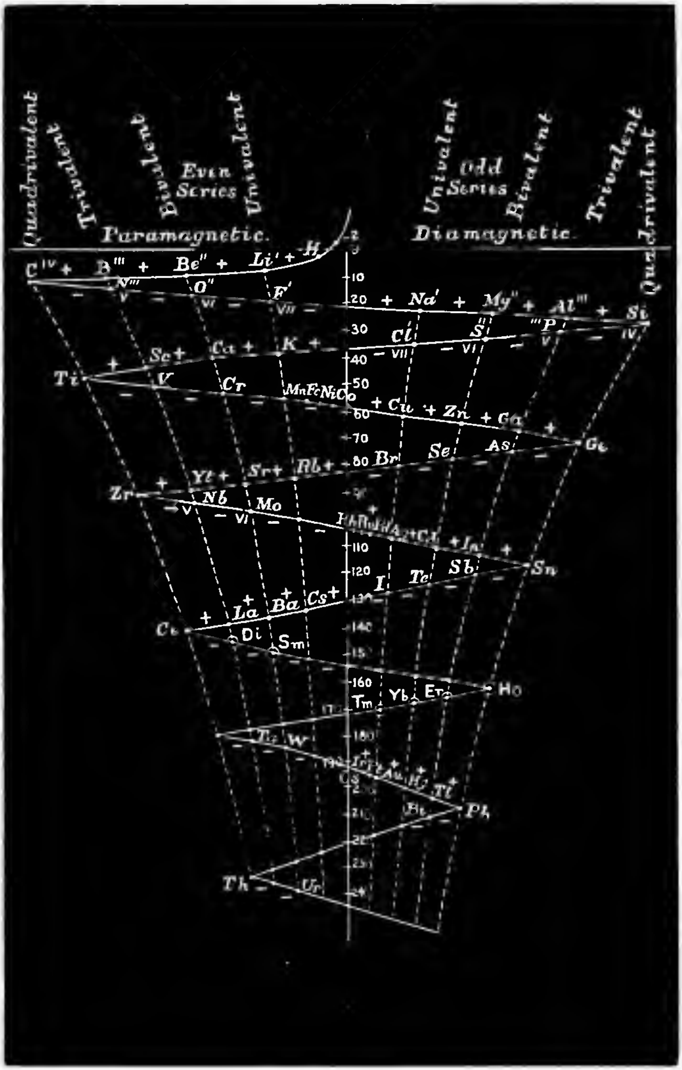

PLATE 7.—Reynolds-Crookes diagram of atomic weights.

protyle to a point at which the first step in granulation takes place; matter as we know it comes into existence, and atoms are formed. As soon as an atom is formed out of protyle it is a store of energy, potential (from its tendency to coalesce with other forms of atoms by gravitation or chemically) and kinetic (from its internal motions). To obtain this energy the neighbouring protyle must be refrigerated by it, and thereby the subsequent formation of other atoms will be accelerated. . . . The easiest formed element, the one most nearly allied to the protyle in simplicity, is first born. Hydrogen—or shall we say helium?—of all the known elements the one of simplest structure and lowest atomic weight, is the first to come into being. For some time hydrogen would be the only form of matter (as we know it) in existence, and between hydrogen and the next formed element there would be a considerable gap in time, during the latter part of which the element next in order of simplicity would be slowly approaching its birthpoint. Pending this period we may suppose that the evolutionary process which soon was to determine the birth of a new element would also determine its atomic weight, its affinities, and its chemical position. In the original genesis, the longer the time occupied in that portion of the cooling down during which the hardening of the protyle into atoms took place, the more sharply defined would be the resulting elements; and, on the other hand, with more irregularity in the original cooling, we should have a nearer approach to the state of the elemental family such as we know it at present. In this way such groups as platinum, osmium, iridium . . . were formed. . . . In the undulating curve may be seen the action of two forces, one acting in the direction of the vectic line, and the other pulsating backwards and forwards like a pendulum. Assume the vertical line to represent temperature slowly sinking through an unknown number of degrees, from the dissociation point of the first known element down to the dissociation point of those last shown on the scale. But what form of energy is represented by the oscillating line? Swinging to and fro like a mighty pendulum to points equidistant from a neutral centre; the divergence from neutrality conferring atomicity of one, two, three, and four degrees as the distance from the centre is one, two, three, or four divisions; and the approach to or retreat from the neutral line deciding the electro-negative or electro-positive character of the element—all on the retreating half of the swing being positive, and all on the approaching half being negative—this oscillating force must be intimately connected with the imponderable matter, essence, or source of energy we call electricity."

A somewhat similar representation of the Periodic Table has recently been put forward by Soddy.[1]

It is shown in Fig. 9, and represents very well the probable course of the evolution of the elements.

The periodic system is far from perfect. It is a generalisation but half revealed, whose summit is hidden, so to speak, in the clouds and whose base is buried deep in the underworld of Nature. As it appears to us, it is only the result of a chance cross-section taken at ordinary temperatures and pressures through the vast body of chemical facts. It is only when we have taken this section at all temperatures and pressures, have studied each set of compounds produced by each element in all theoretically possible levels of valency, and have investigated the influence of all known physical influences on the properties and chemical attractions of the elements, that we will obtain a true notion as to what this wonderful generalisation really signifies. It may be that when

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[1] *The Radio-Elements and the Periodic Law*, p. 11, fig. 3, 1914 edition.

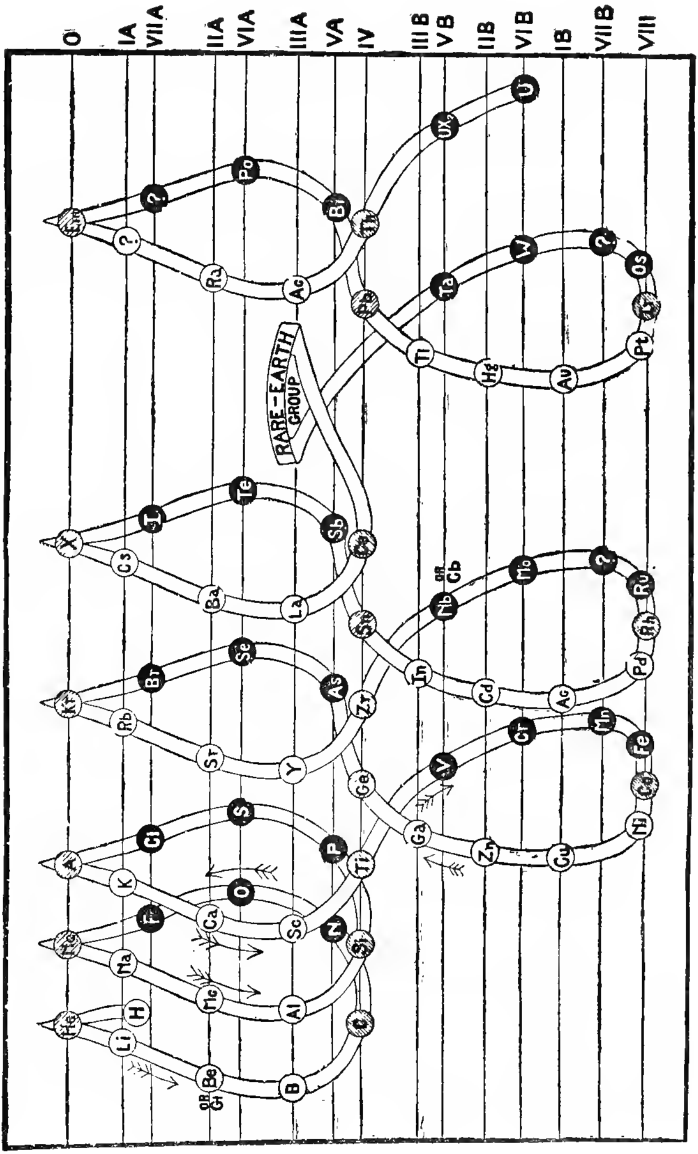

FIG. 9.—Soddy's helical representation of periodic law.

this is done the most wonderful discoveries will roll in upon us, and that we shall find that the properties presented by any one element at ordinary temperatures and pressures are only particular phases or conditions which can be assumed by other elements under other and as yet unknown conditions (much as a body can assume the gaseous, liquid, or solid state under different physical conditions). We cannot at present, however, tell.[1]

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[1] The author has carried out such a study of all the known data relating to the affinities of the elements, and the results are set forth in his work *Researches on the Affinities of the Elements* (Churchill, 1905). The data, however, in spite of the enormous amount of work spent in collecting it, is still far too incomplete for any great generalisation to be drawn with certainty. Fifty years hence matters will be very otherwise, and the time will then be ripe for another effort.

See also Geoffrey Martin, "The Chemical Conditions of the Elements," *Chemical News*, Nov. 10, 1905.

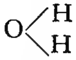
CHAPTER VI

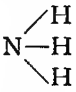
THE RADIO-ELEMENTS AND THE PERIODIC LAW

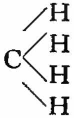
WITHIN the last few years an unexpected light has been thrown upon the Periodic Law and the complexity of matter by recent advances in the subject of the new radio-active elements.[1]

First of all, however, we will have to go back to the subject of chemical combination and valency. It is well known that the elements differ very widely in their capacity for combining with other atoms. For example, an atom of the element chlorine can unite with only one atom of hydrogen, whereas an atom of oxygen can unite with two, an atom of nitrogen with three, an atom of carbon with four, atoms of hydrogen, and so on. This is seen in the following formulæ :—

$Cl{-}H$







Each different elementary atom, therefore, possesses a certain combining power or "valency" as chemists call it. It can only combine with a certain fixed and limited number of other atoms.

If an atom can only combine with one atom of (say) hydrogen, it is called "monovalent"; if only with two atoms it is "divalent," if with three it is called "trivalent,"

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[1] The subject has been very ably discussed by Soddy in his monograph, *The Radio-Elements and the Periodic Law* (Longmans, Green, 1914).

and so on. Thus in the above formula Cl is monovalent, O is divalent, N is trivalent, and C is tetravalent.

Now for a long time past it has been thought that it is the presence of electrical charges on the atoms which makes them unite with other atoms.

For example, on referring to the above table, it will be seen that the carbon atom can unite with *four* atoms of hydrogen to form CH_4. Well, chemists explain this by saying that the carbon atom has attached to it four negative electrical charges (electrons or atoms of negative electricity), thus: $\mathrm{C}\begin{smallmatrix}-\\-\\-\\-\end{smallmatrix}$, while the hydrogen atoms are supposed to have attached to them a *positive* charge, thus, $+\mathrm{H}$.

The union between the two is caused by the powerful attraction of the negative charges on the carbon atom for the positive charges on the hydrogen atoms, thus:

$$\mathrm{C}\begin{matrix}- & +\mathrm{H}\\ - & +\mathrm{H}\\ - & +\mathrm{H}\\ - & +\mathrm{H}\end{matrix}\quad\longrightarrow\quad\mathrm{C}\begin{matrix}\pm\mathrm{H}\\ \pm\mathrm{H}\\ \pm\mathrm{H}\\ \pm\mathrm{H}\end{matrix}$$

In other words, chemical union is due to *electrical forces* emanating from atoms (electrons) of negative or positive electricity which are attached to the surfaces of the atoms. Each unit of electricity corresponds to a unit of "valency."

Moreover, there are two distinct sorts of valencies, which are attached to the *same* atoms. In fact there is a definite rule, first published by Mendeléeff, that the total sum of the positive and negative valencies of an element amounts to *eight*.[1]

Abegg[2] has labelled these positive and negative

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[1] The matter is discussed by the writer in the *Chemical News*, 1902, 86, 64, where proof of the universality of Mendeléeff's generalisation is given.

[2] Abegg, *Zeitschr. anorg. Chem.*, 1904, 39, 330.

valencies "normal valencies" and "contra-valencies," the "normal valencies" being those which predominate in determining the chemical behaviour of the element, while the "contra-valencies" are those which, so to speak, take rather a back seat, and only come into play under certain circumstances. They are "latent" valencies.

Now seeing that the valency of an element depends upon the number of electrical charges that it carries, and that the radio-active elements *throw out* into space both positive and negative electrical charges, it is obvious that it is inherently probable that there would be some connection between the subject of valency and radio-activity.

The first suggestion that there is a connection between radio-activity and valency was, I believe, put forward by the present writer so long ago as 1901,[1] when the subject of radio-activity was in its infancy.

In these communications it was pointed out that the radio-active elements are, so to speak, throwing off positive and negative valency bonds, so that a change of valency must result with each electrical charge thrown out. It was also pointed out that "a divalent element like radium, by the simple process of throwing off electrons (or valency bonds, on the Helmholtz theory of valency) is producing bodies of a non-valent nature," thereby establishing a connection between valency and the radio-activity.

These views were forgotten, and have been completely overlooked by recent writers on the subject. Twelve years later, however, they were revived and extended and put on a firm experimental basis by Fajans, Soddy, Fleck, Russel and other workers.[2]

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[1] Geoffrey Martin, "Radio-activity and Atomic Weight," *Chemical News*, 1901, **83**, 130; "Valcncy and Radio-activity," *Chemical News*, 1902, **85**, 311. "Radium and Helium," *Chemical News*, 1904, **88**, 147.

[2] K. Fajans, *Physikal. Zeitsch.*, 15th February 1913, **14**, 131–136. A. Fleck, *Trans. Chem. Soc.*, 1913, 103, 381 and 1052. A. S. Russel, *Chemical News*, 31st January 1913, **107**, 49.

It has now been certainly established that whenever a radio-active element expels a beta or negative ray—*i.e.* throws out one negative electrical charge—it *reduces its negative valency* by one unit, and whenever it throws off a positive or alpha ray (which carries with it *two* positive electrical charges) it reduces its positive valency *by two units*. Let us take, for instance, the element *thorium*, Th. This has four positive valencies and so gives rise to compounds like $ThCl_4$.

Now the thorium atom throws off an alpha ray (two positive charges) and so its positive valency becomes reduced from $+4$ to $+2$, and a new element, *Mesothorium I*, is produced, which has only two positive valencies, and so produces compounds of the type MX_2, where X stands for a non-metallic element like chlorine.

Again, let us take the case of radium. This is a divalent element, and produces compounds like $RaCl_2$. Now when this throws off an alpha ray (two positive charges) its positive valency is reduced by *two* and so becomes zero. Consequently a non-valent element, the inactive gas *Radium Emanation*, is produced. In consequence of this having no valency it will not unite with other atoms and so is far more chemically inactive than elements like nitrogen.

The same rule applies for every positive or alpha ray emitted by the elements. There are no exceptions.

In exactly the same way, by taking specific instances, it was proved that whenever a radio-active element throws out a beta ray, which consists of a single negative electrical charge, *it reduces its negative valency by one*, and this rule also seems to hold without any exception.

Now there is a very obvious connection between the position of an element in the Periodic System and the number of positive or negative valencies that it exerts.

This is best seen by taking the elements of a series of the Periodic Table, thus:—

PERIODIC TABLE

	GROUP I.	GROUP II.	GROUP III.	GROUP IV.	GROUP V.	GROUP VI.	GROUP VII.	GROUP VIII.
	Na.	Mg.	Al.	Si.	P.	S.	Cl.	Ar.
Positive Valencies .	+1	+2	+3	+4	+5	+6	+7	+8
Negative Valencies	−7	−6	−5	−4	−3	−2	−1	0
Total number of Valencies	8	8	8	8	8	8	8	8

For example, elements belonging to Group I have one positive and seven negative valencies (total eight valencies); and elements belonging to Group II have two positive and six negative valencies (total eight), and so on right up the series.

So that if we alter the fundamental valencies of an element we alter its position in the *Periodic System.* For example, in the case of the element silicon (see above table, Si, Group IV), which has four positive valencies, if we made it expel two positive valencies (an alpha ray), it would have only two positive valencies left and we would shift it from Group IV to Group II, for as will be seen the elements of this latter group have two positive valencies.

If, on the other hand, we made silicon expel a beta ray or negative valency, we would shift silicon into Group V (phosphorus group) because the elements of these groups only exhibit three negative valencies.

Hence we can draw up the following rule, which was first clearly enunciated by Fajans (*loc. cit.*) and which has been firmly established by the brilliant research work of Soddy, Fleck, Russel and others:—

Whenever a radio-active element expels an alpha ray (two positive charges) we cause it to shift its position in the Periodic

Table by two places from right to left in the direction of diminishing mass. When, however, the element expels a beta ray (a single negative charge), it shifts its position in the Periodic Table by one place only, but in the opposite direction to that for the alpha-ray change.

This, then, is the first great generalisation made as regards the radio-active elements and the Periodic System and throws light on a whole array of complex questions, as will be presently seen.

The second important generalisation is this: The mass of an alpha particle (which seems to be a helium atom) is about four times that of an atom of hydrogen. *So that whenever a radio-active element expels an alpha particle, it reduces its atomic weight by four.* For example, radium, atomic weight 226, expels an alpha particle and gives rise to a new element known as "Radium Emanation"—a gas. This necessarily has an atomic weight of $226-4=222$.

On the other hand, when a *beta* particle is expelled the atomic weight does not noticeably change, because the mass of a beta particle is less than $\frac{1}{1000}$th part of that of a hydrogen atom.

Hence, knowing the radiations sent forth by a radio-active element, we can trace both the change in position which the products assume in the periodic table, and also the change in their atomic weight. In other words, we can follow accurately the wandering of the position of the successive products of radio-active change across the face of the periodic system.

The following table, taken from Soddy's *Radio-Elements and the Periodic Law*, p. 3, shows how the position of all the thirty-four known radio-active elements have been placed in the periodic table.

The last and third principle, brought to light by Soddy, Fleck, and Russel, is perhaps the most surprising of all, and reveals an unsuspected complexity of matter;

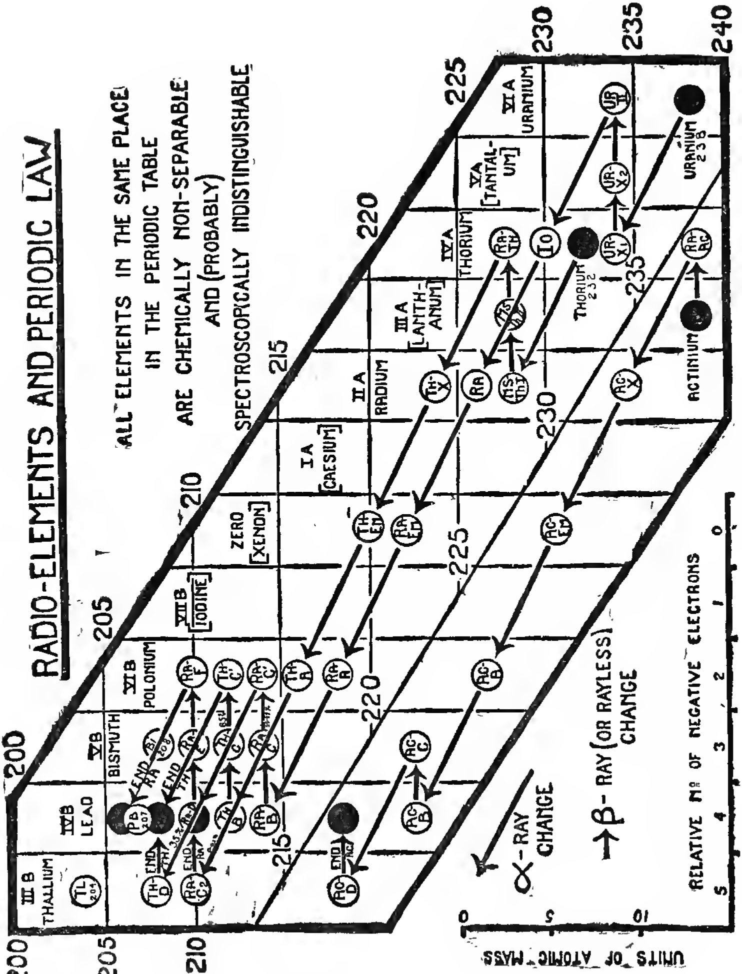
RADIO-ELEMENTS AND PERIODIC LAW
ALL ELEMENTS IN THE SAME PLACE IN THE PERIODIC TABLE ARE CHEMICALLY NON-SEPARABLE AND (PROBABLY) SPECTROSCOPICALLY INDISTINGUISHABLE
200
205
210
215
220
225
230
235
240
III B THALLIUM
IV B LEAD
V B BISMUTH
VI B POLONIUM
VII B [IODINE]
ZERO [XENON]
I A [CAESIUM]
II A RADIUM
III A [LANTHANUM]
IV A THORIUM
V A [TANTALUM]
VI A URANIUM
TL 204
PB 207
BI 208
END TH
END RA
END AC
TH-D
RA-C2
AC-D
RA-F
TH-C'
RA-C'
TH-A
RA-A
RA-E
TH-C
RA-C
TH-B
RA-B
RA-D
AC-B
AC-C
AC-A
TH-EM
RA-EM
AC-EM
TH-X
RA
AC-X
MS TH I
MS TH II
RA-TH
IO
RA-AC
UR-X1
UR-X2
UR II
THORIUM 232
URANIUM 238
ACTINIUM
α-RAY CHANGE
→β-RAY (OR RAYLESS) CHANGE
RELATIVE No. OF NEGATIVE ELECTRONS
0
1
2
3
4
5
UNITS OF ATOMIC MASS
0
5
10

FIG. 10.

at the same time it throws a gleam of light into the obscure depths of the Periodic System, and explains many of its perplexing "exceptions." This principle may be explained as follows:

We have previously stated that there are about thirty-four new radio-elements now known (1914). It is found, however, that they have not all different properties. *Nearly every radio-element betrays a striking chemical resemblance to some other known chemical element, the resemblance being so close that they cannot be separated from each other by ordinary chemical methods;* in fact the properties of a radio-active element approaches so closely to those of its chemical analogue that they can be "accurately described in a single sentence" as those of its analogue. The chemistry, therefore, of the radio-elements becomes the chemistry of a much smaller number—about ten in all—of types of elements (Soddy).

For example it will be seen from the table given here,[1] that radium B, actinium B, and thorium B are all described as quite similar in chemical properties to lead:

THE URANIUM SERIES

NAME OF ELEMENT.	SYMBOL.	RADIATION EMITTED.	COMMON BODY POSSESSING CHEMICAL PROPERTIES MOST SIMILAR.
Uranium 1 . . .	Ur1	α	Uranium
Uranium X . . .	UrX_1	β, γ	Thorium
Uranium X_2 . .	UrX_2	β, γ	Tantalum
Uranium 2 . . .	Ur2	α	Uranium
Ionium . . .	Io	α	Thorium
Radium . . .	Ra	α, β	Radium
Radium emanation .	RaEm	α	(Inert gas)
Radium A . . .	RaA	α	Tellurium
Radium B . . .	RaB	β, γ	Lead
Radium C . . .	RaC	α, β, γ	Bismuth
Radium D . . .	RaD	β, γ	Lead
Radium E . . .	RaE	β	Bismuth
Polonium . . .	Po	α	Tellurium

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[1] Obtained from Dr. A. S. Russel.

THE ACTINIUM SERIES

NAME OF ELEMENT.	SYMBOL.	RADIATION EMITTED.	COMMON BODY POSSESSING CHEMICAL PROPERTIES MOST SIMILAR.
Actinium	Act	None	Lanthanum
Radio-actinium	RaAct	α, β, γ	Thorium
Actinium X	ActX	α	Radium
Actinium emanation	ActEm	α	Radium emanation
Actinium A	ActA	α	Tellurium
Actinium B	ActB	β	Lead
Actinium C	ActC	α	Bismuth
Actinium D	ActD	β, γ	Thallium

THE THORIUM SERIES

NAME OF ELEMENT.	SYMBOL.	RADIATION EMITTED.	COMMON BODY POSSESSING CHEMICAL PROPERTIES MOST SIMILAR.
Thorium	Th	α	Thorium
Mesothorium 1	Msth1	None	Radium
Mesothorium 2	Msth2	β, γ	Actinium and Lanthanum
Radiothorium	Rath	α	Thorium
Thorium X	ThX	α, β	Radium
Thorium emanation	ThEm	α	Radium emanation
Thorium A	ThA	α	Tellurium
Thorium B	ThB	β, γ	Lead
Thorium C	ThC	α, β, γ	Bismuth
Thorium D	ThD	β, γ	Thallium

This property of radio-elements of being so similar in chemical properties to common elements, although one of the most extraordinary phenomena in the subject, greatly simplifies chemical work with the radio-elements. Thorium B, for example, is so similar to lead that there is no known method of separating one from the other. Any reagent which precipitates the one also precipitates the other. In order, therefore, to separate thorium B from other radio-elements, all we have to do is to add a trace of lead to the radio-active solution, and then separate lead by ordinary analytical methods.

It will be found that the thorium B is separated quantitatively with it, and is free from all other radio-elements except those which have the same chemical properties of lead, or which have been generated from the thorium B during the time of separation to the time of examination.

We have explained on p. 140 how the radio-elements change their atomic weights and their chemical positions in the Periodic system, and a study of Soddy's table on p. 141 shows very clearly how one or more radio-elements can come to occupy the same position as other elements in the Periodic System. But the curious fact brought to light by this new line of research is that *several elements can occupy the same position in the periodic system and can all exhibit exactly the same chemical and physical properties, and be chemically non-separable, and yet not be identical with each other.*

Soddy calls such chemically similar elements "isotopes." *It does not matter in the least whether they have the same atomic mass. Elements of quite different atomic weights can have the same chemical properties, and occupy the same position in the Periodic System.*

Indeed this has recently been proved in the case of lead. For example, by looking at Soddy's table on p. 141 the reader will see that the end products of all the known disintegrating series fall into the place in the Periodic Table occupied by lead.

According as these end products are derived from thorium or from uranium, their atomic weights should be different. Thus the atomic weight of the thorium isotope should be 206 and that of the uranium isotope should be 208·4. Experiments carried out on the atomic weights of lead from different sources vary from 206·4 to 207·15—and yet all these samples of lead are chemically and physically identical. (See *Annual Reports on the Progress of Chemistry for* 1914, p. 37.)

Hence it is not the atomic weight which plays the predominating part in deciding the chemical properties of the elements. It is the chemical forces it exerts,[1] which in turn depend upon the electrical contents of the atom. The Periodic Law thus expresses the chemical nature of matter as a function of two variables, namely the atomic mass (weight) and the electrical content. It is the atomic mass which is the predominant variable in the *vertical* columns of the periodic table, because the mass varies in the vertical columns by large steps between the various members of the same families of elements, whose members are not identical in properties. In the horizontal rows of the periodic table, however, it is the electrical content which decides the chemical properties, such as valency, chemical affinity and so on, and so here it is the electrical content which is the predominant variable.

Professor Soddy (*Radio-Elements and the Periodic Law*, p. 7) also comes to the conclusion that different elements occupying the same place in the Periodic Table are indistinguishable in spectra and other physical properties. He explains this by the circumstance that the spectra, in all probability, originates from the movements of only very few electrons in their orbits in an outer ring around the atoms, the same few electrons conditioning chemical valency and affinity and also the great majority of the physical properties as well.[2]

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[1] This was pointed out in 1905 by the author in his book, *Researches on the Affinities of the Elements*.

[2] It is very interesting to note that this new work on radio-activity very strikingly confirms the conclusions published in 1905 in my book, *Researches on the Affinities of the Elements and the Causes of the Chemical Similarity or Dissimilarity of Elements and Compounds* (London, J. & A. Churchill). Here

What is the explanation of the Periodic Law, this mighty generalisation which is written across the whole domain of inorganic chemistry? We do not know. An explanation involves the answer to two different questions:—

1. Why do the atomic weights increase as they do in such an irregular manner from element to element, a difference varying from one to three units, and consequently representing a weight varying from that of 2000 to 6000 electrons? No clear explanation of this has ever been given, but Soddy's work on radio-active elements seems to give the correct solution.

2. Why does the addition of a certain atomic mass cause a periodic recurrence of similar properties?

This involves the further question what do we mean by chemical similarity? What is the cause of it? I think that it was Wilhelm Ostwald (*Allge. Chemie*, vol. i. p. 138, 2nd Ed. 1903) who first clearly stated that the notion of the chemical similarity of the elements was much too vague, up to date, to allow it to be applied with sharpness in fixing the position of an element. The present writer, as the result of a very elaborate investigation of what underlies the notion of chemical similarity, discovered how to deduce a numerical value for it. He first showed[1] that chemically similar elements

it is proved: (1) That the electrical forces (chemical attractions or affinities) which the different elementary atoms exert *completely decide* the chemical nature of the elements, the atomic mass having only quite a subsidiary influence.

(2) That the same factors which govern the chemical properties of the elements *also govern their physical properties as well*, so that chemically similar bodies *necessarily* must be physically similar as well.

(3) That the cause of the *Chemical Similarity* of the elements is due to the fact that they exert proportional (not equal) chemical forces.

(4) By altering the chemical forces an element exerts, we can make it take on the properties of other elements. So that two different kinds of matter atoms would be chemically and physically similar in properties if we could make them exert the same forces. It is not the nature of the matter which counts, it is the nature of the forces it exerts.

[1] Martin, *Researches on the Affinities of the Elements*, pp. 40–56.

exert *proportional* affinities (chemical attractions) on other atoms.

For example, if we compare the affinities which sodium or potassium exert on other elements, we shall find that in general when sodium exerts a weak affinity potassium does the same, and where sodium exerts a strong affinity potassium also exerts a strong affinity. So that the sodium atom may replace the potassium atom in any reaction without altering the way the reaction proceeds—sodium carrying out the same reactions as potassium but somewhat more feebly. And so it is also with fluorine and chlorine—fluorine carrying out the same reactions as chlorine, but more strongly. In other words, *an atom or radicle is chemically similar to another when and only when its affinities are proportional to those of the other. The more nearly equal each to each are these affinities the two elements exert, the more alike are they chemically.* When in addition to this it is found that the absolute magnitude of the forces or affinities that an element exerts on other atoms completely determines both its chemical and its physical properties,[1] we at last arrive at a clear idea of what has to be done in order to explain the periodic system. It is this:—*We have only to explain why each atom attracts all the other atoms with the exact numerical values that it is known to exert.* From this will follow the whole explanation of the periodic system. The matter therefore resolves itself into an investigation of the nature of chemical force, and since the forces are probably electrical in nature, the ultimate solution of the problem is taken altogether out of the hand of the chemist and placed in the hand of the physicist. It is, therefore, not without significance to find that recently the most interesting and notable attempts to elucidate the mystery of the periodic law have come from physicists. In particular

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[1] Martin, *opus cit.*, pp. 10–17, 123.

Professor J. J. Thomson, of Cambridge, has made a most interesting attempt to account for the periodicity of properties by supposing that the elements are built up of successive rings of electrons.[1]

His system, however, suffers from serious defects, which have been discussed by Arrhenius in his recent *Theories of Chemistry* (1907), pp. 93–102. But even accepting it as it stands we cannot say that the problem has been in any way solved, until this theory has been shown to explain accurately the magnitude of the attractions exerted by the different atoms on each other, and this at present it makes no attempt to do.

In the present writer's opinion what is wanted at present are actual measurements of the affinities of all the elements. Not until we know these constants, and we shall some day know them, can we devise a proper theory numerically to fit them. And we must know these constants not only for *one* valency level entered on by the element, but for all valency levels which can be assumed by it. When this is done, and it is a matter of hard experimenting, we can then, and not before, attempt to build up a theory of the atoms which will account for the magnitudes of the forces that they exert upon each other, and thus at a single blow explain the whole of that great generalisation which has for so long loomed so largely in the chemical world. And since we ourselves, our bodies, and all the material universe about us, are built up of these very same atoms which are joined together by this great generalisation, who knows but that the solution of this grand mystery will bring us nearer to the elucidation of other mysteries which have for ages baffled the intellect of man? Then, indeed, we can take up with a new courage the investigation of that grand problem, the nature of life itself. We

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[1] J. J. Thomson, *Phil. Mag.* (6), 1906, 11, 769, and previously.

agree with H. G. Wells when he says,[1] "It is possible to believe that all the past is at the beginning of a beginning, and that all that is and has been is but the twilight of the dawn. It is possible to believe that all that the human mind has ever accomplished is but the dream before the awakening."

And now, having brought the reader to the very portals of the unknown, and having bade him look fearlessly into one of the great mysteries of the universe whose complete elucidation we may confidently leave to the future, we must here cry halt and take our leave.

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[1] *The Discovery of the Future.*

CHAPTER VII

MODERN ALCHEMY

It has been the immemorial dream of the chemists of the east that the elements can be transmuted one into the other, and that he who possessed the secret could at will change a comparatively worthless metal like lead into a valuable metal like gold, and so amass for himself wealth beyond the dreams of avarice.

An incredible amount of experimental work was expended on this object by the alchemists, and out of their labours the science of modern chemistry has arisen. The alchemists, however, did not succeed in their quest. It has been clearly demonstrated that in all cases where superficially there seemed some reason to believe a transmutation had been effected, the fact was in truth not so; either the materials were impure, or the resulting products merely looked like the body to be produced, but were not identical with it.

At the beginning of the twentieth century, then, it was firmly established as a fundamental dogma of chemical science that no one element can be transformed into another. The eighty or ninety odd elements known were regarded as the eternal and unchangeable forms of matter out of which the whole material universe was fashioned. Each element was thus placed in a sort of watertight compartment by itself; it had absolutely no connection with any other element, no common basis or constituent, but stood unique in solitary isolation.

But in 1898 radium was discovered, and with it a whole series of puzzling phenomena. Soon it was proved beyond doubt that not only this element but others as well were decomposing and giving rise in the act of decomposition to helium and other elementary substances. The elements, so far from being the immutable foundation stones of the material universe, were seen to be in the throes of incessant and spontaneous change, evolving and devolving into other forms of matter in a most complex way. A shock was dealt to the smug and self-satisfied attitude of the chemical world at that time. The enormous superstructure of chemical facts and theories, which seemed so well established by such immense labour, revealed unsuspected weaknesses and flaws in its deep-laid foundations such as might bring the whole to utter ruin. Fierce ridicule and scorn were poured forth on those who sought to upset the stability of the chemical world, and indeed the present writer well remembers the open ridicule to which he was subjected when he in 1902 first put forward the idea that the radio-active elements are decomposing elements (see page 91). However, the brilliant experimental work of the Curies, Rutherford, Soddy, Ramsay and others has finally led to the establishment of the great fact that certain elements do most undoubtedly *spontaneously* decompose, and in doing so liberate enormous quantities of energy.

However, up to the present no man has succeeded in controlling the unknown irresistible forces inherent in the matter atoms themselves, which causes them unceasingly to evolve and devolve into other atomic forms of matter. Radio-activity, in fact, seems to be one of the least controllable of natural forces. Neither heat nor cold, chemical nor mechanical forces affect the process in the least. Up to the present Nature has kept control, while man has looked on with hungry eyes, knowing that could he but dominate such gigantic forces, accelerate or retard them to his convenience, he could revolutionise the whole surface of our planet and supply unlimited power to solve its industrial problems. But at last man has begun the long delayed attack on Nature's secret fortress. The first experiments to obtain control of these vast natural forces and *transmute* at man's will one element into another, were carried out by that bold and original experimenter, Sir William Ramsay.

If on the earth experiment shows that the elements are breaking down into lighter and lighter atoms, and so are vanishing, surely in other regions of space matter must be forming, lighter elements must be condensing into heavier ones? Otherwise the whole world and the universe itself in a few billion years would rush into oblivion.

Crookes and Lockyer long ago conjectured that in the nebula and the great waste celestial spaces, the lighter elements condense to heavier, and matter, so far from vanishing, is there being created. Ramsay asked himself, what are the conditions which regulate this growth and decay of matter, this transmutation of the elements? If stupendous forces are evolved when the atoms decompose, tremendous forces, so Ramsay argued, must be brought into play to form them again. Ramsay cast around to apply stupendous forces to these atoms, and hit upon the expedient of employing exploding radium atoms. When radium atoms explode we have seen (see page 93) that masses of matter and electrons are hurled forth with velocities of thousands of miles a second. Ramsay conjectured that the terrific shock of collision with these flying particles would succeed in shattering quite stable atoms, such as those of copper, and produce from them lighter elements like lithium, sodium or hydrogen. So Ramsay and his pupils made the experiment. They showed that if a solution of the radium emanation in water be left to change, one of the products is the element neon. A solution in which copper sulphate is present, however, yields another element—argon, and a trace of lithium. Whether this latter element came from the glass or not, or whether it had actually been produced as a product of atomic breakdown remains at present undecided. Other remarkable experiments in which carbon, oxygen and other elements have been produced in traces have also been described. If these experiments are confirmed it would seem that radium is capable of producing at ordinary temperatures the same effect that is brought about by the transcendental temperatures reigning in some stars. For there is now little doubt that on these the formation of elements one from the other is swiftly proceeding on an enormous scale.

As a matter of fact, however, these experiments have not been confirmed up to the time of writing. The alleged transmutation of copper into lithium and sodium by A. T. Cameron and W. Ramsay in 1908 was denied in the same year by S. Curie and Gledisch and also by E. P. Perman ; also the production of neon from radium emanation by W. Ramsay (1907) and Ramsay and Cameron (1908) has been denied by E. Rutherford and T. Royds (1908). These transmutations, therefore, could not be confirmed by other workers and at present the chemical world regards them with doubt. However the reader must remember that Sir William Ramsay is probably one of the most skilful experimentalists that the world has ever seen, and when we read with astonishment of complicated experimental processes being carried out by Sir William Ramsay and his co-workers on a volume of gas not exceeding a few hundredths of a cubic millimetre—a volume smaller than that of a small pin's head ; our wonder is not that his results have not been confirmed, but that the experiments could have been carried out at all.

Sir W. Ramsay thinks that dry hydrogen becomes polymerised into helium when subjected to the action of cathode rays in a vacuum tube, while for the production of neon the presence of oxygen is necessary,—the oxygen being derived from a trace of moisture or from the bombardment of the glass by the rays. Ramsay modified the experiment by placing dry hydrogen in a vacuum tube and passing an electrical discharge for 5–6 hours between an aluminium cathode and an anode, which were coated with sulphur. He found that argon was produced. When the electrodes were coated with selenium instead of sulphur krypton was produced. Consequently the three elements, neon, argon, and krypton, elements all in one group of the periodic table, and whose atomic weights are in ascending scale, have thus, apparently, been produced from hydrogen in the presence of oxygen, sulphur and selenium—also elements of one group of the periodic table with atomic weights in ascending scale.

The subject entered a new phase in 1913, for in that year Collie, Patterson and Masson began to publish their researches.

Ramsay, it will be recollected, used radium as his source of bombarding particles. Cathode rays (the rays evolved by connecting a very highly exhausted vacuum tube with a high potential induction coil), however, also consist of a stream of the same swiftly flying particles. The cathode rays, in fact, are supposed to be identical with the beta rays expelled by radium, and consist of a stream of negatively charged particles, each of about $\frac{1}{1000}$ of the mass of a hydrogen atom, and fly with the velocity of about 180,000 miles a second. Why not, therefore, bombard stable elements with these projectiles, and see whether the shock of this cannonade would shatter their atoms and produce from their ruins other kinds of elements? Radium is expensive, but cathode rays are easy to produce and are within the means of every chemical or physical laboratory.

So in 1913 Collie and Patterson[1] placed some pure calcium fluoride, CaF_2, in a cathode tube and subjected it to the bombardment by cathode rays. Now calcium fluoride is composed of two elements only—calcium and fluorine. Yet after a time gases were found to be evolved in the tube, gases composed of oxygen, hydrogen, carbon monoxide (CO, p. 210) and a small amount of a new element called neon. In other words, new elements made their appearance in the tube—elements which were not present in the substance bombarded. Whence have they come? Have they been derived by the smashing up of the calcium and fluorine atoms by the vigorous bombardment? Collie and Patterson think so.

Next they tried placing a little bit of glass wool in the tube, and from this there was evolved considerable amounts of the element, neon. Many other similar experiments were made, and nearly all the substances bombarded were found to yield traces of elements which originally were not present in them. It looks, in fact, as if the problem of the alchemists had in part been solved, and that one element had been turned into another.

But now a fierce controversy broke out. Other workers tried to repeat these experiments and failed. Sir J. J. Thomson[2] came to the conclusion that the evolved neon came from the electrodes, while other workers suggested that it had leaked in from outside.

Collie and his co-workers, however, took these objections one by one, and by means of fresh experiments overthrew them. Thus Merton and Strutt had, in a special apparatus, failed to get some of Collie's results, but

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[1] *Trans. Chem. Soc.*, 1913, **103**, 264.

[2] *Nature*, 1913, **90**, 645.

Collie in 1914[1] using Merton's own apparatus obtained very considerable quantities of helium and neon by bombarding powdered uranium metal in an atmosphere of hydrogen. Collie seems to have proved that the nature and size of the electrical coils and tubes used in the experiments have a great influence on the results. The most recent experiments of Collie[2] and his co-workers seem to strengthen the evidence in favour of an actual production of certain elements by the breakdown of stable elements, and here the matter rests.

At the present time, therefore, chemistry is in the throes of a great revolution, and the whole scientific world awaits with suspense the upshot of these new investigations.

Chemists are now told, by serious and accurate workers, that the atomic weights of certain elements can vary by as much as 1 per cent., according to the parentage of those elements ; he is told that the physical constants of metals as now known are worthless, because they are in a state of perpetual allotropic change; finally, he is confronted with the disintegration of the elements themselves under electric forces. The chemist of to-day, then, is in a state of bewilderment and uncertainty: all certain ground seems slipping away from underneath his feet, and he now awaits with breathless impatience the great generalisation which shall link up the new with the old chemistry, and out of the ruins of the latter build up a new philosophy.

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[1] J. N. Collie, *Proc. Roy. Soc.*, 1914 [A], **90**, 554.

[2] Collie, Patterson and Masson, *Proc. Roy. Soc.*, 1914 [A], **91**, **30**.

CHAPTER VIII

APPLICATIONS OF ELECTRICITY TO CHEMISTRY

SOME twenty-five years ago the famous German chemist, Victor Meyer, when addressing an assembly of his brother chemists, boldly prophesied that "There can be no doubt that new and undreamt of discoveries will manifest themselves, that a new chemistry will disclose itself, when we are furnished with vessels that will enable us to work at temperatures at which water can no longer exist, and at which a mixture of oxygen and hydrogen gases becomes an uninflammable mixture." Modern science is rapidly realising the predictions of this great chemist. For recently not only have we, by means of electricity, been able to attain temperatures so intense as to rival those on the sun itself, but we have also discovered means for dealing with these temperatures, for confining and utilising them, in a way that was unheard of in Meyer's day. And what has been the result? A new fairyland of science has come into existence, great chemical industries, employing thousands of men and millions of money, have sprung up as if by magic; and an enormous number of new and important compounds, products of these mighty temperatures, have been brought to light, the proper utilisation of which is now being worked out with feverish rapidity. The introduction of the electric furnace has, indeed, not only revolutionised chemical industry in many of its branches, but has also established several new industries of its own.

We propose to give a short, and necessarily incomplete, account of these new chemical methods. We will start by describing the electric furnace itself as it left the hands of Moissan.

This is simplicity itself. It merely consists of a very powerful arc, produced between two carbon electrodes, placed in a cavity of minimum size at a certain distance above the substance to be heated. In this way the heating action of the current is separated from the electrolytic action. The carbon electrodes are placed between two slabs of quicklime, carefully cut and superposed. The lower slab has a long groove in which the electrodes rest, and in the middle is a small cavity which acts as a crucible. On passing a powerful electric current a

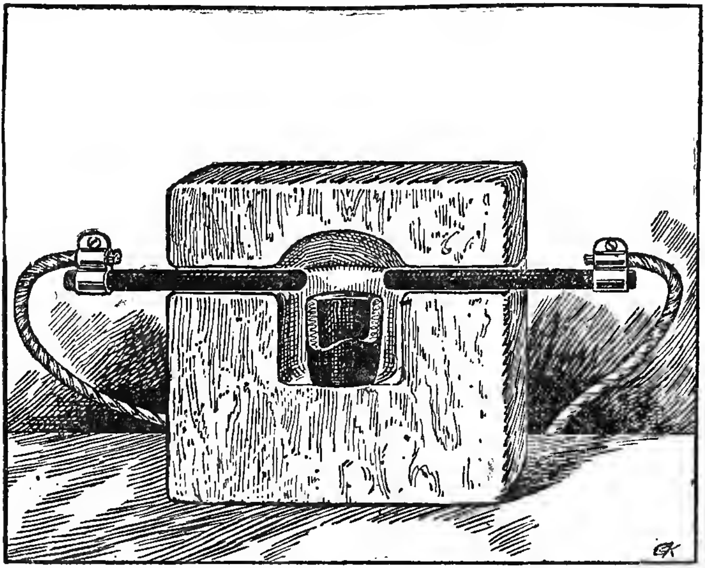


FIG. 11.—Moissan's electric furnace.

temperature of over 3500° is produced. It is limited to this, because above this temperature the carbon electrodes simply boil away. It is possible that in the arc itself a temperature of nearly 6000° C. may be obtained. By the aid of this simple arrangement Moissan was able to demonstrate the great utility of the furnace for reducing many metals, like chromium and molybdenum, which are unmanageable at the highest temperature of an ordinary furnace. He also employed it for making calcium carbide, carborundum, and a host of other valuable products.

One of the first industries to develop was the manufacture of calcium carbide, CaC_2, used for making acetylene gas and for fixing the nitrogen of the air in the form of that valuable manure known as "Nitrolime" or calcium cyanamide, which we have discussed in our previous book, *Triumphs and Wonders of Modern Chemistry.*

Coke and lime reduced to pieces about the size of walnuts are introduced into the huge commercial electrical furnaces, and a current of some 4000 amperes at 50 to 120 volts is turned on. In a very short time a vast arc flashes into existence and an enormous amount of heat is generated. The lime and the carbon then react together, thus:

$$\underset{\text{Lime}}{CaO} + \underset{\text{Coke}}{3C} = \underset{\text{Calcium carbide}}{CaC_2} + \underset{\text{Carbon monoxide}}{CO}$$

These industrial carbide furnaces are simply arc lamps on a gigantic scale. However, instead of carbons having the size and shape of pencils, those used at the top of the furnace look more like one of the huge blocks built into the foundations of a breakwater. The smallest carbide furnaces used at Odda in Norway each consume electrical energy equivalent to 1850 horse-power. The liquid white-hot carbide—at the enormous temperature of 3500° C.

(compared to which molten iron as it pours from great blast furnaces is *cold*)—is tapped out of the bottom of the furnaces into heavy cast-iron moulds, and, after cooling, is crushed, sorted into sizes, and distributed throughout the world.

From Odda in Norway at first only 32,000 tons of carbide were produced. At the present time some 80,000 tons are made at one factory, and extensions are planned which will bring the output up to the enormous total of 128,000 tons annually.

In addition to this, carbide is being poured out of the high temperature factories in America, Italy, Switzerland and other centres of the industry. So that the carbide industry is now one of the great world industries, called into existence almost overnight by the magic wand of the chemist.

The next step is the conversion of the carbide into cyanamide, by heating it to about 800° C. in special retorts and forcing in atmospheric nitrogen. The following change takes place:

$$\underset{\text{Calcium carbide}}{CaC_2} + \underset{\text{Nitrogen}}{N_2} = \underset{\text{Calcium cyanamide}}{CaN_2C} + \underset{\text{Graphite}}{C}$$

It will be seen that some of the carbon of the carbide separates out as graphite. The nitrogen is obtained by liquefying the air by the Linde or Claude process and fractionally distilling it. By this means the nitrogen is separated from the oxygen. At Odda the Linde plant of the Nitrogen Fertilizers Ltd., is the largest in the world.

About 100 *tons* of air are liquefied each day and the contained nitrogen extracted, and forced under pressure into the furnaces containing the calcium carbide, which is crushed to a very fine powder. The initial heating is started by carbon resistances running through the centres of the furnaces; combination soon takes place, and once the action has started it continues of itself, the nitrogen being sucked in and combined with the carbide with the evolution of great heat. The resulting calcium cyanamide, or Nitrolime, containing about 20 per cent. of nitrogen, appears as a grey-black stone-like mass. It is cooled, crushed, ground to a fine power, treated with a little water (to decompose any unchanged carbide) and after drying and storing is sent into commerce as an important nitrogenous manure. Indeed it is equal in all respects to Chile saltpetre. Owing to the world's growing population and the growing exhaustion of the soil, the demand for nitrogenous manure by farmers vastly exceeds the supply. As fast as the manure can be turned out it is bought up and applied to the soil in order to increase the yield of wheat and grain. Without this nitrogenous manure the world's output of grain could not meet the growing demand, and dread famine and want would soon stalk throughout the world.

As a consequence enormous developments of the cyanamide industry are taking place throughout the world. Canada and the United States (at Niagara) are erecting huge factories. Norway and Sweden are being transformed even as I write. Scientists are unanimous that the world has been for many years advancing towards a state of soil starvation. Crops are not keeping pace with the increase in population—not because of decrease in agricultural activity but because the land has been drained of its combined nitrogen through years of strenuous cultivation. Each harvest takes away more nitrogenous matter than is replaced by grazing and other methods known to farmers; and to make things grow again, nitrogenous matter must once more be applied to the soil to give back that which has been abstracted.

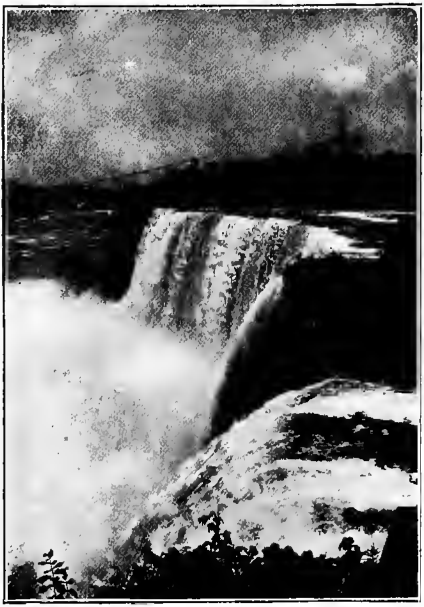
Scientists have asserted that about 12,000,000 tons of nitrate will be necessary to produce the corn required between the present time and 1935. Hence the general recourse of farmers to artificial nitrogenous manures. If the earth is to meet the ever-increasing demand for corn and food it must have more nitrogen.

To supply this want the vast industry of calcium cyanamide has sprung up in all lands possessed of cheap water-power—the "white-coal" of science and romance which supplies electrical energy for making these high temperature products. Nowhere else can these electrical industries take their rise and being. Hence the awakening into life of the frozen North, of Iceland, Norway and Sweden. Sportsmen and tourists would never dream that the wild grandeur of Norwegian scenery conceals in its rushing waterfalls and down-pouring torrents unlimited possibilities for supplying powers for these new industries. Yet so it is, and even at the present time, in the heart of the mountain-flanked fiords of Scandinavia, enormous operations and changes are taking place.

Thus, at Tyssefaldene, on the Sor Fiord—a branch of the celebrated Hardanger Fiord—an immense reservoir has been constructed, with a capacity of 400,000,000 gallons, and the water is conducted through a tunnel pierced through the very heart of the mountains to the power-station at Tysse, on the shores of the Fiord. About 83,000 horse-power are now available. Consequently in the Tysse district electrical power is cheap, and so two great concerns—the Alby United Carbide Factories, Ltd., and the Nitrogen Products and Carbide Company, Ltd., at Odda have come into existence for the manufacture of these products. So that although the production of calcium cyanamide (nitrolime) was only started in 1907, yet in 1913 about 223,500 tons were produced in the whole world, the two above-mentioned factories contributing about 88,000 tons.

But developments are still proceeding in Scandinavia

PLATE 8.—Rhodesia's Gem : the Victoria Falls.



Photo, E.N.A.

PLATE 9.—Niagara Falls.

FUTURE CENTRES OF CHEMICAL INDUSTRY.

Since electricity can be directly used for generating intense heat in furnaces in which steel, aluminium, glass, phosphorus, carborundum and calcium carbide may be manufactured, there can be no doubt that all the great waterfalls of the world, where now millions of horse-power run to waste, will ultimately become great centres of industry and manufacture.

so as to increase the output by utilising the energy derived from three other water-powers in Norway (Aura, Toke, and Blekestad-Bratland), whereby 100,000 horse-power are now being harnessed for the production of another 200,000 tons of cyanamide. The Detti-Foss water-power in Iceland is capable of supplying at least 400,000 horse-power more, so that within a few years there is little doubt that from Norway, Sweden and Iceland alone some 2,000,000 tons of calcium cyanamide will be poured into the world's market to supply our exhausted soil with nitrogen—an output of fixed nitrogen as much as that present in the whole modern production of Chile saltpetre.

For ages snow and ice have been piled up in the frozen North, which, melting in the warmth of the sun, give rise to rushing torrent and waterfall. Now at last these rugged and almost desert regions will awake to fresh life after the sleep of ages. At present it is true that less than 1,000,000 horse-power derived from Norway's waterfalls has been harnessed for generating electrical power.

But over 200,000,000 horse-power are there available, and just as in the past busy manufacturing cities sprang up around coal-producing districts, so in the immediate future great cities will come into existence in districts rich in water-power.

Many of us now living will see before we die waste and desolate lands like Iceland converted into busy hives of industry. Such is the magic power of the chemist. By the labours of men, poor,[1] unknown and usually despised, the surface of the world is transformed, and revolutions wrought greater than any brought by victorious armies and the might of kings. As Liebig the great chemist said some fifty years ago:—"Both the rise and

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[1] See p. 4.

decline of nations are governed by the same law of nature. The deprivation of the soil of its conditions of fruitfulness brings about their decline, while the maintenance of such conditions leads to their permanence, prosperity and power. The nation is not fed by peace nor destroyed by war—these conditions exert only a temporary influence on it. It is the soil on which man builds his home which is instrumental in holding human society together, and in causing nations and empires to disappear or to become powerful. The absolute fruitfulness of the ground is independent of mankind, but he possesses the power of diminishing or prolonging such fruitfulness."

Since it is the chemist, working obscurely in his laboratory, that has brought about these industrial revolutions and has restored prosperity to the soil by his new processes and new substances, I think that the reader will agree with my thesis put forward earlier in this book, that the nation which excels in chemistry will ultimately attain world-wide power. The balance of the chemist is mightier than the sword of the soldier in altering the destinies of the human race.

Yet again there is the new industry of fixation of atmospheric nitrogen which is brought about by driving air through electrical furnaces of special construction. The oxygen and nitrogen of the air unite to form oxides of nitrogen which when led into water yield nitrous and nitric acids ; these are then fixed by leading over limestone and so are converted into calcium nitrate and nitrite, which in turn is used as a manure. This industry is now rapidly developing into an enormous one, but as we have already given a full account of the methods employed in the previous volume, *Triumphs and Wonders of Modern Chemistry,* I must here refer the reader to my former book for further details.

Then there is the manufacture of that splendid abrasive, carborundum (silicon carbide, SiC), which is now manufactured on a very large scale by heating together sand and coke in the electric furnace:

$$\underset{\text{Sand}}{SiO_2} + \underset{\text{Coke}}{3C} = \underset{\text{Carborundum}}{SiC} + \underset{\text{Carbon monoxide}}{2CO}$$

The furnace is shown in Plate 11, which gives a photograph of Acheson's furnace-room. The furnace consists of a rough brick structure, which is pulled down after each operation, and then set up again with a fresh charge. The electrodes are massive carbon rods set longitudinally, and the charge is placed between. By the same furnace, by modifying the proportion of sand, graphite is also manufactured for blacklead pencils, which is actually better than the graphite dug out of the earth. *Siloxicon*, Si_2C_2O, is another product manufactured in a similar way in the furnace by heating sand with twice its weight of coal. It appears to be a product of great industrial importance, because it is quite indifferent towards high temperatures, even molten iron and basic slags having no action upon it. It is therefore used for lining furnaces.

As we have already seen, nowadays phosphorus is distilled out of mineral phosphates in the electric furnace, and turned into matches.

Innumerable carbides, borides, and silicides have also been formed recently, some already of great commercial importance, others merely waiting to have their useful properties discovered.

The organic compound, carbon disulphide, CS_2, so useful as a solvent and extractive, is now made extremely cheaply by a continuous process in which charcoal and sulphur are fed into the top of a stack, at the bottom of which there is an electric furnace which causes them to combine, thus:

$$\underset{\text{Carbon}}{C} + \underset{\text{Sulphur}}{2S} = \underset{\text{Carbon disulphide}}{CS_2}$$

Again, quartz tubing is now manufactured cheaply in the electric furnace. The process consists in spreading sand (silica) over a carbon resistance rod, and subsequently heating the rod electrically to the melting point of sand, when the latter fuses round as a compact mass.

These tubes are of great value to the chemist, as they are capable of standing enormous and sudden variations of temperature, besides being quite indifferent towards the most corrosive liquids (except hydrofluoric acid).

Among the most important uses of the electric current is its employment for manufacturing aluminium from clay, which is now carried out on a very large scale, the aluminium being used for making utensils and various ornamental articles. Even steel is now made by means of the electric furnace. Within the last few years many thousand tons of the very best steel have been produced by its means.[1]

One of the most famous of these steel-refining electric furnaces is the Héroult.

The electric current is carried by two massive solid carbon electrodes, as thick as a man's body. These are about six feet long and over one foot in diameter. The charge, consisting of steel scrap, pig iron, iron ore, and lime, in suitable proportions, is placed on the hearth of the furnace and raised to the melting point by the enormous alternating current of 4000 amperes at 120 volts. The lime and silicates of the ore fuse and form a slag which spreads over the surface of the molten steel,

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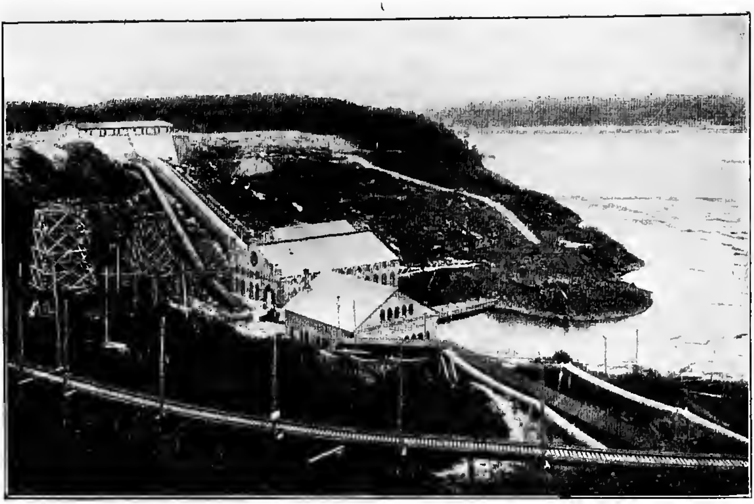
[1] The reader will find an interesting account of the application of the electric furnace to steel making and refining in *Cassier's Magazine*, July 1909, vol. 36 p. 237, by Mr. Kershaw.



From Cassier's Magazine

PLATE 10.—How Water-power is harnessed to produce Electricity.

Power House of the Shawinigan Water & Power Co., Canada, situated on the St. Maurice River Falls. Water is conveyed by huge pipes to powerful turbines situated in the power-house. The turbines work dynamos and thus generate electricity. 100,000 horse-power are capable of being generated here.

From Cassier's Magazine.

PLATE 11.—Electric Furnaces for Carborundum and Graphite of Acheson Graphite Co., Niagara Falls.

The furnaces are built of loose bricks, which are removed at the end of every operation in order to take out the charge.

thus protecting it from oxidation. The electrodes are now lowered until they just dip below the surface of the molten slag, and in order to oxidise those impurities of the metal which it is necessary to remove, an air blast enters and oxidises the sulphur and phosphorus, which are carried up into the slag on the surface. The furnace is now tilted in order to pour off this slag, and the treatment is continued two or three more times with fresh quantities of lime, &c., until a comparatively pure metal is left on the hearth of the furnace. When this point is reached a calculated amount of an alloy high in carbon (carburite) is added to the molten mass, and the charge then run out. The Héroult crucible furnaces produce, as a rule, three tons of the very best steel at a charge. A visit to a work in which these furnaces are employed is indeed well worth making—nothing else can give an idea of the fierce heat prevailing within the furnace. Many other electrical furnaces, of different make, are used for the same purpose.

Another valuable development of the electric furnace is its employment for extracting rare and refractory metals, which formerly were almost unknown. Among these metals are chromium, molybdenum, tungsten, titanium, and many others. On adding traces of these metals to steel its qualities and hardness are greatly improved. The La Neo-metallurgie, of Paris, now manufactures over thirty valuable metals and alloys, whose very names were hardly known a few years ago. The Société d'Electrochimie is another Parisian company which manufactures ferro-silicium on a large scale. This body, a compound of iron and silicon, is especially valuable for adding in small quantities to steel, the silicon combining with impurities in the metal, and thus purifying it in a wonderfully effective manner. The manufacture of metallic sodium, calcium, and numerous other inorganic and organic products of the greatest value in commerce, by means of the electric current, cannot here be more than mentioned.

Lastly, but not least, we have a great industry which has arisen out of the process of electrolysing solutions of brine, whereby there are produced caustic soda, chlorine, chlorates, bleaching solutions, and various other valuable products—all manufactured by electricity, without the hardship and distress inseparable from the use of blazing furnaces as used in the Leblanc process. At the present time more than half the copper in the world is separated from impurities by electro-deposition, cool tanks replacing the old-time smelting furnaces. The process of electro-deposition, in fact, steadily encroaches upon the furnace fires of the foundry, plates for the printer, statues for the sculptor, and a thousand other useful objects being now produced by these new processes.

We must stop here. Enough has been said, I think, to convince the reader that the employment of electricity on a large scale has, within the last few years, created a new chemistry and a new series of industries which will go far towards turning the world's desolate regions into centres of wealth and luxury, thus partially realising the dreams of the socialist. But one thing is certain. Wherever there exist great quantities of running water, wherever water power is cheap, there, no matter whether it be in the icy North, or in sunny tropical lands, will arise in time mighty cities, centres of civilisation and power, whose high-temperature factories will distribute their wares over the face of the whole earth, to the great benefit of humanity. For running water can be applied for working turbines, which in their turn work dynamos, and thus generate electricity.

Even now the brow of Niagara Falls is encircled with a diadem of high-temperature factories, and great towns are springing up around them in every direction. In Norway the running waters are being harnessed to generate the electric current for the manufacture of artificial nitrates, while in the near future we may expect to see great cities springing up on the Zambesi in Central Africa, and on those vast mysterious Falls in the centre of South America, which have as yet been seen by the eyes of very few white men.

Within recent years the electric current has been put to another use which we must here touch upon. The whole tendency of modern civilisation is towards rapidity, whether it be in work, thought, or play. And nowhere, perhaps, is this general tendency more evident than in modern analytical methods. In many commercial processes it is absolutely essential that the different products should be rapidly and accurately analysed, and so it comes about that old laborious methods are being gradually replaced by modern methods which combine high speed with accuracy.

For example, we might mention in this connection the new simple and rapid methods for estimating arsenic, copper and iron introduced by Prof. G. D. Lander, of the Royal Veterinary College.[1]

Perhaps the most startling of the later innovations is the application of electricity to chemical analysis. The new electrical methods, in fact, threaten to displace the old laborious gravimetric methods for estimating certain metals, for by their means we can carry out analyses in a few minutes, which by older methods would have taken many hours or even days to complete.

The old gravimetric processes for estimating metals consist in precipitating them from their solution as insoluble salts by adding a suitable reagent, transferring the mass to a filter paper, washing until free from all impurity, drying, heating, and weighing—operations which often

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[1] See Lander & Geake, the *Analyst*, March, 1914.

take many hours to perform. If two or three different metals are present in the solution the operation must be repeated separately for each different metal; so that it is often extremely difficult, as well as very laborious, to separate out several such metals from a solution, the whole series of operations often taking days to complete. Recently, however, rapid electrical methods have been

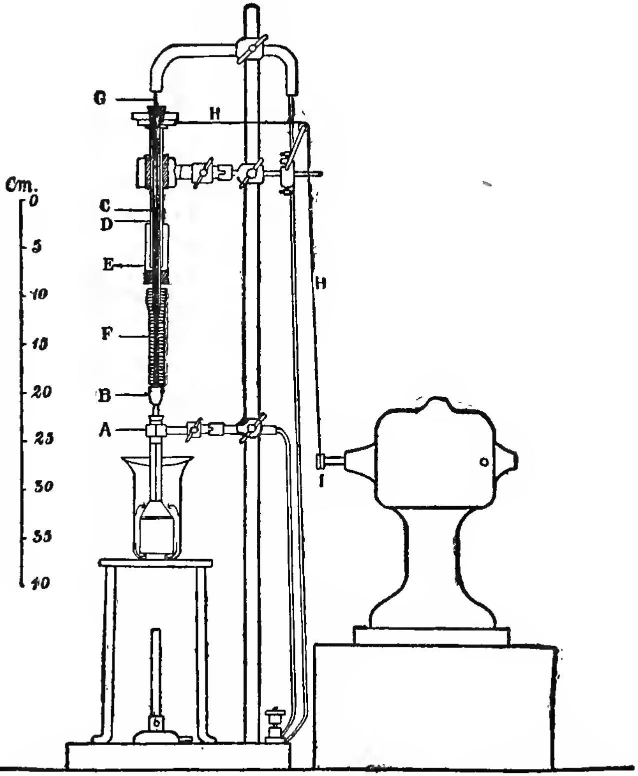

FIG. 12.—Section through Dr. Sand's Apparatus for Rapid Electro-Analysis.

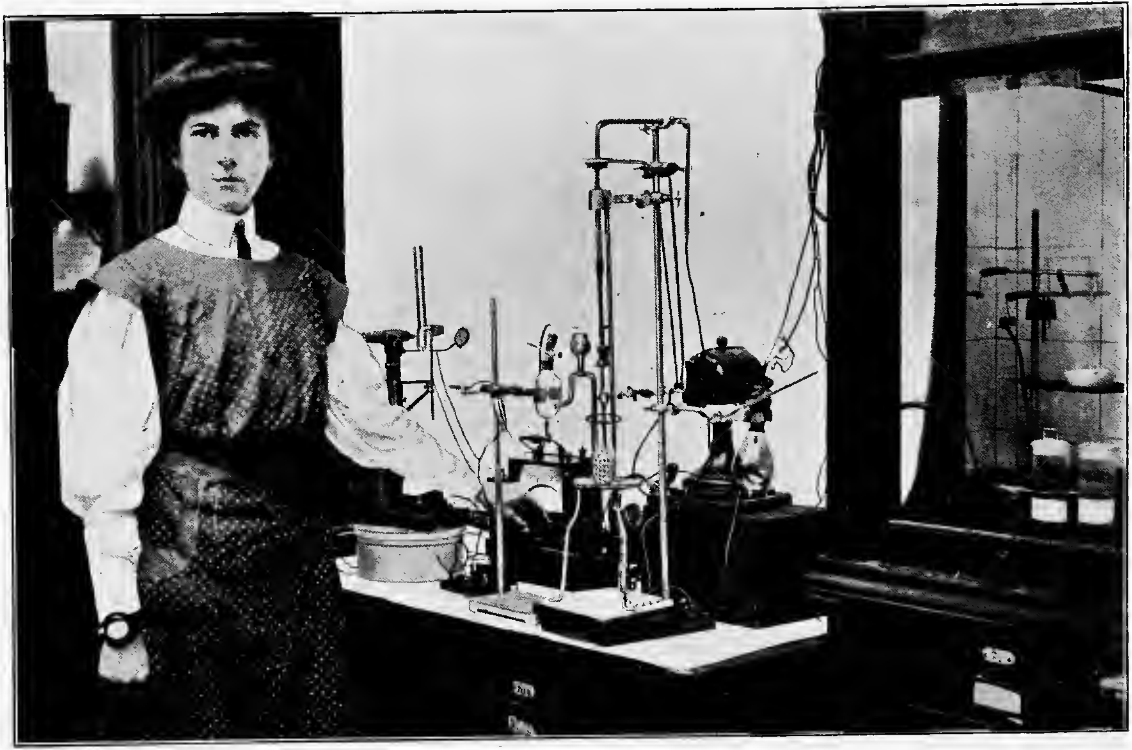

Plate 12.—Dr. Sand's Apparatus for Rapid Analysis by means of the Electric Current.
The operator is seen regulating the current intensity.

introduced which, to a great extent, do away with these laborious processes. In these the metal to be determined is deposited on a platinum electrode by the electric current, and is then weighed. Wolcott Gibbs in America, in 1864, and Luckow in Germany were the first to grasp the possibilities of electro-analysis, and showed how the operation was to be carried out. Since that time a large number of distinguished chemists have been busy elaborating these methods and elucidating their theory. Among these may be mentioned Classen, Vortmann, Winkler, Förster, Nernst, Leblanc, Freudenburg, and Hollard. In recent years, however, these electrical methods have been very greatly extended and improved, especially as regards the time required for an analysis, by Gooch, Medway, Smith, Exner, and others in America. In England Dr. Sand, of University College, Nottingham, has invented apparatus which brings the method to a wonderful state of perfection. Plate 12 is a photograph of the apparatus used by Dr. Sand for the successive estimation of a large number of metals when present simultaneously in the solution. Each metal separates out at a different electrical tension, so that by measuring the difference of potential between the liquid itself and the electrode on which the metal is being deposited by an auxiliary electrode—an improvement introduced into electro-analysis by Dr. Sand in 1907—the current can be regulated in such a manner that only one metal separates out at a time. When it has been completely deposited the current usually almost ceases to pass through the liquid, so that the analyst knows when to stop. Extreme rapidity of deposition is secured by stirring the liquid to be analysed vigorously by means of special motor-driven electrodes (see figs. 12, 13), and at the same time passing a powerful current through the solution. Unless the liquid is rapidly stirred, the electricity at once exhausts it of metal at the cathode, and then decomposes the water around it, generating hydrogen, and thus destroying all possibility of accurate analysis. Stirring replenishes the liquid at the electrode as fast as it is exhausted, and thus secures that the metal is deposited at a constant potential. When the metal is completely deposited from the solution—which takes five to ten minutes as a rule—the cathode is removed, rinsed with water, alcohol, and ether, and dried over a Bunsen flame—operations carried out in barely a minute. It is then weighed, and the metal precipitated on it is thus determined. A few examples taken

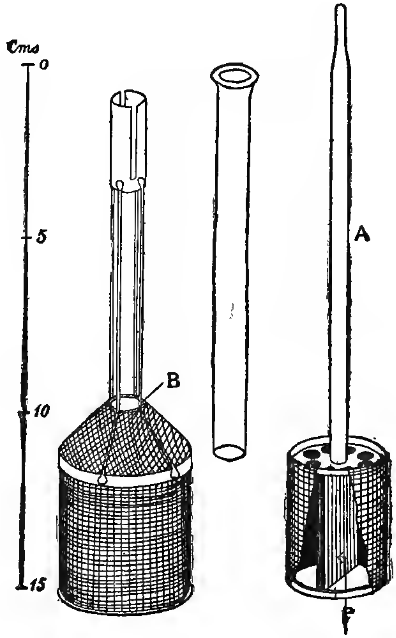

FIG. 13.—Dr. Sand's Electrodes for Electro-Analysis.

from Dr. Sand's most recent papers[1] will illustrate the surprising efficiency and rapidity of these new methods. Perhaps one of the most difficult of electro-analytical operations was the separation of metallic bismuth in a form suitable for analysis. Dr. Sand now achieves this with ease and certainty in only a few minutes. Thus a solution containing 0·2184 gram of bismuth gave 0·2187 gram in nine minutes. The determination of the amount of copper and lead in a solution would take several hours gravimetrically. Electrically a few minutes suffice. Thus in one experiment Dr. Sand passed a current of two amperes for *five minutes* through the hot solution. The lead was in this short time all deposited on the anode as lead peroxide, PbO_2. The current was then increased to 10 amperes, and the copper was deposited on the cathode as metal. On weighing the cathode and anode the respective amounts of copper and lead were found to be 0·2476 gram and 0·1383 gram respectively. Theory required 0·2474 gram copper and 0·1383 gram of lead. These results speak for themselves. But they are only two of many others which could be quoted did space permit.

It may be added that the process is not confined to separating rapidly two metals alone, but three, four, five, six, and even seven metals can with equal ease and rapidity be separated. Thus in one case Dr. Sand analysed a solution containing silver, mercury, copper, bismuth, lead, cadmium, and zinc—an operation which would have been extraordinarily difficult to carry out in many days by the ordinary gravimetric processes. But enough has been said to show the importance of these new methods. They prolong the effective life of the analyst much beyond its former extent, and may possibly in the immediate future become of great commercial importance as well.

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[1] "The Rapid Electro-analytical Deposition and Separation of Metals," by Dr. H. J. S. Sand, *Journal of the Chemical Society* (1907), vol. 91, p. 373.

Still one more application of electricity I must touch upon, and that is its use in chemical research. Electricity may be said to be the great revealer of the inner mysteries of matter. It has lighted up the lamp of research, enabling such workers as Crookes, Thomson, and Rutherford to penetrate into the dark interiors of the very atoms of matter. By means of the electric current the atom has been shattered, the mysteries of radium, thorium, and uranium investigated, and so the great fact of the disintegration of matter revealed. If fire gave the chemist command of molecules, electricity has enabled him to resolve the atom into even more nearly ultimate particles.

Not only does the atom appear divisible, under the electric current, but it is held by some that the elements are themselves transmutable by its aid, and so the ancient doctrines of alchemy have been revived in modern garb. The electric rays have been utilised for demonstrating the existence of individual atoms ; by their aid the arrangement of atoms in crystals have actually been photographed —so it is claimed by sober investigators. And thus the electric ray has revealed for science a new heaven and a new earth, utterly transcending the motions and the phases of matter which the chemists of a few decades ago regarded as ultimate.

CHAPTER IX

THE ROMANCE OF THE HYDROCARBONS

FEW regions of the world are more remarkable than the lands surrounding the Caspian Sea. Once they were covered by the dark waters of a great inland sea, which stretched north and joined the Arctic Ocean. In very ancient times, however, a process of slow drying up commenced. The icy waters steadily receded until after many ages they are now confined to the narrow limits of the present Caspian Sea. As the waters retreated they left behind them vast stretches of waste and barren land, which to-day extend as far as the eye can reach. No natural meadows gladden the view of a stranger visiting these districts. Instead there stretches before him an immense desert of white sand and reddish clay, with here and there some scanty shrubs with dark, sombre leaves. At frequent intervals occur ravines worn in the soil by the torrents of a thousand storms, and marshes filled with reeds and thick slimy waters. Truly a waste, forbidding region! For centuries the land has been called the "Region of Everlasting Fire." And with some show of reason, too. For anyone wandering after sunset in the interminable plain can see rising on all sides from rents and crevices, moving flames, bright fantastic tongues of fire, which untarnished by smoke wave their bright summits to and fro in the darkness, as if beckoning him on to destruction:

> "A savage place! As holy and enchanted
> As e'er beneath a waning moon was haunted
> By woman wailing for her demon-lover!"

These flames are not the disembodied souls of dead men or demons, as was once thought by the natives, but rather are due to torrents of a gas, very similar to our coal gas, which, pouring out from underground regions, have become ignited by a process of spontaneous combustion. The earth in these districts has been evolving these gases for ages. Indeed, if the reader should visit Surakhani, on the shores of the Caspian, he will be able to see a temple built by fire-worshippers, from whose towers streams aloft a column of burning gas. If the priests are to be believed, this column has burnt without intermission since 400 years before Christ. Although this statement is probably incorrect, yet there can be little doubt that some of these remains are of immense antiquity, and probably date from the time of Zoroaster, 600 years B.C. The present temple, of Indian origin, is a fortified square with a high towered gate. In the centre of the court stands a square building supported by four columns, and enclosing a basin-like excavation whence gas streams upwards and is conducted into the tower and its four chimneys. The gas burns at a low pressure, and can be readily blown out and relighted. The flame is rather bluish and does not give much light; at night it presents a most weird appearance. Ancient stone beds and stalls, with mangers cut out of the stone, for the pilgrims and their beasts, still remain in the hollow walls, and various small chapels and dungeon-like rooms doubtless appear now as they did centuries ago (Plate 13).

Near the temple a well may be seen some fifty feet deep, in which the gas accumulates in very large quantities. It was here that the German traveller Koch witnessed a very strange sight. The priest and his assistants spread a carpet over the mouth of the well to prevent the gas from escaping. After being left on for a few minutes, it was quickly removed, and a bundle of brushwood in

From Cassier's Magazine.

Plate 13.—An ancient Fire-worshipper's Temple near Balakhani.

From Cassier's Magazine.

Plate 14.—A glimpse of the famous Russian Oil City of Baku.

which a piece of burning paper had been stuck, was thrown down the cavity. This done, the priest and his assistants ran off as fast as they could. Suddenly a great explosion took place in the well and an immense column of fire leaped forth and ascended to the skies.

Hanway, who visited the country in 1754 on behalf of the British government, thus reports on the district: "What the Guebers, or Fire-worshippers, call the Everlasting Fire, is a phenomenon of a very extraordinary nature. This object of devotion lies about ten English miles north-east by east from the city of Baku, on a dry rocky land. There are several ancient temples built with stone, supposed to have all been dedicated to fire. Amongst others is a little temple at which Indians now

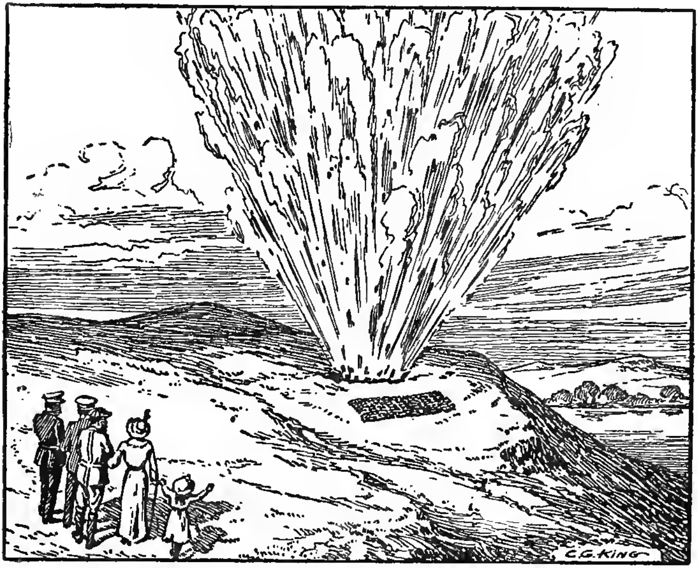

FIG. 14.—Explosion of gas in a well at Surakhani.

worship. Here are generally forty or fifty of these poor devotees, who come on a pilgrimage from their own country. A little way from their temple is a low cleft in a rock, in which there is a horizontal gap, two feet from the ground, nearly six feet long, and about three broad, out of which issues a constant flame, in colour and gentleness not unlike a lamp that burns with spirits, only more pure. When the wind blows, it rises sometimes eight feet high, but is much lower in still weather. They do not perceive that the flames make any impression on the rock. This also the Indians worship, and say it cannot be resisted, but if extinguished will rise in another place. The earth around the place, for above two miles, has this surprising property, that by taking up two or three inches of the soil and applying a live coal, the part which is so uncovered will immediately take fire, almost before the coal touches the earth ; the flame makes the earth hot, but does not consume it, nor affect what is near it with any degree of heat. . . . Not long since eight horses were consumed by this fire, being under a roof where the surface of the ground was turned up, and by some accident took flame. If a cane or tube even of paper be set about two inches in the ground, confined and closed with earth below, and the top of it touched with a live coal, and blown upon, immediately a flame issues without hurting either the cane or paper, provided the edges be covered with clay, and this method they use for light in their houses, which have only the earth for floor ; three or four of these lighted canes will boil water in a pot, and thus they dress their victuals. . . . Lime is burnt to great perfection by means of this phenomenon, the flame communicating itself to any distance where the ground is uncovered to receive it. The stones must be laid on one another and in three days the lime is completed."

A modern writer thus describes the same region:[1]

"From this point (Eblahk) the road runs directly to Baku over 180 miles of desert land. Except for an occasional Tartar Settlement or government railway station, not a house is to be seen, and the only signs of life are a stray horseman or an occasional camel train. The level of the track is now above and now below the sea, the lowest point being 70 feet below the level of the Black Sea. On the north the mountains recede and are replaced by a low outline of hills absolutely devoid of verdure, whereas on the south the river, which has accompanied the road from the summit of the mountain, gradually diverges and empties into the Caspian Sea about 100 miles from Baku. It is supposed that this river bed once took the same course as the present railway, since unmistakable signs of former villages and even farms are constantly being unearthed in this arid region. . . . On approaching Baku evidences of the oil fields become visible on all sides, and great cities of black derricks, set so close together that they appear like a dense forest, mark the well defined area of the productive field. As the train circles round a well-sized hill the city of Baku bursts upon the vision with startling suddenness, and one is soon in what might well be called one of the most interesting cities of modern times. It lies on the sloping shore of the very salty Caspian Sea, and is credited in ancient legends to have once borne the name which in Tartar language means City of Roses. Nothing, however, could be more inappropriate at the present time, when the ruling impression is complete absence of verdure, due to lack of fresh water supply. All the water used by this city of over 75,000 inhabitants is now either distilled from the sea-water, brought in tank cars from distant rivers, or borne in casks on the backs of horses or camels from

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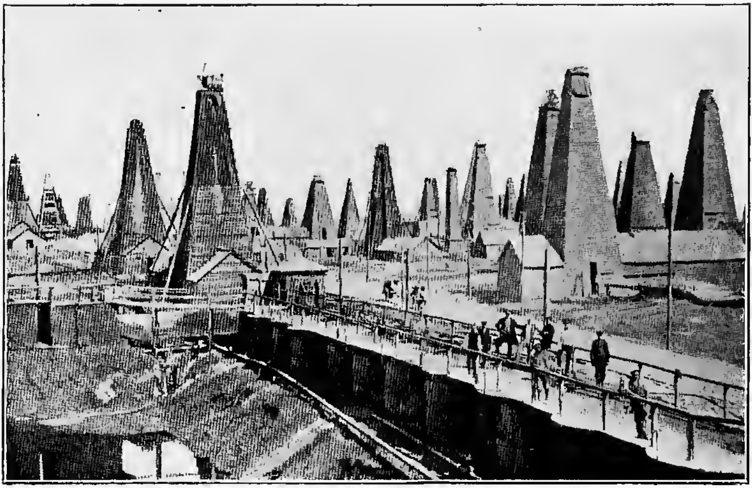
[1] Ernest Potter in *Cassier's Magazine*, Nov. 1900, vol. 19, p. 3.

very carefully preserved wells in the vicinity and fed by not too frequent rains. . . . Evidences of wealth are not only to be seen in the appearance of the city itself, but also among many of the inhabitants. It is not an uncommon sight to see a Tartar or Persian who is worth a fortune, but who cannot write his own name, and has no idea of the world outside Baku."

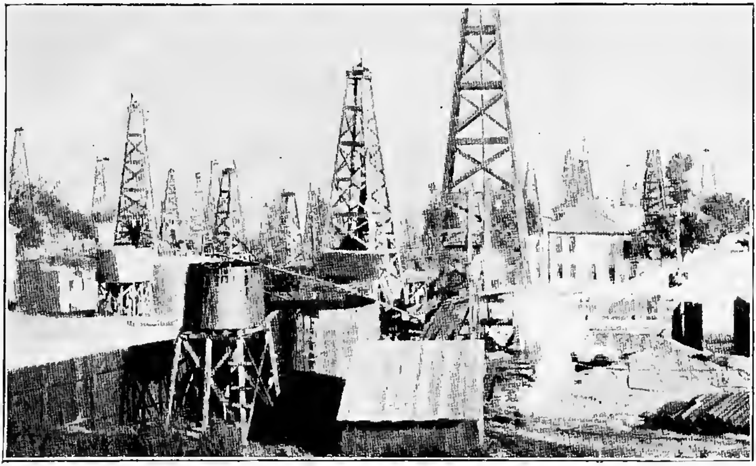
Such gas-wells, however, are not confined to this one region of the world. They occur widely distributed in almost every part of the globe. In North America they are specially plentiful. And here the gas often is impelled upwards with immense force. Indeed it has been known suddenly to rush forth from deep borings under a pressure of 1000 lbs. to the square inch. At an immense gas-well at Delameter in the United States, enough gas was evolved to supply the whole town and the neighbouring districts with heat and light. Several pipes carried off the gas, one leading it direct to the cylinder of a large engine, and so great was the pressure that the engine continuously worked at great speed. When the gas issuing from the cylinder was set on fire it threw out a mass of flames and could have been employed for driving another engine. Another pipe supplied a flame capable of reducing ore enough to supply half the furnaces of Pittsburg. A third pipe, three inches in diameter, sent up a column of fire forty feet high. On a calm night the roaring of the flames could be heard fifteen miles away. The gigantic flame shooting up into the air presented the appearance of a burning steeple· Another well at Fairview supplied a hundred engines for many years with gas, and, I believe, is still supplying them. Many hundreds of such gas-wells are known, far too many for us to attempt to enumerate them here.

Wherever we find gas coming up to the surface from subterranean sources in such great quantities we can be



From Cassier's Magazine.

PLATE 15.—Russian Oil Wells at Balakhani, near Baku.



Photo, F. L. Park & Co., Los Angeles.

PLATE 16.—Oil Wells at Los Angeles, California.

sure that oil is also present; and accompanying the oil and dissolved in it are solid fatty products like paraffin wax, bitumen, and asphalt. Vast as are the quantities of gas, the quantities of oil which sometimes accompany them are often far greater. Oil exists, together with the gas, often under enormous pressure deep down in the earth. Of course this oil is extremely valuable, and when a region is suspected of containing it a boring is made into the earth. This boring is carried out as follows: First a wooden structure, called a derrick, is erected over the site on which operations are to be commenced. The derrick is usually 40 to 70 feet high and is for supporting and controlling the working of the string of drilling tools. The drill is a heavy iron chisel known as a "bit," the weight and effective striking force of which is increased by means of a heavy iron bar termed a "sinker," to which it is screwed. This combined bit and sinker is suspended by a string of wooden or iron poles from a massive beam of wood which is pivoted at its centre and caused to move up and down, like a see-saw, by means of an engine. The bit is thus moved up and then down rapidly at the rate of 40–50 times a minute, and each time the chisel, travelling rapidly with the weight of the sinker behind it, strikes the bottom it plunges into the rock and deepens the hole. The whole set of drilling tools may weigh a couple of tons and are of somewhat complicated design in order to prevent jamming, but we cannot describe them here.[1] Plates 15 and 16 show typical oil wells.

At intervals the tools are withdrawn, and the mud and sand produced by the drilling is removed by pumps or bailers. As the well is sunk it is cased throughout with

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[1] The reader may find a full description in *Trans. Inst. Mining Engineers*, vol. 35 (1907–1908), p. 559, "Notes on the Winning of Crude Oil," by D. M. Chambers. See also "The Petroleum Industry," by George Holloway, "*Knowledge*," vol. 21 (1898), pp. 124, 151, 169.

iron tubing to avoid choking up by detritus or caving-in of the strata. Usually when oil is "struck" it is pumped out to the surface and run into suitable reservoirs. But sometimes the drill suddenly penetrates a vast reservoir of underground oil in a highly compressed condition. When this happens the oil rushes out, often with stupendous force, and rises into the air in a lofty fountain. The quantities of oil which have thus been set free are almost incredible. Thus in 1883 while boring for oil at Droojba in Baku, oil and gas came suddenly rushing up the bore hole with irresistible force, hurled the drilling tools weighing some tons into the air, crashed with a concussion like thunder against the roof and sides of the wooden structure containing the boring apparatus, shattered them in an instant, then burst with a roar against a massive beam left standing, and finally squirted up in a vast fountain eighteen inches in diameter to the tremendous height of 300 feet, and falling as spray formed great *lakes* of oil so deep that a boat could float on them. From afar this mighty pillar capped with falling spray presented a truly wonderful sight; it towered aloft like a huge column of smoke ascending to heaven, while the wind catching it, carried from it a rain of oil which drenched the whole neighbourhood. The engineers were absolutely unprepared for such a vast quantity of oil, and had no means for storing it. Their feelings may be imagined when they saw thousands upon thousands of pounds' worth of oil simply running in a broad river into the sea! When after about three months the well was brought under control and capped it was estimated to have yielded half a million tons of petroleum, most of which was lost. The well poured out about £11,000 worth of oil daily!

The reader's wonder will increase when he learns that this is by no means the largest oil flow known. Thus at

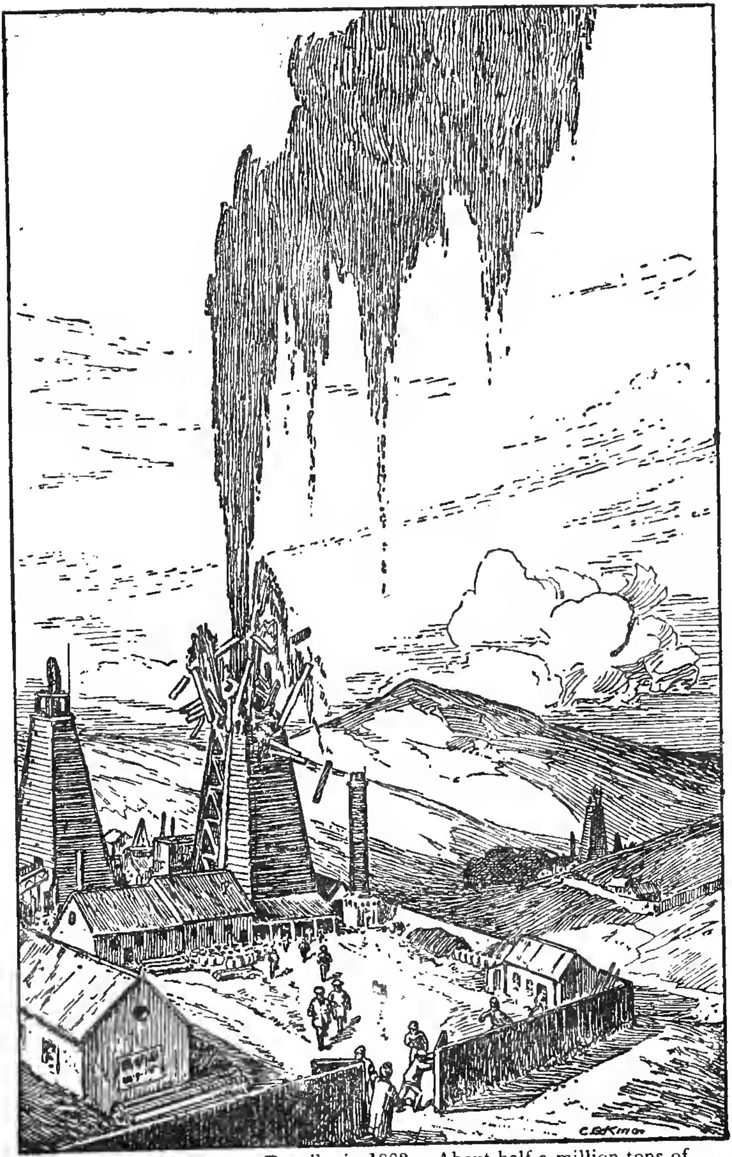


FIG. 15.—Oil burst at Droojba in 1883. About half a million tons of petroleum were lost.

Bibi-Eibil in the same district a similar outbreak occurred; the whole region was covered with oil, cavities in the ground being converted into oil-lakes, and ten million gallons flowed to waste in the Caspian Sea. In 1893 an oil well in Baku yielded 17,742 tons of oil *daily*—a quantity far in excess of the Droojba well.

Great quantities of sand are also usually thrown up with the oil. Thus in the Droojba oil fountain the sand ejected with the oil half buried the neighbouring engine houses and workshops, and many claims for damage were put in. Another well struck by the Mining Company in August 1887 not only threw a column of oil 12 inches in diameter to a height of 200 feet for a period of sixty-nine days, but ejected such vast quantities of sand that some one-story stone buildings about 15 feet high, within 100 yards of the well, *were actually buried out oj sight*, while at the same time an area of some ten acres around the well was covered to a depth of from 1 to 15 feet with sand! Naturally when a well spouts in this way a great waste of oil is almost inevitable, and consequently the engineers endeavour to avoid this by fitting the metal tube coming up from the well with an iron cap with a gate valve. Often, however, the pressure exerted by the oil is so immense that the valves and strong framework of timbers have been blown away, in the manner already related. Thorpe relates how when visiting Baku in 1884 he saw one of Nobel's capped wells flowing. Upon opening the valve the fountain rose to a height of 100 feet with a mighty roar, and continued to flow with undiminished violence until the valve was closed, forming a lake of oil to leeward of the derrick.

These Russian oil fields have been the theatre of some terrible disasters. Thus in the seventeenth century at Schemakla an earthquake shock shattered the town and fissured the ground. Evidently it ruptured some great subterranean oil reservoir, for from out of the fissures torrents of burning oil came pouring, flooding the district and increasing the horrors of the disaster. But the greatest catastrophe of all occurred quite recently, in the autumn of 1905. At this time when the stir and unrest of revolution surged and ebbed throughout the whole of the Russian Empire, the workmen of Baku, wild savage men from Tartary, rose in revolt, fired the oil wells, slew the overseers, and then workless and homeless marched in thousands over the terror-stricken land, burning and plundering as they went. Out of 3600 oil-wells no less than 3000 were fired, and the flames and smoke, shooting upwards in vast columns, turned night into day for miles around, poisoning the air with dense soot and fumes. Few events have been more terrible than this uprising ; the sudden and appalling loss of millions of money, the large numbers of people who perished, coupled with the almost complete ruin of a great province, profoundly affected the imagination of the civilised world.

In America the petroleum industry may be considered to have started in the year 1859, when the now famous "Colonel" Drake started, amidst general hilarity, to drill for oil, at Oil Creek in Pennsylvania. The amusement with which the public followed operations suddenly turned into a veritable oil-fever when it became known that he had succeeded in tapping enormous quantities of oil. Rapid development ensued down "Oil Creek" and along the Alleghany River. Over two million barrels were raised in 1861 and since that date the yield has steadily increased, the United States production now exceeding 120 million barrels.

Indeed, although crude oil is found in various quarters of the world at the present day, especially in Galicia, yet over 90 per cent. of the whole world's supply is obtained from the oil fields of the United States of America and Russia. But there is a vast difference between the two supplies. The American oil fields soon run out, whereas the Russian appear to be more permanent. In consequence of this exhaustion of the oil-bearing district in America great towns containing thousands of inhabitants which have sprung up in the midst of a rich oil-bearing district, bloom for a few years, and then in consequence of the exhaustion of the oil vanish almost as suddenly as they arise. Fortunes were made and lost with extreme rapidity on these oil fields. A poor man would in consequence of a lucky boring suddenly become rich. The phrase "to strike oil" dates from this period of intense speculation and activity.

When the oil stratum is struck, or, more usually, when the well begins to show a decreased yield, it is common in America to explode a charge of dynamite—known as "Torpedoing"—at the bottom of the well in order to loosen the soil and allow the oil to run more easily into the well.

The depths of oil-wells vary greatly. Oil-wells 3000 feet deep are common. Depths of nearly 4000 feet are not infrequently met with in Galicia, and these with diameters of nearly 5 inches at the bottom. In Russia the wells are usually shallower, varying from 700 to 1000 feet, though deeper wells are also met with. In Canada the wells average 1000–1500 feet, in Pennsylvania 2000–3000 feet. Sometimes, in the case of shallow oil-wells, the well is not drilled at all, but a shaft is dug down to the oil-bearing strata. The diggings are carried on by one or two men and the shaft lined with timber to prevent caving in. As the depths increase it is generally found that poisonous gas issues from the bottom and a stream of fresh air must be pumped down to the men below. The system, however, is a bad one, fatal accidents as the result of earth-falls, fire, or gas poisoning being common. It may be stated here that the gas evolved from petroleum affects its victims in a curious way, at first making them intoxicated, so that they sing and dance in a frenzied manner, until they suddenly collapse ; and when once this happens recovery is rare.

The oil thus produced is allowed to run into reservoirs, whence it is pumped into great tanks for storage. Sometimes these tanks are about 90 feet in diameter and 30 feet high, giving a capacity of 2500 tons of oil. But sometimes immense oil-tanks are met with, which far exceed these dimensions. The tanks are usually made of boiler-plate and are roofed over, for there is always a danger that the oil may become ignited by a process of spontaneous combustion when exposed on a hot day to the sun's rays. In some districts earth-storage has been much used, reservoirs being excavated and lined with wood and clay and covered with roofs earthed over. Such tanks are indeed the safest. In America the introduction of "pipe-lines" has been brought to a very high state of perfection. The oil is pumped direct from inland oil-producing regions through hundreds of miles of pipes to the oil-refineries situated, usually, on the sea-coast. The main pipes through which oil is pumped, often as far as 100 miles with one engine, are from six to eight inches in diameter, while the small feed lines which pass to them from the wells are about two inches in diameter. The trunk lines are made of welded wrought-iron, tested to 1500 lbs. the square inch, the working pressure averaging 1000 lbs. The lines are laid a few feet below the surface where possible, and bends are provided for expansion and contraction. As the pipes are liable to become choked by dirt or solid hydro-carbons, a small conical steel wire-brush, known as a "go devil," is occasionally passed through to clear them. This brush travels along with the oil as the latter is pumped through the pipes, and is provided with ball and socket joints, to facilitate its progress round the bends ; it is also fitted with vanes, which ensure its rotation as it advances, and it has at the end a stiffened leather base. This is forced from station to station over miles of country, and is followed by men on foot or horseback, who keep within hearing of the whirring noise of the instrument, and in case of stoppage must locate the spot so as to be able to clear the obstructed section.

The pumps now invariably used for these lines are of the Worthington type, and work at a pressure which sometimes rises as high as 1500 lbs. per square inch. The 760 miles' length of six-inch pipe extending along the New York line is worked by pumps of from 600 to 800 horse-power, and conveys about 30,000 gallons daily. Of course on a long line like this the relay system is employed. There are eleven pumping stations, each with a pump-house and two or more tanks. Each well-owner, as his oil is passed into the pipes, receives a certificate stating that he is entitled to so much oil, and these certificates are negotiable like banknotes among those in the trade. Of course all the oil passes into the common reservoir, so that no producer can receive his own oil from the refinery.

In other countries other means of transport are used, the most common being railway tanks. These are cylindrical tanks of boiler-plate, provided with a dome through which they are filled and a valve underneath for outlet. These are to be seen on all railways. Where possible, water-transport is made use of. Tank-barges 100–150 feet long, of 20 feet beam, divided into a series of compartments by oil-tight bulk-heads, provide a convenient transporting medium.

For ocean transport the oil is now usually conveyed in tank-steamers, in which the whole hold is formed in compartments or tanks to contain the oil. In order to prevent injury to the vessel from the oil rolling about in bad weather, the tanks are kept quite full, small auxiliary "expansion tanks" being fitted to receive any overflow when an increase of temperature causes the oil to expand, or to supply oil to the main tank when a contraction in volume occurs. In earlier days the escape of gas and inflammable vapour from the oil led to terrible explosions, which occasioned great loss of life. But the ventilation is now so perfect that the danger is greatly minimised.

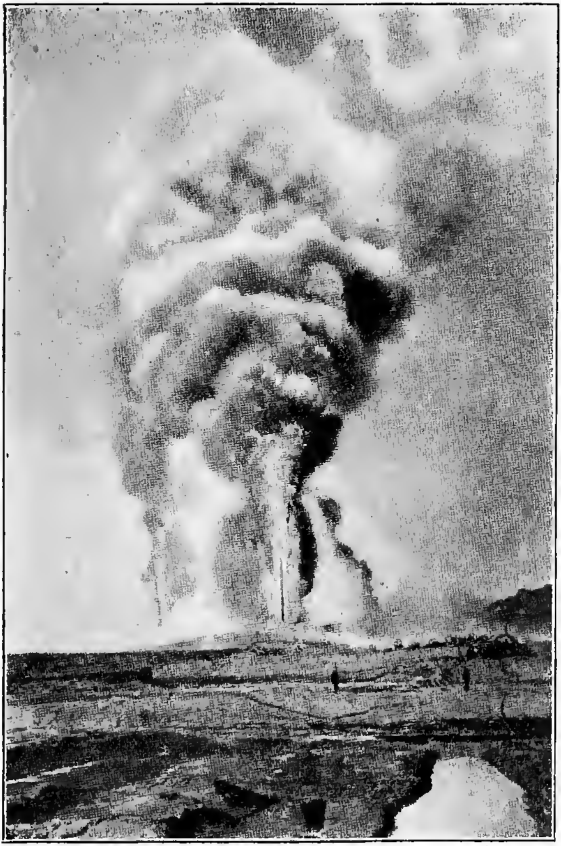
However, even at the present time, the dangers of oil transport at sea have not been entirely overcome, and so recently as 27th April 1914 a Russian oil-ship, carrying a cargo of petrol to Rouen, blew up off Algiers late on a Sunday night. Of thirty persons on board fifteen lost their lives. The captain's wife, who was on board at the time of the explosion, swam for two hours in the sea at night in danger of being overtaken by a flood of burning oil. "My husband put me into a boat after the ship had burst into flames," she said, "but it capsized. I found myself swimming in the black water, which was lit up by the flames from the burning ship. The oil spread on the sea and formed one vast burning film which the wind drove towards me. For two hours I swam frantically from the flames.

"Just as I, exhausted, was about to give up the struggle, I heard a voice shouting in Russian, 'Come here.' It was the chief stoker of the vessel, together with a number of the crew, in a boat nearly full of water. I was hoisted into it, and sat for two hours up to my hips in water, until at last we were saved."

As we have already remarked, gas invariably accompanies the oil, being dissolved in it, and is, as we shall see, only the more volatile products of the crude petroleum; even on the oil fields itself it is the source of danger, on account of its being highly inflammable and when mixed with air violently explosive. Nearly all the fires, often attended with considerable loss of life, which sooner or later visit all oil fields, are attributable to this gas; and the strictest regulations regarding the use of lights, smoking, and the situation of boiler-houses with regard to the wells, are in force. Many a workman, with the intention of having a quiet smoke unknown to the authorities, has struck a match and been promptly hurled to his death by a great gas explosion, which has been known to wreck the great oil tanks, and scatter a flood of blazing oil around, causing the most frightful damage and loss of life. Plate 17 shows an oil-well on fire.

Having arrived at the refineries, the oils are subjected to a process of fractional distillation. Since petroleum is a mixture of compounds of carbon and hydrogen of different volatility, this process separates it into a number of products of different boiling points.

For this purpose various types of still have been devised, the Russians largely using the "Continuous Still," in which the crude oil is supplied as fast as the distillate passes off. For American petroleum, however, non-continuous stills work best. These are cooled down and the residue removed after each distillation. In distilling petroleum some of the constituents are decomposed into other bodies, which are often more volatile than the bodies producing them. In what is known as the "Cracking process" this decomposition is caused to be increased by allowing a portion of the distillate to condense on the cooler upper region of the still, and run back upon the hotter liquid at the bottom. This action, however, is not allowed to take place until the bulk of the lighter oils have been distilled off, as it is the heavier and



From Cassier's Magazine.

PLATE 17.—Russian Oil Well on Fire.

Russian oil wells often spontaneously take fire and burn furiously, causing great damage and loss of property.

less valuable constituents of the petroleum which it is desired to decompose, in order that a maximum of illuminating oil may be obtained.

The stills themselves are great iron vessels, 30 feet and more in length, and of a corresponding breadth and diameter. They are heated by furnaces underneath, and hold from 600 to 1200 barrels of oil. From the stills there passes out an elaborate series of condensing coils, cooled by water, which deliver the distilled petroleum into box-like receptacles with plate-glass sides, through which the runnings of the distillate can be observed, and a test sample withdrawn from time to time.

The distillate is agitated with sulphuric acid, followed by treatment with caustic soda, and then washing with water, which is drawn off after settlement.

Naturally the chemical constitution of these oils aroused the curiosity of chemists, and their systematic investigation brought to light an immense number of new compounds composed of carbon and hydrogen (hydrocarbons).

These natural hydrocarbons belong to three different categories, typified by the petroleum of Pennsylvania, the Caucasus, and Galicia respectively. The American oil chiefly consists of compounds belonging to the "Paraffin" series of hydrocarbons, which possess the formula C_nH_{2n+2}, where n varies from 1 up to a very large number. The Baku oil consists of compounds belonging to the Olefine series, which have the formula C_nH_{2n}. The oil of Galicia includes hydrocarbons of both series, together with aromatic compounds derived from benzene, corresponding to the general formula C_nH_{2n-6}.

The gases which accompany the oils and stream out of the earth in the wonderful manner already described, are the compounds of the series which possess the lightest molecules, and therefore are the most volatile. For example, Methane, or marsh gas, CH_4, obtained from the general formula $C_nH_{2n}+_2$ by putting $n=1$, Ethane, C_2H_6 ($n=2$), Propane, C_3H_8 ($n=3$), Ethylene, C_2H_4 ($n=2$ in the series C_nH_{2n}), &c. &c.

The liquid parts consist of more complex compounds, such as C_4H_{10} (Butane), C_5H_{12} (Pentane), C_6H_{14} (Hexane), &c. &c.

The solid parts consist of immensely complex molecules, containing sixty and more carbon atoms united together.

When these natural oils are distilled, the boiling point of the vapours constantly changes, beginning at 0° C. and going up to above 350°.

That part of the oil which distils over first is a very mobile, colourless liquid, from which the hydrocarbons which boil at low temperatures may be extracted —namely, C_4H_{10}, C_5H_{12} (which boil about 30° C.), C_6H_{14} (which boils at 62° C.), C_7H_{16} (boiling point, 90° C.), &c. &c.

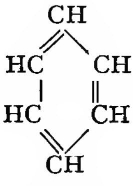
That part of the petroleum distillate which boils above 130° C. and contains the hydrocarbons C_9H_{20}, $C_{10}H_{22}$, $C_{11}H_{24}$, forms the oily substance used for lighting (kerosene). Those portions which are still more complex and boil between 275° C. and 300° C. form an excellent oil for illuminating purposes, but can only be distilled without change by means of superheated steam; otherwise they are largely decomposed.

Parts of still higher boiling points form lubricating or machine oils. While vaseline is a semi-fluid mass of still higher boiling point. The waste fluid masses which cannot be profitably distilled are used instead of coal as a liquid fuel.

By systematic researches these different hydrocarbons have, as already related, been classed in three groups, each one of which can be represented by a general formula:

Group I.	Group II.	Group III.
The Paraffins, C_nH_{2n+2}	The Olefines, C_nH_{2n}	Unsaturated compounds, C_nH_{2n-2}
Methane, CH_4	...	...
Ethane, C_2H_6	Ethylene, C_2H_4	Acetylene, C_2H_2
Propane, C_3H_8	Propylene, C_3H_6	Propine, C_3H_4
Butane, C_4H_{10}	Butylene, C_4H_8	Butine, C_4H_6
Pentane, C_5H_{12}	Pentylene, C_5H_{10}	Pentine, C_5H_8
&c.	&c.	&c.

Those hydrocarbons classed under Group III are so unstable that they hardly occur at all naturally. But a fourth series of hydrocarbons occurs which are of an entirely different type. In them the carbon atoms are united together to form tiny rings or chains, and they are known as "aromatic" compounds. The most important member, benzene, C_6H_6, contains a closed chain of six carbon atoms, its constitution being represented as follows:



This body, and analogues of it, like toluene, naphthalene, anthracene, occur largely in the liquids obtained from coal when this is distilled in gas-making. From it are made innumerable numbers of those beautiful and delicate dyes, medicines, and scenty matters, which are now so famous throughout the world.

When oil evaporates it leaves behind solid matter like asphalt, paraffin, and pitch. It was with this asphalt that the inhabitants of Nineveh paved their streets some four thousand years ago—just as we do now—and used it as a mortar for building houses. There is an island on the eastern side of the Caspian Sea called Tcheliken, where the very cliffs are composed of crude paraffin wax, called "Ozokerite"; while east of Krasnovodsk, on the same shore, "there are immense hills of ozokerite and petroleum." These must have been produced in prehistoric times by vast quantities of oil rushing out of the earth and evaporating away, leaving behind them these solid residues. The most remarkable deposit of pitch or bitumen in the world is the celebrated "Great Pitch Lake" of Trinidad (Plate 18). It is a mile and a half in circumference, and covers 137 acres. The bitumen is solid and cold near the shores, but gradually increases in temperature and softness towards the centre. Men and animals are stated to have been lost in the pitch by venturing too far out on to the lake. The ascent from the lake to the sea, a distance of three-quarters of a mile, is covered with hardened pitch, on which trees and vegetables flourish. Naturally this vast accumulation of asphalt has not escaped the keen eye of the mineral exploiter, and the lake is now being mined. Between 1893 and 1906 no less than 1½ million tons of the mineral have been removed and exported for making roads, pavements, and other purposes. The supply is said to be inexhaustible, and a boring near the centre reached a depth of 135 feet without touching bottom. Nevertheless, in consequence of excavation, the surface of the lake has fallen a distance of 7·1 feet between the years 1893 and 1906. The pitch, in fact, acts as a very slow flowing fluid, and tends to fill up cavities made in it. Indeed, the natural level of the deposit is assumed in a day or so after the removal of the pitch, and so the digging goes forward almost continuously in the same spot. In the course of ages the

Plate 18.—Great Pitch Lake at Trinidad.

Showing the pitch being excavated and loaded into trucks.

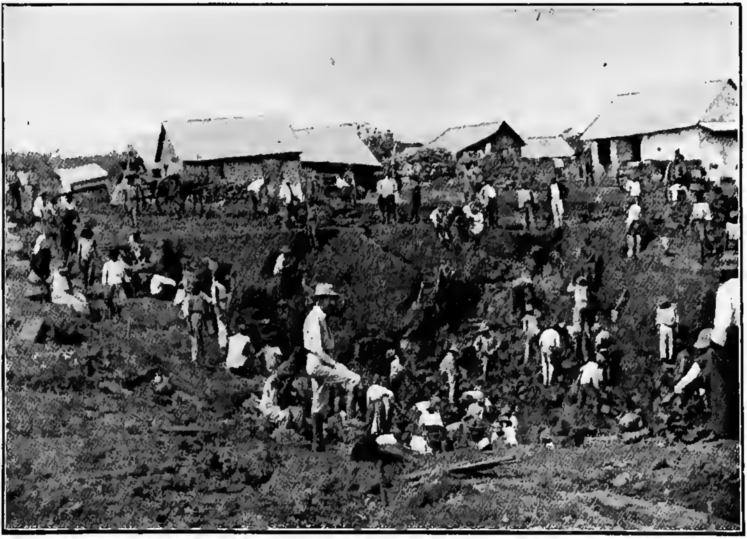


Plate 19.—Village of La Brea, Trinidad.

This is built on pitch, which is shown being dug out by negro workmen.

pitch from the lake has overflown and filled a narrow ravine running in a northerly direction, and upon this deposit in the course of time the village of La Brea has sprung up (Plate 19). The villagers are engaged in breaking up and excavating this pitch deposit, which covers an area of some seventy acres. The lake itself presents the appearance of a dark pavement, with natural furrows running in every direction, forming watercourses, from which the surface drainage extends to an artificial outlet cut in the rim of the lake. The surrounding margin of the lake is covered with rank grasses and palmetto of a luxuriant type, and small islands, dotted here and there, maintain a similar vegetation. These so-called floating islands have been formed either by the accumulation of wind-blown material, or from detached portions of the sides finding their way, by the action of convection currents in the viscid pitch, into different parts of the area. Such flows can be traced at the present time, and these islands are gradually moving to the seat of active excavation. The lake is believed to have been formed by oil flowing for ages from out of the earth, evaporating away, and leaving the solid non-volatile products, which oxidised to form the bitumen.

Mr. Beeby Thompson calculates that there must be at least 10,000,000 tons of pitch in these deposits at the present time, and this represents the residue left from the evaporation of 40,000,000 tons of oil! As the total oil-production in the world is 26,000,000 tons, the reader can form a faint idea of the immense quantity of oil which has been used in the formation of the lake.[1]

The theories to account for the formation of petroleum

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[1] The reader will find a full account of these wonderful deposits in a valuable paper (and discussion) in the *Transactions of the Institution of Mining Engineers*, vol. xxxv (1907–1908), p. 453, entitled "The Mineral Resources of Trinidad," by John Cadman, M.Sc.

are many and various. They may however be divided under two heads, namely, those which derive it from the decomposition of animal or vegetable matter, and those which attribute it to purely inorganic chemical action. Everyone knows that in marshes decaying vegetable matter gives off "marsh gas," which is the same gas which accompanies oil deposits, and is produced by the action of certain minute organisms on woody fibre. Now this marsh gas is the first term of the hydrocarbons of which petroleum is composed, and many authors believe that vast quantities of animal and vegetable matter decomposing under certain conditions, possibly under bacterial action, have given rise to oil instead of passing into coal, which also may be looked upon as a highly carbonised hydrocarbon. Oils are usually found in formations whose geological character shows them to have been at one time the bed of a salt marsh or salt inland sea, and it is believed that it was the remains of untold millions of sea animals, such as fishes and sea-plants, but principally minute micro-organisms such as now swarm in certain gulfs and along certain seashores, as well as in larger pelagic areas, such as the Caspian and Sea of Aral, which mingled with clay and sand formed in the course of time vast deposits of black mud, and ultimately passed into oil. So that the oil we now burn in our lamps may have come from the bodies of live animals which lived millions of years ago, in a strange world in which we should recognise scarcely any resemblance to our modern one. A certain amount of oil is often met with in coal seams, which are undoubtedly of vegetable origin, and this has been held to confirm the organic origin of petroleum.

The inorganic theory to account for the formation of petroleum considers that it is formed by water coming into contact with metallic carbides in the interior of the earth. It decomposes them, yielding various gaseous, liquid and solid hydrocarbons, which constitute petroleum. Moissan, Berthelot, and Mendeléeff have made many experiments to prove that this is possible. Thus, aluminium carbide, C_3Al_4, in contact with water yields methane and aluminium hydrate:—

$$\underset{\text{Aluminium carbide}}{C_3Al_4} + \underset{\text{Water}}{12H_2O} = \underset{\text{Methane or marsh gas}}{3CH_4} + \underset{\text{Aluminium hydrate}}{4Al(OH)_3}$$

Other carbides, for example uranium carbide, yield solid and liquid hydrocarbons. Mendeléeff has shown that iron rich in carbon does actually yield, when treated with acids, a liquid mixture of hydrocarbons exactly similar to mineral naphtha in taste, smell, and reaction. Since very hot water under a great pressure, such as exists in the earth, behaves as a strong acid, and since we have every reason to believe that both metals and metallic carbides exist deep down in the earth's interior, and since we have abundant proof that water does penetrate to such white hot regions—vast clouds of steam are daily ejected by all volcanoes—we have good reason to believe that some at least of the petroleum found upon the earth is derived from this source. "Although the inorganic-origin theory to-day perhaps only counts comparatively few supporters, yet they can boast of world-famed names among their ranks, as also that their opponents have never yet been able to explain satisfactorily both the evident relation of vulcanism and petroleum, and much less the enormous quantities of the mineral accumulated in comparatively small areas."[1]

Sabatier has recently carried out some experiments which lead him to conclude that petroleum is formed in the earth as the result of the action of acetylene gas and hydrogen on the iron, nickel, and cobalt.[2]

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[1] Dr. Sandberg, *Trans. Inst. Mining Engineers*, 1907–8, vol. xxxv, p. 546.

[2] *Loc. cit.*, p. 708.

Possibly since different oils have different chemical compositions, they have been formed in different ways.

We have already described how a gas called *methane* or *marsh gas* (CH_4) rushes out of the ground in oil-districts. We will now give a fuller account of it.

Marsh gas, as its name denotes, is evolved from marshy districts, where it forms part of the ghostly flames which form the "Will-o'-the-wisp" or "Corpse Light," to which so many terrible legends are attached. (Plate 20.)

The Will-o'-the-wisp is now never seen in England, owing to extensive drainage. But formerly it was frequently met with. Thus, so recently as 1855, two travellers were crossing the moors between Hexham and Alston, about ten o'clock at night, when they were startled by the sudden appearance of a light close to the roadside, about the size of a man's hand, and of an oval shape. The light was about three feet from the ground, hovering over moist peat holes, and it moved nearly parallel with the road for about 50 yards, when it vanished. In old times flames were often seen to hover over places where large numbers of men were buried, such as battlefields or graveyards, and hence the legend indicated in the lines of the old rhyme:

"Where corpse-light dances bright,
Be it day or night,
Be it light or dark,
There shall corpse lie stiff and stark."

The inflammable gases (probably containing phosphoretted hydrogen) in this case arose from decomposing animal matter.

These wandering lights were formerly a source of terror to the ignorant, and have often led travellers who have lost their way at night into dangerous bogs, thinking that the light proceeded from some cottage, or was carried

PLATE 20.—The Will-o'-the-Wisp.

Composed of spontaneously inflammable gas evolved from marshy ground.

by a man, a state of affairs described in the well-known lines:

> "Drear is the state of the benighted wretch,
> Who then, bewildered, wanders through the dark,
> Full of pale fancies, and chimeras huge;
> Nor visited by one directive ray,
> From cottage streaming or from airy hall.
> Perhaps impatient as he stumbles on,
> Struck from the root of slimy rushes, blue,
> The wild-fire scatters round, or gathered, trails
> A length of flame deceitful o'er the moss:
> Whither decoy'd by the fantastic blaze,
> Now lost and now renew'd, he sinks absorbed,
> Rider and horse, amid the miry gulf;
> While still, from day to day, his pining wife
> And plaintive children his return await,
> In wild conjecture lost."

Marsh gas, in boggy districts, is being ceaselessly formed by a process of fermentation of cellulose or plant fibre by micro-organisms. Its formation can be easily imitated by placing paper or wood in a flask filled quite full of water, then placing in it some river mud which contains the organism, and allowing the whole to stand for some days. Gas will be evolved and, if the flask be provided with a glass leading tube, may be collected in a glass jar filled with water in the same manner as hydrogen gas.

The gas thus obtained will be found to be colourless, invisible, and devoid of smell. It much resembles hydrogen, being light, and burning with a pale blue flame, forming carbon dioxide and steam:

$$\underset{\text{Methane or marsh gas}}{CH_4} + \underset{\text{Oxygen}}{2O_2} = \underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Steam}}{2H_2O}$$

If mixed with twice its volume of oxygen or with ten times its volume of air (which contains two volumes of oxygen) the gas explodes with great violence. This property has been the cause of many terrible mining accidents. For the gas occurs stored up in coal, being probably formed by a slow process of decomposition going on in this mineral at ordinary temperatures. Reservoirs of the gas in a highly compressed condition are thus gradually pent up in minute cavities, and from these it continually streams out into the mine. Hence besides the danger of being crushed to death by a fall of rock, or immured in a living tomb by an irruption of water, or a fall of rock, the miner has another and often more dangerous enemy to encounter in the noxious gases evolved in coal pits.

Consequently in all modern coal mines the greatest attention is paid to ventilation. By means of huge pumping engines a stream of fresh air is sent rushing through every part of the mine, and thus sweeps away the gas as fast as it is evolved. We may form some idea of the amount of air thus forced in when we learn that in many collieries the ventilating current exceeds 500,000 cubic feet of air per minute, sweeping through miles of galleries at the rate of eighteen to twenty feet a second. The quantity of methane ("fire-damp" is the name given to it by miners: damp corresponds to German "Dampf," vapour) which is poured into the workings of some mines is very large and continually varying. Some seams of coal contain much more than others, and it is not uncommon for a jet of gas to rush out of every hole made in the seam. Thus in the celebrated Wallsend Colliery an attempt was made to work one of the fiery seams, and resulted in a terrible disaster. In his evidence before a committee of the House of Commons Mr. Buddle said, "I simply drilled a hole into the solid coal, stuck a tin pipe into the aperture, surrounded it with clay, and lighted it. I had immediately a gas-light. The quantity evolved from the coal was such that in every one of those places I had nothing to do but to apply a candle, and then could set a thousand pipes on fire. The whole face of the working was a gas pipe from every pore of coal." Sometimes the gas bursts suddenly forth from the coal with a noise like that of rushing waters, or the roar of a blast furnace. These local outbursts are called "blowers." In a single minute they have been known to fill the mine for 1000 feet with an explosive mixture of gas and air. They are not merely dangerous from their inflammable vapours, but also from the pieces of coal which the escaping gas forces from the roof, and whose fall maims or kills the unfortunate miners beneath. As may be easily imagined, old workings or abandoned mines often get filled with the gas, and thus become very dangerous to adjacent workings unless they are completely isolated by stone walls. The immense quantity of gas which was emitted by an abandoned part of the Wallsend coal pit affords a striking example of the danger of such an accumulation. A four-inch pipe was passed from the bottom of the mine to a few feet above the surface of the ground. When a light was brought near a hissing flame roared aloft and burnt night and day for a long time. The pipe poured out in streaming flame thousands upon thousands of cubic feet of escaping gas—enough to illuminate a little town.

The results of a great methane explosion in a mine are indeed terrible. Three or four cubic inches of the gas when mixed with air and ignited detonate like a pistol shot. A cubic foot of the mixture enclosed in a bottle and exploded will shatter the glass, bursting it like an exploding shell. Judge then how terrific are the effects when tens of thousands of cubic feet in the galleries of a mine explode because a miner incautiously strikes a match, or the flame of a safety lamp passes through the gauze which surrounds it. The explosion of a large subterranean powder magazine would not be more terrific. A thundering flame flashes through the tunnels of the mine. It comes out of the darkness with a roar and flies down the main roadways with a velocity far swifter than that of the swiftest railway train.[1] The flame gradually gathers volume and speed, the narrow walls become too small for the rush of expanding gas. The side walls crumble and burst under the sudden strain, while the ground rocks and throws men off their feet. Every man and boy in the pit is stricken cold to the heart at the first murmur of the rolling thunder; for they know that it is the roar of oncoming death. Even the horses, and there are hundreds of them in every large mine, know why the walls and ground shake and vibrate, and in wild confusion men, boys, and horses rush out into the main roadway. The only hope of escape is to get to the shaft, far away down the main artery. As they turn the corner of their little sideroads and reach the main roadway they see the fire rushing down upon them, filling the whole road, a great river of red, blue, and green—for the dust and gases of the shattering roads give it strange colours. They fly before it, horses, men, and boys, shouting, screaming, tumbling one over the other in the narrow passage. The flame comes on swifter than they can run; it reaches them; its strength is demoniacal. It catches them up like straws in a wind and horses, trams, men, and boys are swept before it, being shattered to pieces against the rugged sides of the mine, and crushed into one great heap of wreckage. Very often, however, especially in the old days, the methane burns quietly along the roofs of the tunnels without causing explosion at all. A remarkable scene of this

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[1] Some recent experiments by Dr. Garforth showed that the explosive wave can travel at the enormous speed of 1300 miles per hour! See *Jr. Soc. Chem. Ind.*, July 15, 1913, p. 687.

kind was experienced by Kingsley.[1] He had been visiting a mine to see the sights, and he thus describes the event: "I might have been twenty paces behind the rest of the party when a sudden light started up among them—I can compare it to nothing but a flash of mimic lightning, with this difference, the light flashed up to the roof and assumed the mushroom shape, but it did not disappear. . . . It continued extending and spreading along the roof on every side." All the men rushed panic-stricken from the extending light. There was no difficulty in finding the way, the whole place being illuminated by the burning gas. Looking back, the terrified miners saw the whole gallery "one body of fire—not a bright

FIG. 16.—Explosion in a Coal Mine.—A rush for life.

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[1] *Half-hours Underground* (Daldy, Isbister & Co.), p. 226.

lambent blaze, but lurid, reddish volumes of flame, rolling on like billows of fiery mist." The fire rolled silently forward hardly faster than a man could run. There was no noise or sound of an explosion, one wave of flame tumbling rapidly over the other. Rushing to a lofty passage the men flung themselves on their faces on the ground and awaited the approach of the wall of fire which swept into sight out of the side gallery, sending the glare of its light before it. The flame filled the whole mouth of the side of the gallery from top to bottom, but "when it entered the larger gallery it lifted, just as one sees mist lifting on the mountains, and then rolled along the roof," passing over the men's heads, leaving a space of two or three feet free from flame. They lay under this fiery furnace for some minutes, when it rolled away, eddying, curling, and streaming about the roof.

Rapidly rising, the men rushed down a side passage and reached a well-ventilated part of the mine and thus escaped death by the "choke-damp" which follows in the wake of the fiery blast. Although the flame thus passed quietly over the men, it gathered speed as it went and burst with such violence up the shaft as to blow the roof off the building over it. In bad gas explosions a mighty column of flame and smoke has been known to shoot up the pit-mouth, hurling the buildings situated there into the air with a thunder-like concussion which is heard for miles around.

But you must not think that it is only the methane which is responsible for the terrible explosions which occur in coal mines. For the fine coal dust floating thickly in the air is caught in the advancing flame, burns instantly, and of itself causes a terrible explosion. When we recollect that flour mills have been blown to pieces by explosions caused by the rapid burning of flour dust floating in the air, and that it is dangerous to enter them with a naked light, it is no wonder that coal dust, which evolves far more heat in burning, can also cause and propagate explosive waves. Indeed in modern mines the ventilation is so good that methane scarcely has the chance to collect anywhere in bulk. It now merely starts the explosive wave, and coal dust does the rest. This, however, was formerly not the case and real explosions entirely caused by methane were common. In the year 1856 an explosion took place in the Cymmer coal pit and killed 110 men. In 1857 a similar accident swept 170 men into eternity. In 1858 methane levied a contribution of 215 victims in the coal pits of England alone. In 1866 the fire damp explosion at the Oaks Colliery swept away the appalling number of 361 lives. Naturally, after this elaborate precautions were taken to prevent the accumulation of methane in mines and excellent systems of ventilation were adopted. Yet this did not stop the drain of life. Thus in 1878, 578 men lost their lives, in 1880, 480, while in 1894 a single explosion in a South Wales colliery swept away 290 men and boys. Perhaps the most terrible explosion of all occurred in 1905 in the Courrières mine in France, when 1100 men and boys were killed, and this in a mine quite free from methane! The awful toll of human life has slowly taught men that even when methane is eliminated from mines, explosions will still occur, and that the coal dust floating in the air is the agent which causes them.

And yet, strange as it may at first sight appear, it is not the fiery shattering blast that causes the greatest loss of life. The unfortunate miners may escape being shattered to pieces against the rugged walls of the mine, or being scorched and shrivelled to a blackened mass; for the flames may pass over them if they fall flat on their faces on the ground, rushing above them without harming them.

But the moment they rise, they feel about their faces a mass of red-hot air and dust, and it is as if they have thrust their heads into a cauldron of molten lead.

It scorches and blisters the skin from their faces, and the agony makes them fall writhing upon the ground again. Now it is a curious fact that often the fiery blast rushes along the roof and leaves the air on the ground cool and breathable. The second fall, therefore, may prolong the lives of the miners, but only for a short time. For in the track of the flame comes death, invisible and intangible, not with the roar of thunder and the glare of flame, but silently, stealing through the roadways at the tail of the blast. It is the poisonous "after-damp." Discovering themselves unhurt, the miners who have escaped the blast, rise and rush back, thinking to get out of the pit by another way. All those miners not in the direct path of the blast—sometimes hundreds of men—make a wild rush for safety. But death, too, overtakes them as they go. They begin to feel sleepy and tired as they run. The mysterious, invisible "after-damp" has crept into their lungs, and the men see first the boys fall on their knees and mumble that they are sleepy. The men catch them up in their arms to bear them into safety, and they too fall sleepy, and drop with their burdens into the dust, and fall asleep likewise. Dead, all dead—the after-damp has caught them. They will have no bruises, and their cheeks will be rosy under the black coal dust, their features placid and peaceful. The after-damp deals a painless and easy death. Plate 22 shows men thus killed.

The poor miners caught in an exploded pit thus run two chances of death—one from burning, and the other from being rendered insensible by after-damp. Whether death is caused by the one agent or by the other may be easily read in the faces of the dead. The men killed by the flame are marked with burns and scorching, and their

Photo by Trost.

PLATE 21.—A fifty-thousand barrel storage tank for petroleum in course of construction.

PLATE 22.—Dead miners, overcome by carbon monoxide ("after-damp"), after a coal-mine explosion at Pennycraig.

About 75 % of miners killed in coal-mine explosions die as the result of carbon monoxide poisoning.

features are more or less distorted or disfigured. On the other hand men killed by choke-damp lie as if sleeping, their faces placid, and their clothes unmarked by fire. Of the two death-dealing agencies, the after-damp is the far more deadly. Out of four men killed in a mine explosion no less than three will die peaceably under the influence of the after-damp. For the vast force of the explosion often shatters the galleries and destroys the means of ventilating them. When this occurs there is an end to all hope of safe retreat even for men totally uninjured by the flames. The after-damp formed at once exerts its full effect, and those who cannot rush to the shaft are suffocated. In the explosion at Risca it was found that of those killed no less than 70 per cent. died from the effects of after-damp, men who had not been near the fire at all. In the great Haswell explosion seventy-one deaths out of ninety-five were caused by it. It may be taken as proved that at least 70 per cent. of the deaths in fiery mines are due to after-damp.

What, then, is this "after-damp"? Let me explain. When a gas like methane burns in an abundance of air, it burns to carbon dioxide, thus:—

$$\underset{\text{Methane}}{CH_4} + \underset{\text{Oxygen}}{2O_2} = \underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{2H_2O}$$

But in the depths of mines there is usually not enough air to supply sufficient oxygen for complete combustion, and so another and very poisonous oxide of carbon is formed, called carbon monoxide. Carbon dioxide is not of itself very poisonous, and the percentage formed in the air after an explosion is seldom sufficient to suffocate. It is a smaller percentage of the deadly carbon monoxide produced which does the damage and renders the "after-damp" so poisonous. Before going on, then, to discuss the precautions suggested by science for preventing explosions, I will first of all say a few words about this remarkable gas.

All of you must have read of those terrible tragedies which occur from time to time in every country. Men, yes, and women too, have gone voluntarily to their death because they have found the conditions of life intolerable.

FIG. 17.—Death from carbon monoxide poisoning.

For many centuries on the continent, and especially in France, a method has been practised for passing into eternity which at first sight might strike one ignorant of the science of chemistry as very remarkable. A room is chosen. Every crack in door, window, or fireplace is most carefully closed up. Then a charcoal fire is lighted in the middle of the room, in just such a brazier as you may see in the streets at night when the roads are undergoing repair. The charcoal burns, emitting poisonous fumes. Soon a deadly sleepiness steals over the victim. His head nods, his eyes shut, and he gradually sinks into a deep terrible slumber and passes slowly away. "Ah!" you will say, "the explanation is simple enough. The victim has been overcome by the carbon dioxide evolved from the burning charcoal." But this is not so. People killed by carbon dioxide have been suffocated. They have died not because the carbon dioxide is poisonous, but because of lack of oxygen in the surrounding air. Their blood turns dark purple, the colour of venous blood requiring oxygen, and their faces and lips assume a horrible bluish tint. But look at a victim killed by the charcoal fumes! His lips and cheeks are vivid pink, far pinker than they ever were in life. His blood, too, is not of a dark venous colour; it also is bright pink. We are dealing with no case of suffocation here. The man has not died as the result of the action of carbon dioxide. We are witnessing the effects of another poisonous gas—a substance far more deadly than carbonic acid. What can this gas be? Since it has been evolved from burning charcoal—which is, practically, pure carbon—the reader will at once jump to the conclusion that it is another compound of carbon and oxygen, an oxide different from carbon dioxide. And quite correctly, too. The gas is well known to chemists under the name Carbon monoxide or Carbonic oxide and possesses the formula CO. Its formation in a charcoal fire is also well understood. Indeed it may be prepared in a practically pure state by passing oxygen or carbon dioxide through a long layer of charcoal placed in an iron tube and heated red hot in a fire. The action is as follows: the oxygen first attacks the carbon in the outermost layers, and burns them in the usual way to carbon dioxide, thus:

$$\underset{\text{Carbon}}{C} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Carbon dioxide}}{CO_2}$$

The carbon dioxide then, passing on into the red-hot charcoal, takes up more carbon and becomes carbon monoxide, thus:

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Charcoal}}{C} = \underset{\text{Carbon monoxide}}{2CO}$$

The beautiful blue flames hovering above a clear coal fire are due to burning carbon monoxide produced in this way. Death, therefore, lurks in the gases ascending from every clear fire, though we seldom realise this as we watch the smoke rapidly ascending the chimney from a comfortable red coal fire burning merrily in a grate.

The gas thus prepared, although invisible and colourless, differs very much in properties from carbon dioxide. Thus, carbon dioxide is very soluble in water, but carbon monoxide hardly dissolves at all. Carbon dioxide is a heavy gas, $1\frac{1}{2}$ times heavier than air; but carbon monoxide has almost exactly the same density as air. Carbon dioxide is a dead inert gas which will not burn; carbon monoxide, however, burns with a beautiful blue flame, producing carbon dioxide, thus:

$$\underset{\text{Carbon monoxide}}{2CO} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Carbon dioxide}}{2CO_2}$$

Its remarkably poisonous action depends upon the fact that it combines with the blood in much the same way that oxygen does, turning it a light red colour; and this explains the peculiar pink colour of the lips and cheeks of men who have lost their lives by breathing it. Blood so attacked cannot absorb oxygen and so becomes useless as a means for conveying oxygen into the system. Dr. Leonard Hill thus describes its physiological action:[1]

"Carbon monoxide chemically combines with the hæmoglobin of the blood, and destroys life by robbing

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[1] Lecture delivered at the North Staffordshire Institute of Mining and Mechanical Engineers, January 13, 1908.

the body of oxygen, which is normally carried by the hæmoglobin. The gas is not a poison except in so far as it is an oxygen-robber. This is proved by the fact that animals poisoned by the gas can be kept alive and vigorous on two atmospheres of pure oxygen, for then enough oxygen is dissolved in the blood plasma to maintain life independently of the oxygen-carrying function of the hæmoglobin. If blood be shaken with air containing 0·07 per cent. CO and 21 per cent. O_2, the hæmoglobin is found to be equally shared between the two gases. Thus carbon monoxide has an affinity for hæmoglobin 300 times that of oxygen. When the blood is 20 per cent. saturated with carbon monoxide there occurs dizziness and shortness of breath on exertion. The symptoms are exaggerated by increasing saturation in a very insidious and dangerous manner, there being little sense of discomfort to warn the subject of the increasing failure of his mental and physical powers. At 50 per cent. saturation it is scarcely possible to stand, and the slightest exertion causes temporary loss of consciousness. Exertion by using up the oxygen in the muscles hastens the failure of the heart's action ; there may result degenerative changes in, and lasting weakness of the heart in those rescued from death. It is important to remember that the exposure of the sufferer to cold fresh air aggravates the symptoms, and may be fatal. The heart requires all the available oxygen, and to that end the body must be kept warm by external heat, so that no demand is made on the heat-producing (oxidative) mechanism of the body. The tube from an oxygen cylinder should be allowed to play into the sufferer's mouth for at least a quarter of an hour, and artificial respiration given if necessary. If breathing be re-established properly, all danger from the CO in the blood is over at the end of an hour. Prolonged nursing may be required to steer the patient through the subsequent fatty degenerations of the tissues which may result."

Perhaps the bestway to bring back to life men or animals poisoned by the gas, is to pump pure oxygen into their lungs under pressure. The dying unconscious victims are placed in an air-tight box and pure oxygen gas is pumped in until the pressure reaches two atmospheres. In the presence of so much oxygen animals can breathe gas containing no less than 6 per cent. of the poisonous carbon monoxide. Under ordinary circumstances 0·15 per cent. of this gas in the air is very dangerous, and 0·4 per cent. practically always causes death. What makes the presence of carbon monoxide in air so extremely dangerous is the fact that it gives no indications of its presence until the fatal symptoms begin to appear. For not only is the gas colourless and odourless, but the continuous breathing of such a small amount as 1 part in 10,000 of air may kill the unsuspecting victim. The best test for the gas is a small mouse carried in a cage. This becomes paralysed by carbon monoxide long before a man is affected, and so gives timely warning of the poisonous state of the air.

How many victims have been claimed by this substance in past years will now never be known. The number, however, must be very great. Every case of poisoning by ordinary coal gas is due to carbon monoxide, which is present in coal gas to the extent of 5 to 12 per cent. The gas is produced in large quantities when carbonaceous matter burns in places where there is not sufficient oxygen for complete combustion. Thus after a mine explosion, when a flash of flame sweeps through the underground passages, the coal dust in the air is not completely burnt up and a large amount of carbon monoxide is produced which renders the entry to such exploded pits so very dangerous.

It was carbon monoxide which caused the tragic death of the great French writer Zola in 1902. He and his wife had just returned to their home in Paris after a visit to the country. They dined together and went to bed early, their two little dogs being installed in an armchair in the bedroom. Now unknown to them a fire had been lighted in a stove in their room and through some accident the chimney had become blocked up. The charcoal burning in the limited space began to produce carbon monoxide and dioxide. The gas produced a splitting headache in Madame Zola and she woke up and begged her husband to get out of bed and open the window. He, waking out of an uneasy sleep, at once got out of bed, but the slight exertion caused him to lose consciousness, and he fell in a heap on the floor. Madame Zola then fainted and so could not summon assistance. Next morning the servant knocked on the door. She received no answer. She listened. Within reigned a deathlike silence. Horrified, she summoned the other servants. They assembled round the door and beat upon it. Still no answer. Now thoroughly alarmed they burst it open. A horrible sight met them. Zola lay dead on the floor, while Madame Zola, still faintly breathing, lay in a swoon across the bed. She subsequently recovered, as did the two little dogs.

But a far more terrible disaster than this happened on May 10, 1897, in a lead mine on the Snaefell mountain in the Isle of Man. Somehow or other—the exact cause was never ascertained—some of the timbers supporting the mine roof caught fire late on a Saturday evening when the mine was deserted.

The mass of timber, burning in a very limited supply of air, soon filled the mine with a mixture of carbon monoxide and dioxide. It continued to burn all Sunday unknown to everyone. On Monday morning at 6 A.M.

a band of 35 miners, quite unsuspecting the death which awaited so many of them below, entered the mine shaft and began to climb down into its dark depths. It is easy to imagine the men, each with a little light on his head illuminating the darkness around, steadily climbing downwards, ladder after ladder, laughing and making rough jokes as they went. Suddenly the lower men began to feel peculiar. Everything whirled about them, and they fell one after the other unconscious, until 14 bodies were stretched lifeless on the platforms below. The men still coming down, seeing the fate of those below them, cried out warning to those above, and commenced to ascend for their lives. But the insidious poison now began to work upon them also. Their limbs grew numb and weak, and many fainted and had to be supported by their comrades. Some, indeed, were left behind and were found later in a dying condition. Finally there staggered out of the shaft a few exhausted men who said that the mine was full of some foul gas which made them so weak that they could scarcely climb the ladders. The news that a great disaster had happened spread like wildfire and telegrams were soon flashing all over the country summoning help. Soon rescue parties were on the spot and began to descend and drag out the dead and dying miners by means of ropes. But the poisonous gases began to act upon the rescuers themselves and they too became weak and paralysed and were forced to beat a retreat. Meanwhile the great engines above were driving compressed air into the mine, which displaced the poisonous gases and bettered the condition of the shaft from hour to hour. The rescuers soon descended again and succeeded this time in recovering all the bodies except one which lay at a still lower level. They soon had worked their way down to a platform some 780 feet below the surface, and through a manhole in this they could see dimly the body of the last man lying ten feet below. To view this better one of the miners put a light through the manhole but it went out, showing that the space below was still filled with unbreathable gas. The leader of the rescuing expedition,

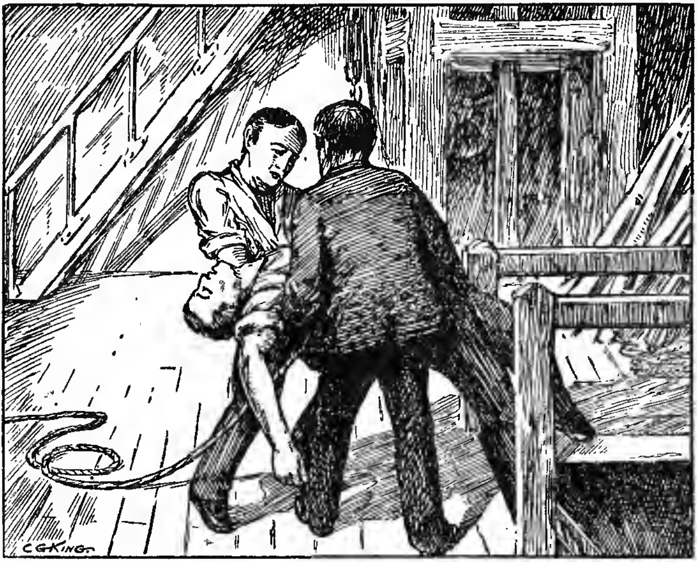

FIG. 18.—The Snaefell disaster—bringing up miners overcome by carbon monoxide.

Mr. Williams, now endeavoured to collect samples of the air below the platform. This he accomplished by holding a bottle full of water under it, allowing the water to run out, and then recorking it. He had already obtained two samples in this way when suddenly, without any preliminary warning, the men above saw him fall unconscious. He would beyond all doubt have perished there and then had he not, luckily, been supported by a rope around his waist. As it was the men dragged his unconscious body by means of this rope up from platform to platform for a distance of eighty feet, and then placed his mouth to a hole punched in a compressed air pipe, and applied artificial respiration. These prompt measures saved his life. Mr. Williams, relating his experiences later, described how first he discerned a strong disagreeable smell arising from below. "My next sensation was indescribably pleasurable, and one which I wished to last for ever, for as it passed away, and I recovered consciousness, I ungratefully said to Dr Miller, 'Why did you not let me die?'" Afterwards a painful headache set in which lasted for some days.[1]

The late Dr. Le Neve Foster, who formed one of the rescuing party, thus describes the paralysing action of carbon monoxide:—

"The poison took effect most suddenly. Everything seemed in a whirl and the atmosphere seemed to be a dense white fog. . . . It is a curious fact that we all sat without moving or trying to escape; the foot of the ladder was close by, yet none of us made any effort to go to it and ascend even a single rung. We none of us tried to walk a dozen steps, which would have led us to the other side of the shaft partition, where we all knew there was a current of better air. We simply sat on and on, rooted to our seats. . . . The general sensation was like a bad dream."

This unfortunate gentleman never really recovered from the effects of breathing such a large quantity of poisonous gas, and a year or two afterwards succumbed to a malady which is believed to have directly arisen from this experience.

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[1] See Foster and Haldane's *Textbook on Mining Chemistry.*

The reader must not look upon this gas as utterly bad. It has its good properties too; like fire, it makes a very bad master but a good servant. For example, it is a splendid fuel, giving forth an intense heat when burning to carbon dioxide, $CO + O = CO_2$. Indeed the fierce heat of many of the furnaces which redden the sky at night of manufacturing districts, is often largely due to the use of this gas as fuel. The avidity with which it combines with oxygen and removes this element from metallic ores makes it a valuable reducing agent for obtaining metals from their ores. Under the name "water gas" it drives many a powerful gas engine, it

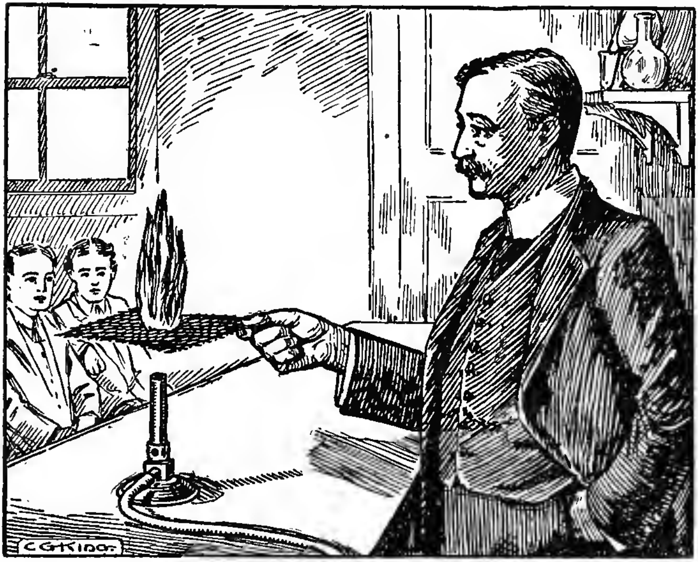

FIG. 19.—Principle of a safety lamp—a flame will not pass through wire gauze.

being in this case produced by driving steam through tall cylinders filled with white-hot coke:

$$\underset{\text{Coke}}{C} + \underset{\text{Steam}}{H_2O} = \underset{\text{Carbon monoxide}}{CO} + \underset{\text{Hydrogen}}{H_2}$$

As thus produced it is mixed with half its volume of hydrogen.

Let us, however, now return to the subject of mine explosions.

Naturally many attempts have been made to overcome the terrors of explosive gases in mines. These attempts depend upon the fact that a burning flame will not go through fine metal gauze. Every gas must be raised to a definite temperature before it will burn. For example, a mixture of methane and oxygen will not inflame below a red heat. Conversely, if the burning gas is cooled below a red heat it ceases to burn. Now when a flame of burning gas reaches wire gauze, the gauze takes away its heat so rapidly, conducting and radiating it into space, that the gas passing through is cooled below the temperature necessary to make it burn. Hence the flame is quenched when it reaches the gauze, only a stream of unburnt gas passing through.

If now we surround the flame of an ordinary oil-lamp on every side with gauze, and introduce it into the midst of an explosive gaseous atmosphere, all that will happen is that the gas actually inside the gauze will take fire and burn, but the flame will not pass through the gauze and set alight the gas outside. This, in fact, is Sir Humphry Davy's celebrated "safety lamp." When the miner armed with this enters an explosive atmosphere the lamp warns him of impending danger by enlarging its flame. A blue light fills the space within the metal gauze, but as if chained by some magic power the flame is unable to pass beyond and ignite the tremendous mass of gas waiting to explode outside. "Just as we view in safety fierce beasts behind their iron gratings in a menagerie, so, too, the miner looks calmly upon his terrible foe imprisoned within its flimsy cage of iron gauze." Yet even this lamp is not quite safe. If the flame impinges too long upon the wire it may render it red hot and this will then ignite the gas outside. Even the rapid motion produced by the swing of the arm when walking may produce explosion. Blowing out the light is likewise attended with danger, as the flame may be driven through the gauze and spread terror and death around. Nevertheless the introduction of the safety lamp has undoubtedly preserved the lives of many miners and

FIG. 20.—Davy's safety lamp.

has certainly prevented many serious accidents. For example, in the Walker Colliery on the Tyne a bore-hole having been made, a roar like the blowing off of steam was heard by the drillers, and a heavy discharge of gas filled the air courses for a distance of 1900 feet. At a distance of a quarter of a mile from the scene of the outbreak a mining official met the rush of foul air and saw the safety lamp in his hand enlarge its flame. He at once drew down the wick and put it out, but his feelings may be imagined when he saw the gas in the lamp still continuing to burn, making the wires red hot and threatening at any instant to pass through and ignite the gas outside. Had it done so a great disaster would have taken place, as there were hundreds of men working in the pit at the time. With a sigh of relief he saw the burning gas inside flicker and go out, leaving him in darkness. Groping his way forward as rapidly as possible, he came upon four men and two boys 200 yards further on whose lamps were rapidly reddening. He shouted warning, and they had the presence of mind to plunge them into water and thus avoid all danger of explosion.

Our ordinary coal gas contains much methane, and is prepared by heating coal in retorts. Heat, in fact, here accelerates an action going on very slowly at ordinary temperatures in coal beds. Besides 30–40 % of methane, coal gas contains 45–57 % of hydrogen, 5–12 % of carbon monoxide, and small quantities of other substances.

Pure methane may be prepared by merely throwing aluminium carbide into warm water.

The usual method of preparing the substance in the laboratory, however, is by heating together in a copper flask sodium acetate and soda lime.

Another very remarkable and important gas is:

Acetylene, C_2H_2. This is also colourless, and it possesses when pure a pleasant ethereal odour, but, as usually prepared, is accompanied by evil smelling impurities. The gas is poisonous and may be easily produced by merely throwing calcium carbide into water:

$$\underset{\text{Calcium carbide}}{CaC_2} + \underset{\text{Water}}{2H_2O} = \underset{\text{Acetylene}}{C_2H_2} + \underset{\text{Slaked lime}}{Ca(OH)_2}$$

In a suitable burner the gas burns with an indescribably brilliant flame, which almost rivals that of the electric arc, and for this reason has been employed for bicycle lamps, and for lighting up places where coal gas is not available—such as small villages, country houses, and railway stations. When calcium carbide, CaC_2, began to be manufactured very cheaply, about 1892, naturally acetylene gas also became very cheap, and some firms began to sell it in a liquid form for illuminating purposes. This could easily be done, for the gas liquefies at the melting point of ice under a pressure of 21½ atmospheres. All this time these men were unwittingly handling a stuff which can explode with a force comparable to that of gun-cotton! A terrible accident revealed this fact to the world. In 1896 at the Paris Works of Raoul Pictet two workmen were handling one of these cylinders filled with compressed acetylene. They were in a building with walls over 30 feet high, situated at the back of the main factory, and separated from it by a courtyard. Suddenly the inmates of the main factory were startled by a thunder-like explosion, which shook the earth and broke all the glass windows in the neighbourhood. Rushing out in a panic a terrible scene met their eyes. The cylinder of acetylene had exploded with incredible force, killing the two men and blowing down the walls of the building in which they had been working. The whole courtyard was strewn with fragments of masonry and broken glass. Near the gasometer was a boiler-house, and the stoker engaged there had escaped by a miracle, although bleeding from cuts caused by flying splinters of glass. Had the gasometer of acetylene gas exploded the consequence would have been far more serious.

Later investigations showed that acetylene compressed to over two atmospheres can be made to explode by a detonating fuse, a sudden blow, or an electric spark,—being, in fact, a very dangerous substance. By explosion it is resolved suddenly into its elements, thus :

$$\underset{\text{Acetylene}}{C_2H_2} = \underset{\text{Carbon}}{C_2} + \underset{\text{Hydrogen}}{H_2}$$

If the pressure is below 2 atmospheres the gas will not explode, but may slowly decompose, depositing carbon in the form of a fine soot, and generating hydrogen. For this reason vessels filled with liquid acetylene are dangerous even when decomposition takes place slowly and not explosively, for the accumulated pressure of the hydrogen generated will finally shatter the stoutest steel vessel. These discoveries killed for a time the rising acetylene industry, and caused much money to be lost by those who had invested their capital in it.

We see, therefore, that an intense chemical energy slumbers in the acetylene molecule, and it is the direct transformation of this chemical energy into light energy which causes the wonderful dazzling brilliancy of its flame. Acetylene is "endothermic." That is to say, there is heat locked up in it, which energy is again set free when the molecule decomposes. This is, in part, the reason why the substance is explosive.

The gas is soluble in about its own volume of water. It is very soluble in acetone, which will take up over 25 times its volume of the gas at 15° C. at ordinary pressures, and 300 volumes at 12 atmospheres' pressure. It has been proposed to use the solution in acetone instead of liquid acetylene, as the solution is non-explosive, and gives off a very large volume of gas.

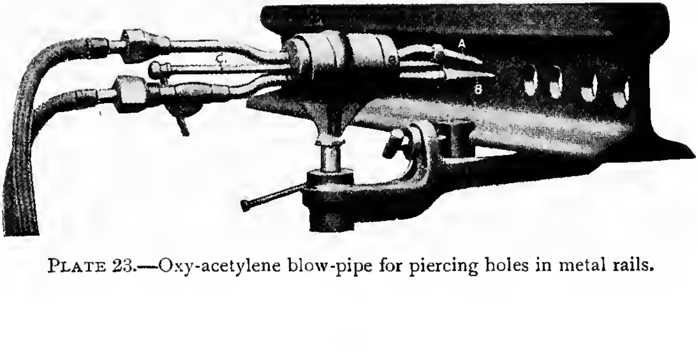

Plate 23.—Oxy-acetylene blow-pipe for piercing holes in metal rails.

Advantage is taken of this fact by the Acetylene Illuminating Co., who employ light steel cylinders filled with a baked porous material. The pores of this material are charged with a known quantity of acetone after the removal of air, and the cylinders are then charged with acetylene under pressure. On opening the cylinder valves the gas is steadily given off until the contents are exhausted. Many motor buses are using these cylinders as illuminating agents, and also railway men who have to work in dark tunnels use them instead of the old petroleum "flares."

Another extensive use of acetylene is its employment for welding and cutting metals. As previously mentioned, a wonderful amount of heat is given out when acetylene gas is burnt, amounting to 14,200 calories per cubic metre, and so an enormously hot flame is produced by using acetylene instead of hydrogen in the oxy-hydrogen blowpipe flame, the best welding results being obtained with 1·6 pure oxygen to 1 of acetylene. The flame thus produced has in its centre a small white cone, at the apex of which the temperature is about 6000° F. (3300° C.). This flame consists almost entirely of carbon monoxide, which is being converted at its extremity into the carbon dioxide. Round the flame is a relatively cool jacket of hydrogen, which, not being able to combine with oxygen at the very high temperature in the immediate neighbourhood of the flame, remains temporarily in the free state, and thus excludes the possibility of oxidation, which makes the flame very suitable for welding. In this flame iron and the most refractory metals melt and run like water and so can be fused together into homogeneous masses.

Another very important use to which the oxy-acetylene blowpipe flame is now put to, is cutting and boring holes in thick iron objects. An oxy-acetylene blowpipe used for the purpose is shown in Plate 23. First of all, through a jet A an oxy-acetylene flame is made to impinge on the piece of iron. The latter is heated to an enormous temperature, and while it is thus heated oxygen from a jet B is made to play on the heated surface. The heated iron catches fire and burns away into molten iron oxide. The jet of oxygen is made sufficiently strong to blow away this liquid iron oxide in front of it, and thus a clean narrow cut is effected through the metal at a speed of travel as rapid as that of hot sawing. The metal on each side of the cut is neither melted nor injured in any way, as the action is too rapid for the heat to spread, the edges thus presenting the sharp and metallic surface of a saw-cut.

The cutting may be made to follow any line, circle or curve. Thus when A and B are made to revolve a circular hole is produced. In Plate 24 is shown the cutting of armour-plate 9 inches thick with the oxy-acetylene flame.

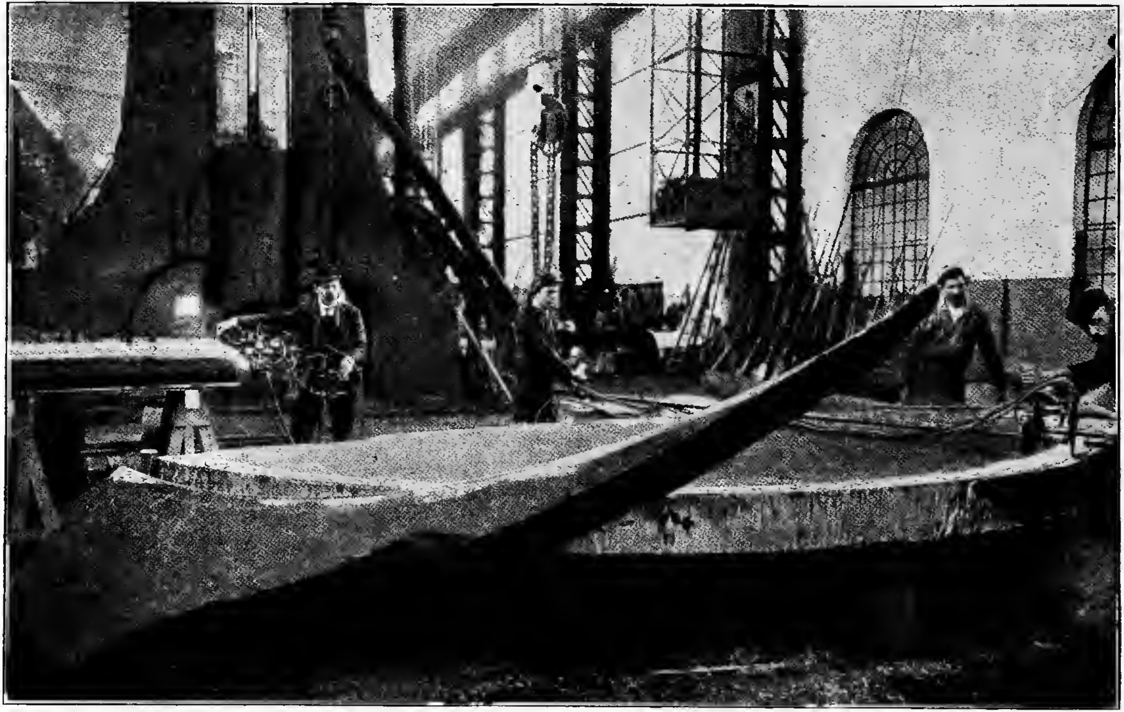

Plate 24.—Cutting 9-inch thick armour by means of an oxy-acetylene blow-pipe flame.

CHAPTER X

THE ROMANCE OF SUGAR

"FAMILIARITY breeds contempt" is an old but true saying, whose truth is strikingly exemplified by the sugar on our tables. We are all perfectly familiar with sugar; we have seen it day after day from our childhood up; we have in our past life eaten, probably, several hundredweights of the substance as part of our food; and yet how few of us have ever thought of the wonderful history of an ordinary lump of sugar? Whence came it? Out of the rushing wind, brought into being by marvellous forces within the living body of a plant, forces which built it up atom by atom out of the invisible gases of the air; and from the plant it has been separated by a curious series of operations which have aggregated its molecules together to form the beautifully crystalline masses so familiar to us all.

The first thing that the curious reader will ask is this: of what is sugar composed? Sugar is made up of three elements: firstly, of carbon, the black element so familiar to us as coal and charcoal, which, when crystallised, becomes a gleaming diamond; secondly, of hydrogen, the strange light gaseous element contained in water; and lastly, of oxygen, the life-supporting element which exists free in the atmosphere around us; of atoms of these three elements, chemically united in certain proportions, is our ordinary sugar built up. There are many hundreds of different sorts of sugars, but in the following pages we shall only be concerned with the one known to us as cane or beet-sugar, whose chemical name is "sucrose." Its ultimate particles, molecules chemists call them, are so small that no human eye has ever seen them, so small that hundreds of millions can be packed into the breadth of an inch; and yet each one of these tiny molecules is in itself a wonder system built up of forty-five atoms—namely, 12 atoms of carbon (C), 22 of hydrogen (H), and 11 of oxygen (O), a fact expressed by chemists by the formula $C_{12}H_{22}O_{11}$.

It must be remembered that the formulae of the chemist represent the molecules as systems in supreme repose, whereas we know that in reality they are systems in swift and intricate motion.

Although for convenience each individual atom in our formula may be thought of as a minute structureless sphere, yet this is far from the reality. The atoms themselves are immensely complex structures, being veritable universes of smaller particles. A single atom of hydrogen, the lightest atom in the sugar molecule, consists, according to the researches of modern physicists, of hundreds of minute particles called "electrons," flying round in tiny astronomical orbits within the atoms, like planets round the sun, with the scarce credible speed of a hundred thousand miles and more a second. So that each of the tiny sugar molecules, although so immensely minute that millions upon millions are aggregated together within the smallest grain of sugar visible to the eye, comprises within its limits a whole universe of smaller particles, consisting, it may be, of some five hundred million moving electrons, flashing round their orbits with the speed of light. Yes, reader, vast forces and furious scarce dreamt-of motions lie concealed within that small lump of sugar that you are so calmly putting into your tea, forces and motions—if modern physicists

Photo, J. White.

PLATE 25.—The home of the sugar-cane—a scene in Jamaica.

are to be believed—gigantic enough to wreck a town if suddenly released, so enormous are the stores of energy inherent in matter atoms. However, it is not this side of the subject which it is desired to treat of here, interesting although such a discussion could be made. What I wish to do is to give you an account of how the sugar finds its way from the air, through the body of a plant, to your breakfast table—a transformation as remarkable as anything fabled in the Arabian Nights, with the additional advantage of being perfectly true.

Sugar occurs in the juices of many plants. The sweetness of apples, pears, strawberries and hundreds of other fruits is due to the presence of sugar of some kind or other. Two plants, however, are the main sources of commercial sugar, namely, the beet—a turnip-like plant which grows very well in temperate climates—and the sugar-cane, a bamboo-like plant which flourishes in tropical lands. Both plants contain about the same amount of sugar, which in the best varieties may amount to 18 per cent. of the weight of the plant.

Let us look at these plants growing in their native lands ; first my reader must take a trip with me over the ocean into a tropical sugar-producing land like Jamaica. There under a blue sky and torrid sun he will see miles upon miles of sugar-cane plantations, all most carefully worked. These sugar-canes grow to the height of several feet with a luxuriance which can scarcely be realised by dwellers in temperate climes. They are planted in rows on low-lying ground, often along the borders of lagoons. There, in the hot moist districts, surrounded on every side by a glorious wealth of green foliage, millions of these tall bamboos spring upwards, and when ripe are cut down and converted into sugar. Every year no less than three million tons of sugar are exported, which represents the destruction of some eighteen million tons of canes. This exported sugar, however, only represents a fraction of that made and consumed on the spot.

What a contrast the cultivated beet fields of Europe make to these glorious tropical gardens! On the plains of France, Germany, Belgium, and Russia may be seen field after field planted with beet, stretching away in dull monotonous reaches as far as the eye can compass, and looking for all the world like English turnip fields. Anyone watching these fields on a warm day in early summer, each covered with innumerable multitudes of little green-leaved plants reposing motionless in the sunlight, could well imagine that he had before him an ideal scene of rustic idleness and lazy enjoyment. A visit to a tropical sugar-plantation immensely strengthens this impression; for there can be seen countless multitudes of tall bamboos, growing in indiscriminate luxuriance, gently waving their green tops in the warm breeze, and apparently basking in idle and graceful inactivity in the scorching rays of the tropical sun. But never was a first impression more utterly erroneous. These plants are not, in reality, in changeless repose; quite the contrary. For even as we watch them they are in ceaseless activity, drinking in the carbon dioxide gas from the air, sucking it in swiftly through every pore of their green leaves, decomposing it by mighty chemical forces at play within the living cell, and turning it rapidly into the sugars in their juices, and later into starch and woody fibre. It is indeed hard to realise that all the sugar that you have ever seen, all the millions of tons lying stored up in the great warehouses of the world, all that in the grocers' shops, and even that now lying in the little sugar basin on the table before me as I write, once floated in the air as invisible gas! Very strange but perfectly true.

Let us examine this wonderful process a little more carefully. The whole of Nature is in a state of mighty cyclic change; this fact is especially manifest in the organic world; for the bodies of all animals, even as they live, are slowly burning away into invisible gases by a natural process of respiration, and the carbon in their bodies ultimately escapes into the air in their breath in the form of an invisible gas called carbon dioxide. This is carried by the wind throughout all the world, and serves as a food for the growing plants; for the sunlight, sweeping earthwards on its giant race through space, strikes the plant and awakens into a curious state of chemical activity the green colouring matter termed chlorophyll, which gives to earthy vegetation its characteristic colour; and lo and behold a miracle is performed; for although man, with his furnaces and strong chemicals, can only with the utmost difficulty decompose the carbon dioxide, the plant working silently in the sunlight does this at ordinary temperatures, absorbing its carbon and setting free its oxygen. The exact nature of the process is unknown, but it is believed that the carbon dioxide is converted first into a substance called formaldehyde, thus:—

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Formaldehyde}}{HCHO} + \underset{\text{Oxygen}}{O_2}$$

But this is only the first of a wondrous series of changes which take place within the living cells; ceaselessly and swiftly the molecules of formaldehyde group together and combine to produce the sweet sugars found in plant juices, thus:

$$\underset{\text{Aldehyde}}{6HCHO} \longrightarrow \underset{\text{A simple sugar}}{C_6H_{12}O_6}$$

Nor is this the end. The simple sugars change to more complex, and our ordinary sugar is produced; and after a time this passes into still more complex substances, such as starch or cellulose, which are stored up in the woody tissue. And thus we see that the carbon atoms in our bodies ultimately find their way into plants, and these being eaten, again restore to us our lost carbon ; so that the carbon in our bodies has gone on circulating throughout the whole world in one vast cycle of eternal change, year after year, age after age, for unnumbered centuries—from air to plant, from plant to animal, from animal to air, in one continual round. Is it not strange to think that the very carbon now in our bodies, or that in the sweet sugar that we eat, once formed part of a plant or animal living a million years ago, ages before the sound of man's voice was heard upon the world? The tiny atoms which build up each particle of sugar can tell a story of their long journey down the ages more wildly grand and more romantic than any story ever conceived by human mind.

Let us now watch the actual manufacture of sugar. We will imagine that we are in a beetroot-growing district of Europe, standing in the middle of a large field. On every side about us we see busy labourers at work. Away in the distance the great buildings and tall chimneys of the sugar factory rise into the air. The time is the end of September, the harvest has been gathered, and now the time has come for turning the beetroots into sugar. The fields are all activity; everywhere are men and horses and waggons; stalwart labourers are digging up the beets, slicing off their green heads (which are poor in sugar, and so are left behind to serve as food for cattle) and casting them into waggons. As each waggon fills off it goes towards the factory, the driver cracking his whip and urging the struggling horses forward over the ploughed field. The factory reached, the waggon discharges its load rapidly into the hoppers of a great washing machine, and then with more shouting and cracking of whips, the waggon rumbles away again to the busy fields to gather in another load.

In the washing machine the beetroots are freed from all dirt and stones and are then cast forth, dripping but clean, upon a moving way which carries them automatically into the open mouths of the hoppers of the slicing engine, swiftly driven by steam, which cuts them up into thin slices and shoots them into a series of tall iron cylinders standing below. Warm water circulating in these cylinders soon extracts all the sugar from them. The water is drawn off and lime added, which neutralises any acids present and precipitates many impurities. Next a stream of carbon dioxide gas is driven through the liquid in order to precipitate the lime, and the turbid fluid is filtered through filter presses. This treatment with lime and carbon dioxide is repeated two or three times and then sulphur dioxide gas (the gas evolved from burning sulphur) is passed into the liquid. This causes a further precipitation of lime and other impurities, and at the same time imparts a clearer colour to the sugar solution. The precipitated solids make very valuable manures, containing as they do much combined phosphorus and nitrogen.

The purified juice is then evaporated until sugar crystals separate. Very simple, you will say. Yes, but before the sugar is obtained in tons at a time in the high state of purity in which it is placed on the markets of the world, it must be worked up by all kinds of complicated and ingenious machinery. The sugar industry, in fact, is a highly technical chemical trade, brought to an extreme state of perfection by competition. Let us now visit the factory itself. We enter a lofty hall and perceive high above us a great machine. Away up, on a little platform, stands a workman, unconcerned amidst the whirl and roar of rushing machinery, the controller of its movements. From the base of the machine comes pouring down a shoot in an incessant stream a torrent of white finely sliced beet. We are, in fact, looking at a gigantic beet-slicing machine, which in a single minute will cut up to thin slices *several tons* of beet.

The sliced beet is poured into great iron cylinders placed below. These cylinders are called the "diffusers" and there are a dozen of them arranged in a circle, while the shoot is brought over each in succession and disgorges into it the dripping mass. When a cylinder is full a brawny workman seizes the iron lid, forces it over the mouth of the cylinder, and screws it down tight. Then he pulls a lever. A stream of hot water from a boiler pours into the cylinder and begins at once to dissolve the sugar out of the beet. This operation is repeated with every cylinder in turn, the hot water passing from one cylinder into the other until it finally issues surcharged with sugar. When all the sugar is extracted from the beetroot in any one cylinder a workman rotates a wheel, and suddenly the bottom of the cylinder opens, and an avalanche of beet rushes forth and drops into a pit below. From here it is conveyed by a rapidly moving chain of buckets into another house, where it is squeezed dry in special machines, and sold as food for cattle. Meanwhile powerful pumps force the hot water containing the sugar through a series of iron vessels, containing lime, and through others where the lime is precipitated by carbon dioxide and sulphur dioxide gases. The purified liquid is forced through layer after layer of cloth contained in filter presses: after which it is pumped directly into the evaporating pans. We enter another chamber to see there a great iron apparatus filling most of the space ; in form it is globular and from its summit an immense iron neck passes upwards and disappears through the wall near the roof. This structure is one of the great vacuum evaporating pans in which the water is boiled away, and a sugar solution is obtained concentrated enough to allow of crystallisation. A closer inspection reveals to us its *modus operandi.* The apparatus is simply a huge retort, with a valve at the bottom, by means of which the juice can be poured out into a vessel placed below. The huge neck which passes upwards is connected to a powerful air pump, driven by steam power, which rapidly sucks out the air from the chamber and creates a vacuum. The sugar solution is forced into the chamber and then heated to its boiling point by driving steam through it. Then the pumps are turned on and a vacuum created. In a vacuum water boils much more easily than under ordinary atmospheric pressures, and so it comes about that the water escapes as steam, leaving the sugar behind. In these large vacuum pans something like three tons of water can be evaporated in a single minute. When the solution is so concentrated that it is about to crystallise, a workman pulls a lever, and away below us out of sight beneath our feet in another room, the bottom of the pan opens, and a steaming mass of fluid sugar rushes headlong into a great iron tank called a "heater." Underneath this runs truck after truck on iron rails, and as each passes beneath the heater a workman pulls a lever and allows the sweet fluid to fill it to the brim. The full trucks empty their contents automatically into centrifugal machines whirling beneath at the rate of 1000 to 1200 revolutions a minute. In these the moisture is thrown out, and the sugar crystals rapidly dried.

It is indeed difficult to realise the magnitude of the sugar industry; for example, in the greatest sugar manufactory in the world, at Wanze in Belgium, no less than 1250 tons of beet are treated in a single day. So extensive are the operations of this firm, and so great is the expense of daily carting these hundreds of tons of beet over miles of ploughed fields to the central factory, that the beets are cut up at thirteen side stations and their juice pumped through pipes, five or six inches in diameter, of a combined length of thirty-five miles, to the central factory, where the fluid is boiled down and the sugar extracted.

The sugar factories are all situated in the country districts and work only two to four months of the year, immediately after the harvest. Every effort is made to shorten as much as possible the time of sugar-making, because the beetroots on storing rapidly lose their sugar, and in some cases are rendered quite useless for working up. The workmen in the sugar factories are, as a rule, employed in agricultural work in the summer months. "The beet-sugar industry," says Ost, "has made Germany independent of foreign countries for an important article of food, and in place of a previous expenditure now represents a considerable source of revenue. But besides this it has had an extremely beneficial effect upon our agriculture. The originally sugar-poor beetroot has, by rational and careful breeding, become so much improved, that instead of the original 5–6 per cent. of sugar, beets are now commonly met with containing 15–18 per cent. of sugar. One acre of land produces in general some 320 cwts. (and sometimes much more) of beetroot, from which 45 to 80 cwt. of sugar are obtainable. In some special cases a single acre has been known to yield some four tons of sugar. This corresponds to a yield of carbohydrate which is not exceeded even by the starch obtainable from potatoes. . . . But not only has the farmer reason to be thankful for increased prosperity resulting from the sugar industry, but also engineers, ironmasters, and builders reap a rich harvest from the materials used in erecting the numerous factories."

Some idea of the magnitude of the industry may be obtained from the fact that each year in Europe, within the short space of two months, some thirty-five to forty million tons of beetroot are dug out of the earth by agricultural labourers, who by this work are kept, with their wives and children, upon the land. These millions of tons of beetroot are carted by hundreds of thousands of waggons and horses (thereby giving employment to innumerable carters, horse-dealers, waggon-makers, wood-merchants, corn-merchants, &c.) to the thousands of factories, where the sugar is extracted by immense machines, marvels of engineering skill, whose construction employs a regular army of engineers and gives a powerful impetus to the engineering trades. Nothing is lost. The dried beet, after the sugar is extracted, goes back to the farmer to feed his cattle, the waste products and precipitates go to the land as a rich manure, and the six or seven million tons of sugar thus obtained as the nett result of these operations speed away by rail and canal to nourish the sugar-using factories, such as the sweet and chocolate makers, the bakers and confectioners; and thus it ultimately passes into food and down the throats of the hungry millions. So agriculture flourishes, thousands of men are maintained in steady employment, and food is cheapened, while the state draws a considerable revenue from the taxation of sugar.

Great Britain at the time of writing, largely owing to faulty legislation, does not manufacture beet sugar; were the people of these islands to make the 1,500,000 tons of sugar they now import, employment would be found for 300,000 labourers, and the industry would act as an agency of rural repopulation, in addition to bringing about a great expansion of the engineering trade in furnishing the necessary plant, and a revival of the sugar refining industry. However, until the economic conditions are fundamentally altered by legislation it seems unlikely that such an industry will take root in the immediate future in this country.

In 1909–1910 the world's total production of beet sugar was 6,700,000 tons. While in the same year slightly more cane sugar, namely 7,800,000 tons, were produced, making in all some 14,500,000 tons. To show the reader what a vast amount of sugar this means, I might mention that if all this sugar were piled up into one great heap it would form a huge mass nearly 700 feet high, 700 feet broad and 700 feet long. Half a dozen St. Paul's cathedrals could be built solid out of it. The pyramids of Egypt would be puny masses compared to such a mass of sugar. If all the sugar extracted by men from plants during the last fifty years were piled up on a square whose side was 700 feet long, the solid pile would be six miles high!

Cane sugar is extracted in much the same way as beet. First the canes are smashed by ponderous slow-moving rollers; then the sugar is extracted by soaking in hot water, and the sugar is obtained from this in the usual way by evaporation after a preliminary treatment with lime and carbon dioxide.

Formerly the sugar plantations were worked by slave labour, and very large amounts of sugar were exported. In 1840 something like £5,000,000 worth of cane sugar was exported from Jamaica alone; then, in consequence of the competition of beetroot sugar, the island industry fell into a bad way. Nevertheless, so rich is the soil and so favourable to growth is the hot moist climate, that, were proper methods of cultivation introduced, Jamaica and the West Indies generally may be restored to their former prosperity. At the present time the amount of cane sugar produced is increasing and great developments in this direction are taking place in Cuba and in the Philippines under American control.

PLATE 26.—Cultivation of Beets for the manufacture of Beet-sugar.

Photo, E.N.A.

PLATE 27.—Group of workers on a sugar plantation, Guadeloupe.

In cultivating sugar-cane the coloured labourers work in the broiling sun, as near to the steaming lagoons as they may safely venture. As the season advances the long rows between the stifling canes have to be hoed; finally, when the crop is ripe the huge mills are set in motion, and all day long the negroes are at work in the field, rapidly cutting down and loading up mule-carts or light railway waggons with the canes. The yards around the crushing mills are scenes of the liveliest animation. The shouting drivers, lashing their mule teams, drive up to the mouth of the hopper, and the canes are bundled with lightning-like rapidity into the crushing rollers. All day long, and often for the best part of the night as well, the mills are at work. Even the hours of sleep are limited to those demanded by stern necessity. And so the work goes on with fevered intensity until the crop is safely reaped and the last load of canes crushed and converted into dripping syrup and shredded megasse (as the crushed cane is called). The reason for this haste is that unless the work is performed with great rapidity the sugar in cane juice undergoes fermentation in the hot tropical climate; the loss from this cause is often very considerable, a delay of a few hours sometimes meaning the spoiling of hundreds of pounds' worth of sugar. The larger factories now bring up their canes from the plantations in railway tracks.

Children have an instinctive love of sweets, which expresses a natural physiological need, as Herbert Spencer pointed out long ago in his notable book on education. "Consider," he said, "the ordinary tastes and the ordinary treatment of children. The love of sweets is conspicuous and almost universal among them. Probably ninety-nine people in a hundred presume that there is nothing more in this than the gratification of the palate; and that, in common with other sensual desires, it should be discouraged. The physiologist, however, whose discoveries lead him to an ever-increasing reverence for the arrangement of things, suspects something more in this love of sweets than is commonly supposed; and inquiry confirms the suspicion. He finds that sugar plays an important part in the vital processes. Both saccharine and fatty matters are eventually oxidised in the body, and there is an accompanying evolution of heat. Sugar is the form to which sundry other compounds have to be reduced before they are available as heat-making food; and this formation of sugar is carried on in the body. Not only is starch changed into sugar in the course of digestion, but it has been proved by Mr. Claude Bernard that the liver is a factory in which other constituents of food are transformed into sugar, the need of sugar being so imperative that it is even thus produced from nitrogenous substances when no others are given."[1]

And now mark the curious philosophy of commerce. Because children love sweet things there has grown up a vast industry to supply their wants. In London alone hundreds of acres of land are occupied by factories engaged in producing sweets in quantities which are simply prodigious. Let us take a peep at a single factory in London. The magnitude of the trade may be realised when we say that in this single factory nearly three thousand hands are employed and about £80,000 are paid weekly in wages. The works cover nearly ten acres of land and use up thousands upon thousands of tons of sugar yearly. In one of the factories everywhere masses of sugar were piled, waiting to be turned into sweets. Down the centre of a great room we saw scores of young women apparently kneading

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[1] Herbert Spencer, in *Education*. (Edition published by Watts & Co., 17 Johnston's Street Court, Fleet Street, London, E.C.)

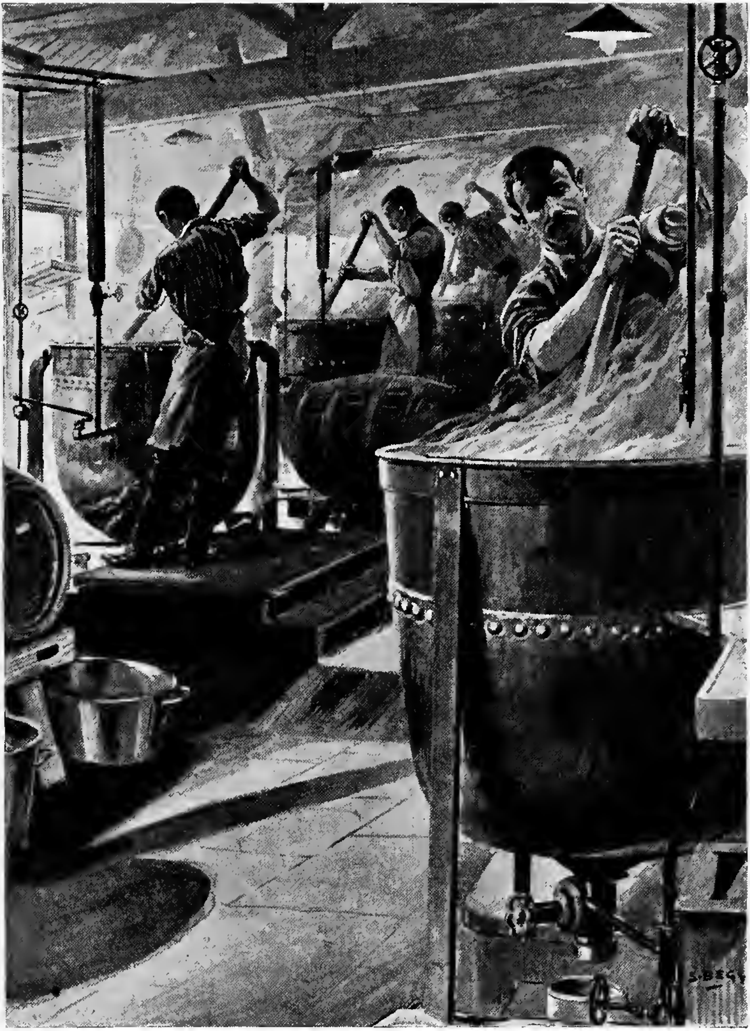

PLATE 28.—Boiling sugar for making sweets at the works of Messrs. Fry & Sons, Bristol.

The sugar is boiled in vessels heated by superheated steam.

dough on long tables. A closer view, however, tells us that what we took for dough was, in reality, a mass of melted sugar, which had been poured molten at a temperature of 160° C. from great copper pots on to the flat surface of the tables, and now was being worked up by hand. From the young women the doughy mass passed to rolling machines, in which it is stamped into little lozenges, which fall out at the other end in a continual shower into a vessel placed to receive them. From this building we passed into another where the process of making jam was in full play. The first room we entered was piled high with baskets of fresh fruit, just as it had come in that morning from the strawberry grounds. Then we passed into a room filled with rows of huge gleaming copper vats, all worked by steam, and all in full blast at the moment we entered. Above each vat, fixed in the floor above, is a shoot down which from time to time a red avalanche of strawberries came rushing headlong, to be engulfed in the seething sugary volcano that yawned below. These vats were kept boiling by jets of steam blown in under pressure, the strawberries all the while being stirred round and round by revolving paddles. From time to time the mass of boiling jam is tipped out into huge tubs to cool; thence it passes to a series of smaller cans, and finally it is bottled. Plate 28 shows sugar being boiled.

Next we were conducted into the caramel room, and there we saw tons of this sweetmeat in the making. Caramel is a sticky substance into which ordinary sugar is converted when heated to 210° C. for some time. And so we went on through room after room filled with humming machinery and busy workers, each room occupied with the manufacture of a different sort of sweetmeat. Here was a liquorice factory in full blast—great boiling tubs of black fluid, curious machines whirling swiftly and ejecting miles of black rope-like liquorice with untiring persistency. There they are making jujubes and turkish delight by the hundredweight, and yonder is a huge factory in which chocolates are being turned out by the ton. In one room we saw them grinding the sugar, by means of powerful crushing machines whirling round at the terrific speed of 2700 revolutions a minute, to a dust finer than any flour. Everything in this room, workers included, was white as driven snow, being covered with a layer of fine sugar dust, which was flying about in clouds.

It may interest our readers to know how sweets are given their characteristic shapes. Three processes are in use—moulding, friction, and stamping. Two kinds of mould are common—the starch and the indiarubber. The first sort is used with the commoner sorts of sweets and consists of a sort of tray filled with starch flour, whose smooth surface is stamped into little rows of hollows into which the molten sugar is squirted through dozens of holes simultaneously from curious looking machines. With the more costly sweets the indiarubber moulds are used. Perfectly round sweets are produced by friction. This is a very interesting process. The sweets are thrown in thousands into huge pans tilted at an acute angle, and revolving at a great speed. We were shown a great room filled with these machines in action. The din was awful, for the sweets as they revolved in the pans were carried up the sides of the rotating vessel, and falling back, set up a continuous rattle. The revolving process sometimes goes on for days before all angles are ground off by mutual rubbing, and the sweets become perfect spheres.

Almost every clime is laid under a contribution for making sweets. From China comes the ginger, from Ceylon are brought weekly hundreds of mats filled with cocoanuts, which are chopped and grated by machinery. It seems curious that, to satisfy a child's craving for something sweet to suck, in the Soudan and Western Africa dark-skinned peoples are busily extracting the gum arabic required for pastilles, lozenges, and other similar sweets. Everywhere there is a smell of sweet flowers; for in order to flavour the sweets fine essences of flowers are used, being obtained principally from the south of France, that paradise of flowers, where large factories extract the sweet scents of the rose, violet, hyacinth, sweetbriar and similar flowers. From Japan and America come the peppermint flavours. Many of these essences are most costly, a small cupboard sufficing to contain bottles of the fine essences of flowers whose contents are worth between £400 and £500.

Many of the machines employed in making sweets are marvellous examples of engineering skill, and are most interesting to watch at work. Indeed the thousands of different sorts of sweets needed by the public can only be produced cheaply and rapidly by machinery, hand labour becoming too dear, if not impossible. The whirling steel arms and wheels are stronger than any human muscles, and crush and squeeze the toughest raw products of the sweetmaker's art into the finest pastes.

CHAPTER XI

THE ROMANCE OF ALCOHOL

THE development of modern civilisation has been closely dependent upon supplies of coal and oil. These two products are, so to speak, the mainsprings which drive the wheels of modern civilisation, and were supplies of them to fail, then also the complex machinery of modern life would cease to run. Without coal or oil not an engine could be driven, and so all our great industrial concerns, which directly or indirectly support the bulk of our population, would suddenly stop. The great iron works would shut down, discharging their millions of hands, and then immediately all engineering operations would cease—for engineering practice is based upon the production of iron, for which coal is needed to reduce the metal from its ores. Much the same applies to oil, on which whole industries are being rapidly founded, using this material as motive power. In fact, it is no exaggeration to say that, failing coal and oil, engines would cease to run, and so communication between town and town, and the transit of goods and people from one place to another would be enormously reduced. Steamers and ocean liners would lie hopelessly at anchor in our ports, and so as regards communication with other countries we would be reduced to our sailing vessels again. In fact, modern industry would be rendered almost impossible without coal and oil, and the world would be reduced to the state of things which preceded the invention of the steam-engine.

Well, reader, the supplies of coal and oil are by no means inexhaustible. Their supply is great but fixed. Once they have been totally extracted from the earth they are irreplaceable. It is quite true that the supplies of these products will certainly last for some centuries at the present rate of supply. Yet the amount of coal mined annually is increasing and will, at the present rate of consumption, be entirely used up in the course of the next 500 or 1000 years—and what is a thousand years in the life of the world? The same applies with even greater force to oil, for many of the old sources of this commodity have already been worked out, or at any rate are not capable of great extension.

The future of our civilisation would therefore appear to be gloomy. There is, however, one much abused chemical which will possibly be the saviour of civilisation in remote days to come—a chemical which, so long as the sun shines and the earth bears vegetation, is producible in practically unlimited quantities.

It is, like oil, a colourless, mobile fluid, which burns with a colourless, very hot flame, and so can be used for heating purposes, for driving motors, and for giving light. Moreover, in addition to its use as a motive power, and for heating and illuminating, this fluid is one of the most valuable of modern chemicals. Upon its use are founded whole industries, and were its production not artificially restricted by intricate legislation, almost every article of commerce, from smokeless powders to photographic films, from lead pencils to straw hats, would be appreciably cheapened. The reader will now be all agog to hear the name of this wonderful and useful fluid, and why the governments of the world should go out of their way to hinder its production in unlimited amounts? In reply I will tell you that the substance has been known as far back as we can go in the history of man; that it is known to savages ignorant of all knowledge of reading and writing; the chemical is in fact—*Alcohol!* Yes, this substance, which has been abused from thousands of pulpits for I do not know how many centuries, which has been forbidden as a beverage by one of the world's great religions, and which, rightly or wrongly, has been blamed for producing a greater amount of misery in the world than any other drug, is most certainly, next to water, the most valuable of all chemicals!

I propose to give the reader a brief account of the manufacture of this substance.

Alcohol was certainly discovered by an accident. When or where is unknown. It was discovered at an epoch so remote that all memory of the event has passed away. It most certainly dates from a time when men had hardly begun to build houses, but lived like wild beasts in holes in the ground or upon trees, and was certainly connected with the discovery of the construction of rough vessels of clay to preserve fluid and water for considerable lengths of time. One might perhaps tell the story of the discovery of alcohol as follows:—Once upon a time there lived a family of savages in a great primeval forest, many many thousands of years ago. In the morning the men went forth to hunt wild beasts, while the women busied themselves with their domestic duties. Now this family had long discovered that the juice squeezed out of fruits made a refreshing drink in the hot summer months. But one day this juice was allowed to stand overlong in its earthenware pots, whereby it altered its taste and smell, and when the men-folk returned home weary and thirsty from their hunting expedition, they called loudly for fresh juice to quench their thirst; for then, as now, men were not content with water for a natural drink,—just as at the present time tea, coffee, lemonade, beer, or similar fluids are invariably preferred to cold water. Indeed, this seems to be a deep-seated physiological instinct, and as such demands the attention of the race philosopher. Once we know *why* men dislike cold water as a daily drink we shall have a valuable starting-point for battling with the great drink problem. And now, to return to our savages, there being no fresh and sweet juice available, the old juice which had stood for some days was put before them. This they drank, remarked on its peculiar taste, grew merry, danced and sang, and finally fell asleep. Next morning, no doubt, found them in vile tempers, complaining of headache, and inquiring what manner of drink had been given them, which first made them merry, then mad, and then sent them to sleep? This, no doubt, was one of many such episodes whereby men became acquainted with the fact that sweet plant juices changed on keeping into a fluid no longer sweet, but which produced intoxicating effects. And so because a hundred thousand years or so ago, some savages drank old fermented fruit juice, at the present time great factories have arisen employing hundreds of thousands of people in every part of the world.

The alcohol industry is, in fact, not only one of the oldest, but also one of the largest of industries at the present time.

I propose to give a very brief account of the production of wine and beer, and finally an account of how the pure alcohol is isolated from its watery solutions and used for industrial purposes.

First of all, let us take the case of wine. If the reader will follow me to the sunny southern lands, such as Italy, Spain, and Southern France and Germany, where the grape flourishes, he will towards the end of October find the vineyards full of men and women, picturesquely clothed, busily gathering in the grapes in baskets. The fruit is conveyed into the factories and there the juice is squeezed out of it. Nowadays in the larger factories this is done by powerful hydraulic presses, but in the old days the grapes used to be thrown into a sort of tub fitted with a false bottom filled with holes, and men and girls, running round and round on the grapes with naked feet pressed the juice forth into vessels placed below to receive it. This juice is called "must." Next the "must" is kept at ordinary temperatures for a few days, and it turns into wine.

There are two sorts of wine, *red* and *white.* If red wine is required purple grapes must be used, and the skins must be left for some days in the fermenting liquid, when the red colouring matter in the skins passes into the liquid and gives it a fine red colour. The liquid is then pressed away from the grape skins and allowed to stand until the process is complete. Purple or red grapes, however, give a white or colourless wine if pressed away from the skins before the fluid has begun to ferment into wine. After the fermentation has taken place, which may last three to fifteen days, the wine, before it is drinkable, must be stored in wooden casks in a cool cellar for a great many months, and sometimes for years.

This change of the grape juice into wine is due to the growth of innumerable myriads of microscopic plants, called yeast, in the syrup. These little plants are present in the air in innumerable myriads, as well as on the grape skins and stalks; consequently they fall into the grape juice and find in it a considerable amount of a sugar called "grape sugar," as well as mineral salts and nitrogen-rich compounds.

These substances form an excellent food for the plant and so it rapidly begins to breed and multiply, and in a very short time the whole of the juice is saturated with them. Now the organism absorbs the sugar as food and splits it up into alcohol and an invisible gas called carbon dioxide. The alcohol and the carbon dioxide must be regarded as the excreted waste products from the body of the microscopic plants, while the sugar forms its food. In other words we must conceive that the yeast plants "eat" the sugar and then excrete it out as alcohol and carbon dioxide, thus:

$$\underset{\text{Grape sugar}}{C_6H_{12}O_6} \xrightarrow{\text{Yeast}} \underset{\text{Alcohol}}{2C_2H_5OH} + \underset{\text{Carbon dioxide}}{2CO_2}$$

How this change is brought about no one has any idea; it is certainly one of those mysterious vital actions which are now being so much investigated. Buchner in 1897, by smashing up the yeast plant by grinding with sand or kieselguhr, showed that in the yeast juice a peculiar substance called "zymase" is dissolved, which when merely brought into contact with sugary solutions causes their decomposition into alcohol and carbon dioxide, without itself, however, being much altered. It is a marvellous substance which is capable of bringing about an almost endless amount of change without itself changing—but the mechanism by means of which it achieves these astonishing effects is unknown even to this very day. Many other "enzymes" (as such substances which thus act without themselves changing are called) occur in the yeast cell, each enzyme capable of carrying out one specific chemical change, and the investigation of these enzymes, whereby living matter is enabled to perform with ease the most astonishing chemical changes, is one of the most interesting provinces of chemistry at the present time. I must also remark that the yeasts which give rise to wine are different from the yeasts which give rise to beer and other alcoholic drinks. In fact, there are almost as many different species of yeasts as there are species of animals, and even among the wine yeasts themselves there are a great many different varieties which give rise to wines of different flavours. Each wine district, in fact, possesses characteristic and distinct races of yeast, and thus it comes about that wine from the same district but from different vineyards, can be readily distinguished by experts merely by the various tastes and bouquets of the wines. Another point I must emphasize is that cane sugar or similar sugars which have the chemical formula $C_{12}H_{22}O_{11}$ are *not* directly fermented to alcohol by the "enzyme" called zymase contained in the yeast. Other enzymes (usually contained in yeast) must first break them down into simpler sugars, thus:—$C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6$, and it is only when this change has been effected that the formation of alcohol begins. As a matter of fact, in grape juice the sugar is already a simple one, $C_6H_{12}O_6$ to start with, and so the fermentation proceeds right away.

The making of beer is a process fundamentally different to the making of wine, for here the starting-point is not the juice of a plant already containing sugar only waiting for the advent of the yeast to be changed into alcohol. In beer we start instead with grain containing a solid white powder called "starch." Sugar is the source of wine, but starch is the source of beer.

Starch in some form or other must be familiar to everyone. It forms the basis of flour from whence bread is made, and in a fairly pure form is used for stiffening linen collars and shirts in laundry work. Starch, however, is a very wonderful, immensely complex substance. Next to cellulose or wood it is the most abundant material found in the vegetable world, existing in all plants with the exception of fungi. It is formed in the plant by the combining or condensing together of simple sugars of the $C_6H_{12}O_6$ type. Starch is born of sunlight and of the gases of the air. First it came into being in the green leaves of the plants; these breathe in the invisible gas, carbon dioxide, contained in the winds blowing round them, and then, by the aid of chlorophyl, the green colouring matter of the vegetable world, convert this gas into simple sugars ; next these condense further and become changed into the complex insoluble starch in certain parts of the plant. Starch forms a migratory reserve food for the growing plant, being transformed by mysterious "enzymes" into soluble sugars, which pass into the sap of the plant, and thence are carried throughout the plant, building it up and appearing at different stages of plant growth as wood and gums. Yes, reader, the stiff, hard wood of the oak tree has once been starch, which has later, by strange processes taking part in the living body of the tree, been transformed from this to wood ; and before it was starch it was sugar, and before it was sugar it was an invisible gas, carbon dioxide, rushing in the winds that blow through the leaves of the tree tops ; and before it was carbon dioxide, who can say where or what it was ? Perhaps the carbon dioxide was breathed forth from the lungs of an animal, perhaps it was belched forth from a great volcano ; and no doubt most of the carbon which goes to form starch and wood and sugar has been circulating for endless ages throughout the world, entering and passing out of the bodies of plants and animals in endless succession ; so that, viewed from this standpoint alone, starch is a truly wonderful substance with a marvellous history behind it.

But our wonder deepens into awe when we begin to understand the complexity of the structure of the tiny molecules of which starch is built up, so tiny that ten million placed in a row would not cover the breadth of your little finger nail. According to Brown and Morris, it has the complex formula, $C_{1200}H_{2000}O_{1000}$, being composed of 4200 atoms all linked together in a most complicated manner. When we reflect that each leaf in a forest contains simply billions of these complex molecules, and that in each of these single vastly complex molecules the atoms are not at rest, but are in eternal motion like the planets round the sun, each performing its own little evolutions in the molecule with enormous rapidity and great regularity, we obtain an inkling of the wonders that we would see in organic nature if we only possessed the means of rendering visible the molecules. Think of it—each carbon atom consists of 20,000 smaller particles, each oxygen atom of 30,000—if modern physicists are to be believed—so that a complex molecule like that of starch may contain well over 300 million electrons—as many particles as exist visible stars in the universe around us!

Such a molecule is itself a universe, and yet each leaf and each wheat grain contains countless billions of them. Nature, when we examine her closely, becomes wonderful beyond all belief.

Before we can turn starch into alcohol, however, we must break it down into simple sugars, and then treat these with yeast.

Now in practice this is carried out as follows:

The grain of barley, containing the starch, is soaked in water. Then life comes into it. The apparently dead, inert grain was only sleeping, and when provided with the necessary degree of moisture, the complicated machinery of life stirs in it. Mysterious forces come into action, and the barley "sprouts." It develops a little leaflet which grows upwards and a little root which grows downwards. This sprouting barley is called "malt," and Plate 29 gives a rather good picture of the "malting floors" on which the process is carried out in practice. Here you will see a vast chamber stretching away over acres, and spread over the floor is the moist barley. It is growing. As a result of this growth, one of those

PLATE 29.—Malting Floor of Messrs. Guinness & Co.'s Brewery in Dublin.

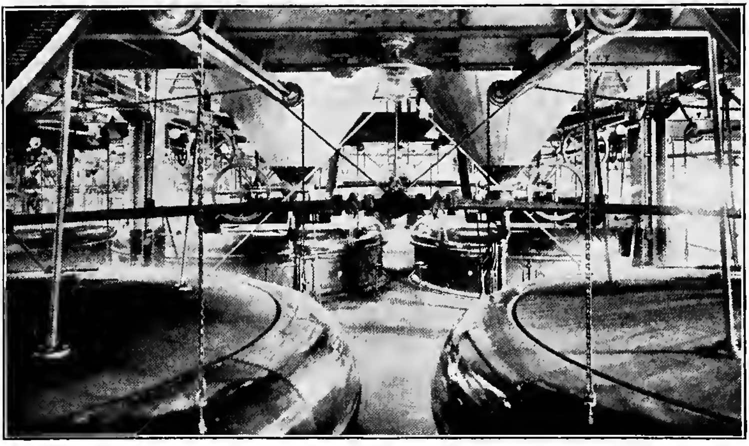

PLATE 30.—Mash Tuns of Messrs. Guinness & Co.'s Brewery in Dublin.

mysterious enzymes, which we have referred to above, now comes into existence in the growing barley grain. It is called "diastase," and has the property of breaking down the complex starch molecule into sugars.

To get it into action, brewers, after heating the malt to stop germination, proceed to mix the ground grain with hot water, when the diastase, which is soluble in water, dissolves out and thus gets a chance of coming into contact with the starch and breaking it down into soluble sugars. This process, called "mashing," is done in great "mash tuns" (see Plate 30) provided with rakes and other apparatus, which stir up the mass to the consistency of porridge, and thus allows the diastase to convert as much starch as is thought proper into soluble sugar. There is thus produced out of the starch a large quantity of a soluble sugar called *maltose*. This has the same formula as cane sugar, viz. $C_{12}H_{22}O_{11}$, but has a different atomic structure. When this mashing process is complete, as it is in the course of a few hours, the solution is run off and drained away from the solid residue of malt. The liquor which has drained away from the malt is sweet, because it contains sugar derived from starch, and it is now known as "wort." In it there is a considerable amount of diastase, which continues the change, and it is necessary to stop this. So the liquor has to be boiled. For this purpose the sweet wort is pumped into large vessels, called "coppers," which sometimes are capable of holding some 600 barrels. Underneath these coppers are furnaces which raise the great mass of liquid to its boiling-point; at the same time hops are added to the boiling liquor, which, mixing with the boiling wort, impart to it a slight bitter taste and form substances which tend to conserve the beer. When sufficiently boiled, the hops and wort are run out together into vessels called "hop backs," fitted with a straining floor, which retains the hops, but allows the liquor to flow off.

Up to this point the liquid is guiltless of intoxicating qualities. It consists simply of sugary stuffs dissolved in water. But now yeast is added, and very soon a great change passes over the sweet liquid as it lies sleeping in the black depths of the great fermenting tuns. The yeast consists of round, almost transparent, living cells, which are grouped together in chain-like clusters. The sugar in the liquor serves as their food. They devour it, and reject from their bodies alcohol and carbon dioxide. When placed in the sweet sugary fluid the cells multiply enormously and soon convert the most of the sugar into alcohol.

The yeast, and also the malt, contains a quantity of another "enzyme" called "maltase" which now acts on the sugar maltose, and breaks it down into simple sugars, as the complex sugar maltose is not itself directly fermentable into alcohol; this it does, thus:

$$\underset{\substack{\text{Complex sugar,}\\ \text{called maltose}}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} \xrightarrow{\text{Yeast}} \underset{\substack{\text{Simple sugar,}\\ \text{called dextrose}}}{2C_6H_{12}O_6}$$

Once this breakdown of the complex sugar is achieved, the enzyme "zymase" contained in the yeast cells gets to work and converts the dextrose into alcohol, as was explained above, under Wine, the reaction being this:

$$\underset{\text{Dextrose}}{C_6H_{12}O_6} \xrightarrow{\text{Yeast}} \underset{\text{Alcohol}}{2C_2H_5OH} + \underset{\text{Carbon dioxide gas}}{2CO_2}$$

Let us now visit a brewery. Enormous quantities of carbon dioxide gas—a suffocating heavy gas—are evolved. It is this gas, dissolved in the beer, which imparts its sharp, brisk taste, and causes it to effervesce when removed from the bottle. Fermentation, indeed, is a turbulent process. As it sets in, the smooth black surface of the immense volume of liquid begins to change. It becomes covered with a scum of foamy bubbles, and in a short time the whole looks like a huge wash-tub full of creamy soap-suds, breaking and seething in restless foam. It is the carbonic acid gas liberated from the ferment which thus puffs up the surface into a mass of foam. If the reader will now put his head into the space and take a breath, he will start back. For the heavy unbreathable gas catches his throat and produces a feeling of momentary asphyxiation. Indeed many fatal accidents have occurred in breweries by men venturing incautiously into fermenting tuns which, unknown to them, are full of the heavy unbreathable gas. Entering, they are overcome, and fall in a senseless heap upon the floor, and if help is not immediately forthcoming, death ensues.

After the fermentation is completed in the tuns—which requires a period of two or three days—the beer is pumped into large open tanks for the purpose of cooling, and also for skimming off the yeast, which during fermentation reproduces itself some fifteen times in amount. As soon as the liquid is sufficiently cleared of yeast, pumps are set into motion and the liquid is speedily driven into great vats. After maturing in these the liquid is drawn off into casks and exported. So much for beer.

Let us now obtain a glimpse of another part of the alcohol industry, namely, the manufacture of spirits, such as whisky, brandy, potato spirit, &c.

But let us first explain the difference between drinks like beer and wine, on the one hand, and spirits like Scotch whisky on the other. Beer or wine contains only small amounts of alcohol, the fiery spirit which causes intoxication being dissolved in the watery matter. Strong beer, for example, may contain only 3 per cent. of alcohol.

In whisky or brandy, however, the percentage of alcohol is very much higher. It is prepared by heating a fermented liquid like beer. The alcohol boils at a lower temperature than the water with which it is mixed, and consequently boils off before the water. Its vapour is collected and condensed again and forms the spirit.

For making Scotch whisky the initial procedure is very much the same as in making beer. First the barley is moistened, spread over floors, and allowed to germinate. In so doing the starch in the barley is converted into sugar by means of the ferment diastase. Then the "malt" so produced is heated in the smoke arising from peaty fires burning underneath, which kills the growth and gives the malt the peculiar flavour recognisable in the taste of Scotch whisky. After which the fermentation is carried out with brewers' yeast just as in the case of beer. Then the liquid, now rich in alcohol, is pumped into the stills. These are great copper pots which taper upwards with a neck which bends at right angles about 15 feet from the base of the pot. Underneath the still is a furnace (in some patent stills the heating is done entirely with steam) and the liquor in the still is soon heated to boiling. The alcohol boils off before the water, and the vapour, passing away up the neck of the pots, finds its way along a pipe which connects the top of the still with a series of spiral pipes (called the "worm") which are enclosed in a large wooden vessel outside the building. A stream of cold water is continually running through the vat, and the alcohol vapours passing down the pipes in the cold water are by this means condensed to a liquid form and runs into a receptacle called the "safe." The liquid so obtained is very impure and must be redistilled before it is fit to drink. The Scotch whisky thus obtained is usually blended with other sorts of drink, and often contains over 60 per cent. of alcohol, In Germany enormous quantities of alcohol are manufactured from potatoes. The potato, like barley or wheat, consists principally of starch, and by the action of diastase this can be broken down into sugars, which can then be fermented by yeast into alcohol and carbon dioxide. The potatoes are placed in boilers and maintained under a steam pressure of 3–5 atmospheres. Then the valves are suddenly opened, and the steam, rushing roaring forth, relieves the internal pressure. Then the steam in the potatoes bursts explosively forth and reduces all the potatoes to a mash. This is run off into another vessel, diastase added, and the starch converted into sugar. Then brewers' yeast is added and the sugar is fermented into carbon dioxide and alcohol. The liquid is then heated in ingenious stills, and a practically pure alcohol is obtained so cheaply that it can be used for driving motor cars, just as oil is used in this country.

Indeed, were it not for the revenue duties, pure alcohol could be manufactured at the ridiculously low price of 4*d.* to 6*d.* a gallon.

I must now say a few words about the production of alcohol from wood. Wood is by far the most abundant material in the vegetable world, and therefore could we convert it directly into alcohol in an efficient manner it would form the cheapest supply of this material. Wood is simply a condensation product from starch, and like starch can be broken down again into sugars. Now this can be done in a great many ways. In one process the wood is treated with concentrated sulphuric acid, when it swells up and dissolves to a paste-like compound called amyloid, which is precipitated by water. If much water be added to the solution and the whole is heated in a boiler to 120° C., the wood is converted into a simple sugar called dextrose (also produced from starch, as above described, in the making of beer), and on neutralising the acid and adding yeast the sugar may be fermented directly into alcohol. Another method is to heat the wood directly with dilute acid in a boiler to a very high temperature, when it splits up into sugary solutions.

However, in 1913, a notable advance was made by Willstatter and Zechmeister,[1] who showed that a very strong solution of hydrochloric acid gas in water (40–41% HCl) will, at ordinary temperatures, completely convert cellulose (*i.e.* wood) into dextrose—a simple sugar—in 24 to 48 hours—a discovery which may lead to the direct conversion of wood into alcohol on an enormous scale.

Although wood has actually been turned into alcohol by these processes, yet the methods are not so economical as those described above, where alcohol is produced by the breakdown of starch. However, seeing what enormous supplies of waste wood are at the disposal of man, if only economical methods of carrying out the conversion of wood into sugar could be found out, no doubt a great industrial revolution would be effected and technical alcohol would become one of the most abundant of all chemicals.

Let us now treat of some of the peculiar properties of this alcohol. Most people only know of it as a poisonous substance which, taken in excess, causes such misery among wide sections of the people. Few people, however, are aware of the fact that alcohol in its pure state is one of the most useful and commercially important chemicals in existence. Undoubtedly next to water it is the most valuable liquid known, and it is the purpose of this article to give some account of the uses to which the substance can be put, and to show what an immense benefit to industry in general would flow from the re-

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[1] Ber. 1913, **46**, 2401–2412.

moval of the enormous duty now placed on alcohol, which causes it to be such an expensive product.

But now I hear my readers beginning to make objections. I hear them say, "If alcohol was made so cheap that for fourpence or sixpence a whole gallon could be bought, would not drunkenness increase to a frightful extent?" Well, it must be confessed that the question is a very difficult one. In most countries where alcohol is allowed to go practically duty free for industrial purposes, laws are generally in force which compel the manufacturers of such alcohol to add to it substances which render it unfit for drinking, and which, moreover, are very difficult to remove. Such chemicals, however, often spoil the use of alcohol for the manufacture of many substances in which it is most important that the alcohol should be pure. At present the question of how to ensure that duty-free alcohol should only be employed for industrial purposes is more or less unsolved. It may be that education in early youth against the evil effects of spirit-drinking may do something towards the solution of the problem, although even this is very doubtful. Leaving this question, therefore, as it is, let us go on to examine the industrial effects which would follow the removal of the enormous duty which is now levied upon the substance, and which so inflates its cost of production. Industrially alcohol is widely used as a solvent. Substances which will not dissolve at all in water often dissolve freely in alcohol. Thus it is used to dissolve shellac; and shellac varnish, as well as the innumerable colours which are mixed with it, is extensively employed all over the world for painting purposes. Shellac varnish, in fact, enters extensively into the manufacture of furniture and all kinds of wood-work, such as carriages, electric trams, pianos, trunks, umbrellas, and other articles too numerous to mention. It is safe to say that hundreds of thousands of pounds of shellac are used up in this way, and the best solvent for the substance is this very alcohol. Shellac is employed in the most unexpected places. For example, in manufacturing lead pencils, it is shellac dissolved in alcohol which holds together the moulded graphitic powder; in making electrical machines, from the vast dynamos which whirl in the electric-lighting stations to the smaller motors which rapidly and powerfully drive the tramcars through the streets of a busy town, shellac enters largely; all the copper wires conveying the current are usually painted over with this shellac, which forms a splendid insulator. Even in hat-making we find it; for shellac dissolved in alcohol imparts stiffness to silk and straw. Consequently a reduction in the price of alcohol would lead to a reduction of all these articles, ranging from furniture to lead pencils, from electric motors to top hats—so complex are the ramifications of modern industry! But stay, we have not finished yet. What about our beds, the brass parts of which are covered with shellac varnish? For this substance is commonly used to coat polished metal-work in order to preserve its lustre. So that such articles as brass bedsteads, gas or electrical fittings in houses, lamps, clocks, musical instruments, toys, and all the thousand and one articles employed in our civilisation would thus benefit from tax-free alcohol. Even billiard balls, piano and organ keys, dolls' heads, paper-cutters, and similar articles, would become cheaper, because they are made from celluloid, which can only be produced through the solvent power of ether (which is made from alcohol). Photographs would become cheaper. For the films and photographic papers contain collodion, which indirectly uses up large quantities of alcohol in its manufacture. Millions upon millions of pounds are annually expended on these photographic processes, and enormous amounts of alcohol are annually used up in their manufacture. Were alcohol much cheaper, not only would illustrated papers and books become cheaper, but even the price of the photographs hanging on your walls would be reduced.

Thus, dear reader, you have perhaps never realised how deeply alcohol is related to our civilisation, how it enters into almost every trade and industry in some form or other, and this quite apart from its use as a drink.

The artificial inflation in the price of alcohol by Governments for revenue purposes has actually hindered whole industries from developing in this country. Thus the manufacture of smokeless powder requires large amounts of alcohol, it being calculated that each ton of smokeless powder produced involves the use of nearly a ton and a half of alcohol; and as this latter product is most heavily taxed, naturally the price of the former product is greatly increased. It is the tax on alcohol which has kept the old black powder alive. In the production of artificial silk, to mention another industry, alcohol is almost a necessity, and yet its high price makes the artificial silk far more costly than it would naturally be. Ether and chloroform, valuable anæsthetics which have relieved millions from horrible sufferings, are made directly from alcohol, and with its reduction in price the first cost of these chemicals would come down to such an extent as to allow their use in different industries as solvents.[1] Indeed these bodies are, apart from their use as anæsthetics, one of the most useful solvents for certain classes of goods. Again, directly and indirectly, alcohol enters into the constitution of innumerable artificial dyes, and one of the reasons why the manufacture of this vast branch of science languished for many years in this country while it flourished abroad was simply

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[1] Chemical research is much retarded by an enormous duty levied on ether. The whole duty only produces a very little money, and yet the retarding influence of the tax is very great.

owing to the tax on alcohol, which rendered for many years the manufacture of many fine chemicals impossible in England. The loss in employment and money was enormous, and has been calculated as running into twenty or thirty million pounds yearly.

We are all aware that alcohol burns. We have a familiar illustration of this fact at Christmas time when the plum puddings are brought in covered with blazing rum or whisky, whose blue flames cast a ghastly glare over the darkened room. Yet few of you are aware that alcohol may, provided it be only made cheap enough, be used as an illuminating and heating agent. Abroad in Germany and Belgium innumerable heating stoves and lamps are in use in which alcohol is burnt as a cheap and efficient fuel. Of course since alcohol burns with a non-luminous flame it cannot be used directly for illuminating purposes, like a candle or oil-lamp flame, for example. But in these days of incandescent mantles this presents no difficulty. The hot non-luminous flame is merely made to impinge upon a suitable mantle, and instantly there shines forth a pure white light which quite equals that produced by the burning of coal-gas used in connection with mantles.

Before leaving this subject, however, I must say a few words about a very curious substance that has been used of recent years as a fuel. This is "solidified alcohol" or "Smaragdin." It is sold in small solid cubes, and consists of alcohol with the addition of a little ether, which together dissolve a small amount of gun-cotton or collodion. This sets to a jelly-like solid, which will keep for a year or more if confined in a closed vessel, with only little loss by evaporation. This fuel burns quietly, leaving no residue. It can be burnt in any non-combustible receptacle, and so can be used for heating where no alcohol burner is available. From this, or modifications and improvements of the substance, no one can tell what undreamt-of industries may arise on alcohol as a basis, provided only that methods could be invented for making it extremely cheaply.

In Germany alcohol has been actually employed for driving engines and motor-cars, just as gasoline is in this country and in America. In Berlin a few years ago could be seen taxi-cabs running about which were driven by alcohol derived from potatoes, but the cheapened supply of motor spirit has now spoilt this use of alcohol. In the remote future, however, its use for this purpose will increase ; for it must be remembered that the supplies of petroleum are strictly exhaustible. Many of the oil fields of America are completely played out, and a time will surely come when, as the supplies diminish, the price of the oil will go up, until at last it will become cheaper to employ alcohol as a motive power. When this time comes agriculture and farmers generally will benefit enormously. For alcohol is ultimately derived from the soil, being produced indirectly from sugary or starchy matters occurring in plants of all kinds, and in an exceptional degree in potatoes, turnips, wheat, barley, &c. Even wood (cellulose) can be turned into alcohol.[1] The production of alcohol, therefore, ultimately rests with the farmer, and thus maintains in the agricultural districts a regular army of stalwart agricultural labourers engaged in tilling fields. But even more important cosmic questions loom in the distance. For alcohol is indirectly produced by sun power bottled up in the growing plants, and as long as the great sun continues ceaselessly to pour out through space its enormous flood of energy in the form of heat and light, so long will alcohol be available to man as a motive heating and illuminating power.

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[1] See p. 255.

CHAPTER XII

THE ROMANCE OF COAL-TAR

"ROMANCE of coal-tar?" I seem to hear my reader exclaim as he reads the heading of this chapter, "What romance can there be in connection with such a black, messy, evil-smelling substance?" Well, I will mention one fact in connection with it which seems to me as strange as any romance that I have ever heard of. Is it not wonderful that the bright colours which dye our carpets, our furniture, our clothes, once formed part of a plant or animal living millions of years ago, the product of the stored-up sunshine of warm summer days of ages gone and forgotten æons of years ago? Yet this is so, for these dyes were all made from coal-tar, which in turn was made from coal, and coal is but the decayed remains of vast masses of vegetation, choking up great swamps with their luxurious growth in a primeval world which ceased to exist some eight million years or so ago! Yes, the very atoms in these modern colouring matters, in modern perfumes, medicines, explosives, and scents, once coursed in the bodies of the living organisms of those far-off ages, and before that, as an invisible gas, carbon dioxide, in the rushing winds of a world which was in existence long before the sound of human voice or even that of animals broke the silence of the primeval forests.

There is therefore romance and to spare in the black, ill-smelling coal-tar, for it has behind it a very wonderful past. But it is not the romance of its past history that I am going to relate in this chapter. There is still another romance in connection with it which seems to me every bit as strange as the other. For out of the black coal-tar an immense industry has arisen. From it are now extracted in huge factories innumerable products of the greatest commercial use and importance—beautiful colouring matters, some as delicate as the rose tint in a young girl's cheek, others as gorgeously brilliant as the colours which glow on tropical flowers and birds, or which paint the morning and evening skies with indescribable glory; powerful drugs, whose effects as sleep-producers, fever-abaters, antiseptics, and stillers of pain, have placed in the hands of doctors weapons which have relieved the sufferings and saved the lives of untold numbers of men, women, and children; explosives of terrific power; delicious perfumes; chemicals hundreds of times sweeter than any sugar that you have ever tasted—all these things, and many more, have been extracted by the magic power of chemistry from the evil-smelling black fluid floating in the tanks of tar distilleries and gas-works!

For a long time after the coal-gas industry had commenced the dirty coal-tar was regarded as a positive nuisance by gas manufacturers. No one knew what to do with it. Its removal often involved the manufacturer in considerable expense, and it is on record that two men who carried on in those early days the distillation for the purpose of extracting an oil from it, were given the tar free on condition that they removed the substance at their own expense. Sometimes it was simply thrown away! But all this is now completely changed; it is now a most valuable substance, and from it are extracted such a host of things that it even moved *Punch* to wonder:

"There's hardly a thing that a man can name
Of use or beauty in life's small game
But you can extract in alembic or jar
From the 'physical basis' of black coal-tar—

Oil and ointment, and wax and wine,
And the lovely colours called aniline;
You can make anything from a salve to a star,
If you only know how, from black coal-tar."

Coal-tar is, as you all know, a by-product obtained in the manufacture of coal-gas. The coal is heated in large iron tubes or retorts, and there it is decomposed into a great number of different substances, among which are gas, watery fluids rich in ammonia, tar, and coke. The gas passes over into the large gasometers, while the coal-tar and ammoniacal liquors are caught in the "tar-wells."

The coal-tar distilling industry commenced with a tragedy, whereby a young and promising life was cut off at the very threshold of an opening career. It had been known for many years previously that when coal-tar is heated an oil distils over, which can be used for illuminating or heating purposes, and which is known as coal-tar naphtha. So long ago as 1825 the immortal Faraday had obtained from it pure benzene. Hoffmann, a clever young German chemist, who had been called in from Giessen to conduct the then recently opened "College of Chemistry" in London, set, in the year 1848, a young Englishman called George Mansfield to distil this coal-tar naphtha in large quantities. Mansfield in a brilliant investigation soon proved that the naphtha contained a great many bodies, which he, by most laborious work, succeeded in separating one from the other. Among these bodies may be mentioned the oils benzene, toluene, xylene, and the solids phenol (carbolic acid), naphthalene, anthracene, &c.

Mansfield foresaw the important commercial results which would result from the use of these substances as raw products, and, after spending a few years investigating them he began to erect plant for distilling the naphtha on a larger scale than had been previously attempted. All went well at first until one day he observed that the liquid was boiling too rapidly. He tried to reduce the fire, but alas! too late. The oil began to boil furiously, and came pouring forth out of the still on to the floor. Had Mansfield at once run out of the danger zone all would have been well, but he remained, and as he was endeavouring to remedy matters, suddenly the liquid caught fire. A roaring mass of flames shot upwards from the blazing oil, and in an instant enveloped the unfortunate man. Speedy assistance was at hand, but it came too late. He was carried away, and died a day or so later. Thus perished miserably one of the founders of the great coal-tar industry, a trade in which to-day hundreds of millions of pounds are invested, and

FIG. 21.—Death of Mansfield.—Burnt to death in Holborn, London, while distilling coal-tar in 1855.

hundreds of thousands of men kept employed, throughout the whole civilised world. Mansfield's processes did not, however, perish with him, and at the present time, some sixty years after his death (1855), they are still in use, with scarcely a change. But since his day the industry has grown enormously; in England alone there are now distilled annually some 400,000 tons of coal-tar. Mansfield's primitive stills have grown into stills of giant size, often occupying the whole of a lofty building, rising several stories above the earth. The immense body of the still, often holding thirty or forty tons of fluid, occupies the basement of the building, while the neck and condensing columns extend upwards, sometimes to the very roof. We must now say a few words about the products obtained in the systematic distillation of coal-tar. These are many and various. At first, at moderate temperatures, there distil over oils like benzene (so well known to the housewife for cleaning purposes) and toluene. At higher temperatures, substances like phenol (carbolic acid), naphthalene, anthracene, and heavy lubricating oils come over; while there remain behind in the still pitchy substances which are used for making black varnishes and lacquers, for burning as a patent fuel, for preserving timber, and for making dust-free roads.

Let us now see how the oils benzene and toluene, so obtained, are changed into dyes and perfumes. First of all, these colourless fluids are converted into "nitro-bodies," by allowing very strong nitric and sulphuric acid to act upon them. For this purpose the benzene is pumped away into a series of cast iron cylinders, contained in a separate outhouse. The cylinders are provided internally with cast iron arms, which are made continually to revolve and stir up the liquids inside, while externally they are covered with a flowing stream of cold water, which by its cooling effect moderates the violence of the reaction. The benzene having been introduced, a fine stream of a mixture of strong nitric and sulphuric acids is allowed to flow slowly in, until after some ten hours or so the operation is complete.

The following reaction takes place :

$$\underset{\text{Benzene}}{C_6H_6} + \underset{\text{Nitric acid}}{HNO_3} = \underset{\text{Nitrobenzene}}{C_6H_5NO_2} + \underset{\text{Water}}{H_2O}$$

If toluene is used :

$$\underset{\text{Toluene}}{C_6H_5CH_3} + \underset{\text{Nitric acid}}{HNO_3} = \underset{\text{Nitrotoluene}}{C_6H_4(NO_2)CH_3} + \underset{\text{Water}}{H_2O}$$

In the early days of the industry these operations were attended with considerable danger, and even now accidents are far from rare ; for unless the cooling machinery is carefully controlled, and the interior liquids kept stirred the whole time, the chemical action may cause local heating, and the liquid may inflame, and a sheet of fire, shooting upwards, may start a great conflagration. Indeed, the "nitrotoluene," produced in the same way from toluene, has been known to explode with terrific violence. Only a few years ago, in Manchester, a tank of nitrotoluene blew up, luckily at night-time, when no one was in the neighbourhood, and completely wrecked the house in which it was situated.

Far more serious, however, was an explosion in 1914 at Rummelsburg, near Berlin, where a whole factory engaged in making nitrobenzene blew up with fearful force. The building was completely wrecked, huge iron staircases and heavy machines being blown right into the air, and practically everyone in the working parts of the factory perished.

Between thirty and forty people met their death, and as these included everyone actually engaged in the work, the exact cause of the explosion will now never be elucidated. However, it is supposed[1] that a workman

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[1] See the *Chemiker Zeitung*, April 25, 1914, p. 537.

allowed the mixture of strong nitric and sulphuric acid to flow into the cylinder containing the benzene, and forgot to turn on the stream of cooling water. Somehow or other a large quantity of acid collected underneath the benzene, and as soon as the stirring arrangement was set in motion a violent action took place, the boiler got powerfully heated, and the great pressure set up by the benzene vapours and the nitric acid fumes caused the boiler to explode with fearful force and wreck the whole place. Possibly higher nitrated bodies than *nitrobenzene*—such as *dinitrobenzene* and *trinitrobenzene*—had also been produced by the prolonged heat of the acid, and these themselves are explosives, and even may have caused the explosion. The vast masses of highly inflammable benzene and nitrobenzene, blazing fiercely, soon reduced everything in the factory not already destroyed by the force of the first explosion into a mass of twisted and charred débris.

Consequently in the "nitrating house"—as the place where the operation is carried out is called—every precaution against fire is adopted. Hosepipes line the walls, and the tanks can be deluged with cold water merely by pulling a lever. The temperature of the oils in the cylinders is carefully watched by means of thermometers immersed in them, and any undue rise of temperature calls for immediate steps to obviate danger.

As the final result of this treatment, the benzene is converted into a powerful perfuming oil known as "artificial oil of bitter almonds," or "essence of mirbane" to the layman, and "nitrobenzene" to the technical chemist. Hundreds of tons of this substance are used yearly for scenting purposes, especially for soaps, while by mixing it with a certain proportion of vanillin, also obtained from coal-tar, a beautiful perfume known as "white heliotrope" is largely manufactured. But the chief use of nitrobenzene is for making "aniline." This wonderful substance, the parent of so many others, is found to a small extent in coal-tar, but it is far easier to turn nitrobenzene directly into aniline than to extract the latter directly from coal-tar. For this purpose scrap iron, together with hydrochloric acid, is placed in the nitrobenzene, and steam is then blown in. The hydrogen produced by the action of the iron on the hydrochloric acid soon reduces the nitrobenzene to aniline, thus:

$$\underset{\text{Nitrobenzene}}{C_6H_5NO_2} + \underset{\text{Hydrogen}}{2H_2} = \underset{\text{Aniline}}{C_6H_5NH_2} + \underset{\text{Water}}{2H_2O}$$

The aniline is then distilled off in special stills.

Aniline was manufactured on an enormous scale in Germany for the purpose of making dyes, something like 8000 tons being produced yearly. The origin of this great industry is very interesting. In 1856 Dr. William Perkin, then a mere boy of eighteen, was investigating aniline with the object of making quinine, a drug which was at that time most valuable and expensive on account of the scarcity of Peruvian bark, and the story runs that one afternoon, tired and disappointed with a day of failures in his laboratory, Perkin mixed all the liquids with which he had been working into a large glass vessel, when to his astonishment and delight a beautiful and brilliant colour flashed into view. But, alas, the true story is neither so romantic nor encouraging, and I would not advise any young would-be discoverer to adopt this method of work. What really happened was the production of a black dirty precipitate, which settled at the bottom of the vessel when the aniline solution was mixed with some potassium dichromate.

Any other worker would have thrown away such "muck" in disgust. But not so Perkin. With quiet persistence he set to work, and after extracting it with alcohol, found that it contained the wonderful colouring matter since so famous as aniline purple or mauve.

Perkin was only eighteen years old at the time, yet such was his energy and enthusiasm that he induced his father and brother to set up a manufactory for its production on the large scale. The difficulties were extremely great. Although he had never seen the inside of a chemical manufactory, yet new plant, and new materials, and new conditions were all undertaken, and in spite of the greatest difficulties Perkin's genius triumphed, and he not only prepared the substance on the large scale, but he actually placed it on the market successfully. The moral of all this to the young man may be summed up in one word: *persevere.* Do not be discouraged by the advice of older men, who invariably take a gloomy view of all new processes and possibilities of success, and who are usually animated by a keen desire to keep a young enthusiastic worker "in his place." This was the beginning of the enormous aniline oil industry.

The news of Perkin's success spread through all Europe, and many now entered the field. Renard and Frank introduced the splendid crimson dye "magenta" in France, while shortly afterwards Simpson, Maule, and Nicholson started the manufacture of this colour in London. And then broke a glorious day for chemistry. Colour after colour of amazing brilliancy and of the most various hues began to be produced at a rapid rate. Vast colour works sprang up in all directions, especially in Germany.

How truly gigantic some of these great German colour works were, can be seen from the following facts. One of the largest works was those of Bayer & Co., Elberfeld. This single firm employed in 1913 no less than 8000 workmen, 330 university trained chemists, 10 medicine doctors, 1 philologist, 40 engineers, 400 other technical

PLATE 31.—Where German Work-people live.

Colony of workmen's houses built by the great chemical firm of Fr. Bayer & Co., of Elberfeld, Germany. Notice the allotment gardens.

employees, and 1300 clerks and travellers, making a grand total of more than 10,000! If we take into account the wives and children of the workmen, over 25,000 people were dependent for their daily bread upon this one firm. No wonder that a whole town grew up around the factory, owned by the firm, which built hospitals, public baths, workmen's cottages, trains, railways, &c. Our illustration (Plate 31) shows a colony of workmen's houses built by the firm. The magnificent chemical library contains something like 14,500 volumes (including the libraries of Professors Kekulé and Victor Meyer) and 80,000 pamphlets, and may be considered the most valuable one of its kind in the world. In the reading-room were about 360 technical journals and periodicals from every part of the world.

In these colour works many interesting sights are to be seen. It is especially interesting to watch the workmen streaming home after their work. You will often see that the men are dyed gorgeous colours through frequent contact with the different colours—their clothes often exhibiting all the hues of the rainbow, and their hands or faces being stained bright blue or green! One gentleman in a large German firm is adorned with a beautiful pair of pink whiskers. It appears that the unfortunate man accidentally got his face immersed in a dye-bath, and the colouring matter adhered with such tenacity to his hair that it assumed this astonishing colour, and it would not wash off again.

Another curious accident happened at a colour works near Frankfort. It appears that these works discharged their waste water into the river some distance above a bathing station. One fine morning the bathers, plunging into the stream, found to their horror that on emerging they were dyed all the colours of the rising sun! Complaint was made and the difficulty was got over by the authorities forcing the works to let their waste water run away during the night.

The growth of the colour industry brought much prosperity into neighbouring trades. The manufacture of inorganic chemicals like potassium dichromate and nitric acid required for the production of these colours suddenly took a mighty upward leap, and works sprang up all over the country in order to supply the growing needs of the dye-makers. It even called new industries into existence —such as, for example, the manufacture of anhydrous sulphuric acid.

Little did young Perkin, as he stood in his laboratory viewing the lovely mauve dye that he had called into existence, dream that he was to be the founder of a vast industry, which may well be estimated as worth £50,000,000 yearly! Germany alone exported no less than £18,000,000 worth of fine dye-stuffs.

In 1819 naphthalene was discovered in coal-tar by Garden, and it was regarded more or less as a curiosity. Later, in Germany alone, ten thousand tons were produced, and used for making explosives or dyes. Indeed, some of our most beautiful colours are obtained from it, ranging from buttercup yellow on the one hand, to greens, pinks, reds, and scarlets on the other. To entomologists this naphthalene is of interest, for it is regarded as one of the best preservatives for moths, butterflies, insects, and other natural history specimens. The lower animals find its smell particularly objectionable, and keep away from its neighbourhood.

Anthracene, a white crystalline body, was discovered in coal-tar in 1832 by Dumas and Laurent. And now notice how intimately chemical science penetrates into the life of peoples. Because a hundred years ago men began to distil coal for making gas, to-day a vast agricultural industry, which once occupied thousands of square miles of land, not only in Europe but in countries as remote as Turkey, Persia, and far-off India, is annihilated, and its very existence practically forgotten. This industry was swept away in the course of a few years, because it was found that the chemical anthracene could be converted into the very same dye as that contained in madder root, which is known as "alizarin," or "turkey-red." The madder industry had flourished from times immemorial in the East, and only some fifty or sixty years ago in France alone some £2,000,000 worth were exported annually. Equally extensive tracts of land were employed in its production in Russia, Turkey, and other countries. Suddenly, like a thunder-clap, came the news of the artificial manufacture of alizarin from anthracene, and within a few years after this discovery madder had ceased to be cultivated on the large scale, and the millions of acres of land formerly employed in its production were laid waste, to be ultimately employed for growing other products.

This industrial revolution was brought about by two German chemists, named Graebe and Liebermann, who proved that when a portion of the dye is heated with zinc dust, anthracene distilled over. So that alizarin is derived from anthracene. In a very short time these chemists solved the converse problem, namely, how to produce alizarin from anthracene, although the process of manufacture was at first too expensive for the substance to be directly placed on the market.

As soon as it became known that anthracene could be turned into alizarin immense excitement prevailed in the commercial world, and many chemists turned to work with feverish haste upon the problem.

In 1869 two patents were almost simultaneously taken out—one by Perkin in England, and the other by Caro, Graebe, and Liebermann—for the purpose of manufacturing alizarin cheaply. And then the fate of the madder industry was sealed, while the price of anthracene went up by leaps and bounds; for up to this time anthracene had been considered to be a mere useless by-product, and was sold at a few shillings a ton and used as a cart grease. Shortly after the discovery its price had risen to £100 the ton!

The production of indigo, that king of dyes, by artificial means is another romance of the coal-tar industry. Indigo, of course, is a very old dye. Thousands of years ago it was used by the inhabitants of Egypt and India, and from the East its use spread to Europe. So long ago as 1879 the great German chemist, Adolph von Baeyer, showed that indigo could be produced artificially from coal-tar products, but only at a cost considerably greater than that of the natural dye. Then a great firm, the Badische Anilin und Soda Fabrik, took up the question. Thousands of pounds were spent on erecting plant and trying experiments, and dozens of highly trained doctors of chemistry were kept continuously employed upon the problem. After fifteen years of intense practical and mental work, during which time vast quantities of money were poured forth and apparently wasted, success was at last achieved. And now artificial indigo is produced at such a low price and of such good quality that the indigo planters are unable to compete against it, and the cultivation of natural indigo has, in consequence, enormously decreased.

The whole affair was, indeed, a triumph of the German chemists—where man's technical skill and science were pitted against nature herself, and won. More recently a new chapter has been opened up by the discovery of extraordinary fast and brilliant red, green, and yellow dyes, which are derivatives of indigo. This was also a discovery of German origin.

To-day about 2000 individual coal-tar dye-stuffs are known, ranging through all the colours of the rainbow, and complying with every demand of stability, taste, and fashion. The common notion that the aniline dyes are gaudy, clash with nature, and are fugitive, is utterly erroneous. They surpass in beauty and brilliancy the colours supplied by nature, and the shades obtained with some of them are faster, under the influence of light and chemicals, than the fastest which nature produces.

Moreover, they are used not only for dying textile fabrics, like wool, silk, cotton, &c., but for innumerable other things, such as paper, bones, ivory, feathers, and straw. Indeed, in America, whole pieces of even the bulkiest furniture are dyed by dipping them bodily into vast tanks of dye-stuffs. They go in as ordinary white pine wood and come out "real mahogany," or "walnut," "rosewood," or some other fancy wood!

But coal-tar colours are used on the Lilliputian as well as on the enormous scale. Doctors and biologists employ them for staining specimens for examination under the microscope, thus enabling them to detect and identify bacteria, the finest nerve ends, and other minute parts of animal and vegetable tissue. Indeed, it was by this employment of methylene blue that Koch discovered the bacillus of cholera and tuberculosis, and thus opened the modern campaign against infectious diseases, which has already been attended with such enormous success.

You would scarcely believe that such research work would lead to the discovery of a new class of valuable dye-stuffs, and yet this was the case. In 1886 Ehrlich observed that methylene blue and some similar dyes were the only ones which stained the living nerve tissue. He suspected that this was due to the fact that they contained combined sulphur, and in order to verify this theory he applied to Dr. Caro to make him a body of similar constitution in which the sulphur was replaced by oxygen.

Dr. Caro set to work, and in a very short time had discovered the rhodamine colours. In other words, experiments with nerve tissues gave birth to the manufacture of new coal-tar colours of the greatest importance to the cloth trade. So closely are theory and practice related in the chemical world.

And now a few statistics about the quantity of colouring matter extractable from coal may interest my readers, and will certainly bring before them the great importance of the whole coal industry. From one ton of coal may be had about 200 lb. of tar, from which may be obtained dyes sufficient to colour the following lengths of flannel three-quarters of a yard wide: 700 feet turkey-red, 1400 feet magenta, 1½ miles of scarlet, 370 feet orange, 2 miles yellow, ¾ mile violet! As in England alone every year some ten million tons of coal are used for making gas, it is almost impossible to realise the immense amount of colouring matter that it represents. The strip of flannel above mentioned would have to be of such a length that it would wind round the whole earth some two thousand times before all the colouring matter had been used up. It would stretch from the earth to the moon and back again some twenty-five times! Even our ordinary boot and shoe polishes are derived from coal, consisting of a coal-tar dye, nigrosene, mixed up with various waxes and greases.

After this I trust my reader will look upon ordinary common coal with somewhat more respect than formerly, for it is, indeed, a veritable storehouse of marvels.

But dyes are not the only things obtainable from coal-tar. By no means. Millions of pounds' worth of drugs are yearly extracted from it, and among these are some of the most wonderful known to mankind.

This industry also owes its origin (just as the colour industry did) to the efforts of chemists to produce quinine artificially—a problem which even to-day, after the weary work of fifty years, is still unsolved.

It was soon discovered that by decomposing quinine a substance called quinoline, which was well known to be in coal-tar, was found. It was then thought that quinine must in some way be derived from quinoline, and that perhaps other derivatives of quinoline might possess properties similar to quinine. Chemists soon set to work to make these derivatives, and in this way discovered those valuable drugs thallin and kairin ; the former of these has a special power in mitigating the dreaded yellow fever of the colonist, and was for some years manufactured on a very large scale. Unfortunately these substances produce such drastic effects on the body that their use is now abandoned. In 1883 Dr. Knorr of Elangen discovered antipyrin, which is considered even better than quinine as an assuager of fevers, and is much cheaper in price. Enormous profits were being made by its manufacture, when an accident suddenly brought to light an equally efficient drug. This was acetanilide. The story runs that two physicians, Kann and Hepp, who were connected with Strassburg University, were friends of a chemist at the Hoechst Works, where the antipyrin was then being manufactured. A patient afflicted with a skin disease having turned up, they determined to try the effect of naphthalene taken internally, and in 1886 asked the chemist to send this chemical. The chemist immediately directed the laboratory boy to fill a bottle with naphthalene and send it off. But the boy most carelessly took the wrong bottle, containing acetanilide, and dispatched this to the doctors. The doctors duly received the substance, and proceeded to administer it. To their astonishment they found that it had an altogether different effect from that which they expected. It promptly reduced the existing fever. When the substance was nearly all used up, they then wrote for a further supply of the drug. When this arrived they found to their great wonder that it behaved in an entirely different way from the previous sample, not having any effect on the fever at all. Evidently a mistake had occurred, and on investigating matters it was found that the second time the chemist himself had correctly sent naphthalene, while the first time the laboratory boy had sent acetanilide. And thus through a lucky accident acetanilide was introduced into medicine, and to-day is used by the ton in all parts of the world for reducing fever and assuaging neuralgia. And thus it came about, through the curious irony of fate, the most powerful competitor of antipyrin was discovered accidentally in the *very same factory* which at the time was making enormous profits out of the manufacture of antipyrin.

Innumerable other drugs, some possessing the most surprising properties, have since been extracted from coal-tar. We need only mention phenacetin, lactophenin, phenocoll, veronal, and sulphonal. The last is a hypnotic, producing a deep and quiet sleep lasting several hours, after which the patient awakes refreshed and strengthened. African explorers have frequently used it during the many illnesses and hardships experienced by them.

However, all such soothing and sleep-producing drugs must be taken with caution or they may set up a slavery worse even in its effects than that produced by alcohol. Some of the most wonderful drugs of all are the local anæsthetics, such as stovaine, cocaine, novococaine, and a host of others. A few drops of these injected into the body produce insensibility to pain in the immediate neighbourhood of the injection, and thus are much used in the painless extraction of teeth and other minor surgical operations. Indeed, the most remarkable operations can be carried out by their aid without the patient feeling any pain—operations which a few years ago would have been deemed impossible. Thus in the case of a girl admitted to a hospital, it was found necessary to remove the appendix, but her state of health forbade the use of an ordinary anæsthetic like chloroform. So some twenty drops of stovaine were injected into her back in the spinal column, near the level of the waist. In ten minutes she had lost all sense of feeling from the chest downwards. A screen was placed across her body, shielding the part to be operated upon. The girl chattered and read, and was unaware that the operation was being carried out, until it was nearly completed. This and a host of equally wonderful achievements have been made by surgical science, thanks to the coal-tar industry.

To mention just one case—there is the discovery of bloodless surgery. Substances—*e.g.* adrenaline—can be obtained indirectly from coal-tar, which when injected cause such a powerful contraction of the blood vessels that the blood is driven out of the flesh in the immediate neighbourhood, and so surgical operations can be made without loss of blood. A very dilute solution of this adrenaline when painted over a red nose instantly renders it quite pale! Unfortunately, however, the colour is not evenly discharged, as the drug penetrates at a different rate through different parts of the skin, and so, as the action of the drug soon ceases, adrenaline is not likely to be used as a cosmetic.

It is interesting to note that the dye-stuff methylene blue and some similar bodies are very valuable internal remedies, the former being used for the relief of pain in that fearful disease cancer. However, we cannot go into this question of drugs, which really belongs to another chapter. We have merely mentioned these facts, in order to show that out of the tar barrel have come a series of wonderful medicines as well as wonderful colours. And now I will relate a story which illustrates the old truth that success in any line does not now depend upon rule of thumb, but upon the application of pure science, and that experiments, interesting only at first for their scientific value, ultimately lead to the creation of whole industries. We have seen that this was the case as regards the discovery of mauve by Perkin, the first aniline colour. Well, the story that I am going to tell you is this. Once there was a young man, Fahlberg by name, who was working under the directions of Professor Ira Remsen in the John Hopkin's University. He was experimenting with coal-tar derivatives, and neither he nor the professor had the faintest idea that anything of commercial value would come of it. It was a case of the pursuit of truth for truth's sake alone. Well, after a hard day's work in the laboratory, this young man went home to tea. He disliked the sweet taste of sugar, and consequently was much annoyed to find that his bread and butter tasted sweet. He called in the landlady and asked her how she had managed to get sugar over his food, but she denied the imputation. Had it come from his own hands? He licked his fingers, and lo and behold, they were sweeter than any sugar! Evidently some chemical with a sweet taste was adhering to them, and it must have been of altogether extraordinary sweetness, because it had not been removed by the thorough washing his hands had undergone before he had left the laboratory. Full of excitement he hurried back to his working place, and began to taste the contents of the various flasks, glasses, and dishes standing there; finally he came across one whose contents seemed remarkably sweet.

And so it was that saccharine was discovered, a substance no less than 550 times sweeter than sugar. The substance was found to have no perceptible influence on the health, being eliminated undecomposed from the animal body. Moreover, it possesses considerable antiseptic power, so that its great sweetness combined with its preserving properties made it useful for sweetening fruits, preserves, jellies, jams, and such like things, where ordinary cane sugar would go mouldy and ferment in the course of time. And so Fahlberg soon began to erect factories for its manufacture on the large scale. The success at first was enormous. When you come to consider that only four pounds of this material are equivalent in sweetening power to one ton of the best cane sugar, and cost only a few pence to produce, this can be easily imagined. So sweet is the substance, in fact, that if a little be placed on the tongue it will destroy for some time its tasting power, just as a fierce white light will blind and dazzle the eye for some minutes afterwards! In a short time the great sugar industry was threatened, and all the Governments of the world were set into such a state of alarm that laws were at once enacted which prohibited the industrial use of the sweetener as a substitute for sugar, permitting its employment only for medicinal purposes. Sugar, of course, is a most valuable food-stuff, while this saccharine is eliminated unchanged from the body. Consequently its employment as a sweetener instead of sugar in making jams would be something like employing chalk or china clay instead of flour in making bread. Such a high duty is now placed upon the substance that cane sugar can more than compete with it. However, the body has its valuable uses. In kidney troubles, like diabetes, where sugary materials have an extremely bad effect on the system, doctors recommend the use of saccharine instead of sugar for sweetening tea or coffee. Its sale is now in the hands of druggists.

One rather unlooked-for consequence of the high duty levelled on saccharine by the custom-house authorities of this country is the revival of a brisk smuggling trade in this chemical. It is stated that for years one gentleman used to pass to the Continent and back in clothes which had been impregnated in a concentrated solution of saccharine, which on his arrival here was extracted and the saccharine recovered. Women, especially, are notoriously employed in this nefarious trade, and it is quite a common occurrence for lady passengers to carry on them small bags of saccharine. Only recently one woman was found to be wearing two linen bags, especially made for the purpose, containing £22 worth of saccharine! The fines amounted to £50. In searching a passenger arriving at Harwich a custom officer discovered strapped to his chest and back specially made bags containing sixteen pounds of this sweet chemical. He was fined £40, and the treble duty and value amounted to £58—so that the game seems hardly worth the risk!

But here we must pass on to another subject—that of perfumes. Innumerable scents are known, and some of them have been in use from time immemorial. It is the first instinct of a woman to make herself attractive, and thousands of years before our era we know that the black-eyed ladies in the harems of the famous old fighting kings of Assyria and Babylon were accustomed to anoint themselves with scents. Most of these perfumes are extracted from sweet-scented flowers, and the industry is quite a large one, Germany and France both producing annually scents to the value of some millions of pounds. However, the sweet-scented flowers must now submit to the competition of artificial scents, many derived from the tar barrel. Is it not strange that scents as delicate as any from a garden of roses can be culled from the evil-smelling black refuse of gas-works? Nitrobenzene, or "oil of Mirbane," is one of the coal-tar perfumes to which reference has already been made. Again, the odour of musk is to-day successfully imitated by a nitrated hydrocarbon derived from coal-tar. The delicate perfume "new-mown hay," so suggestive of yellow fields of odorous hay, bright sunshine, and pure country air, was discovered by Dr. Perkin, and is produced from a substance called "coumarin," which in its turn is derived from coal-tar. Vanilla, the delicate flavouring essence obtained from the vanilla bean, which was once so extensively cultivated in Mauritius and the Cordilleras, has been to a large extent supplanted by "vanillin"—a coal-tar product. But the most wonderful artificial scent of all is, perhaps, "ionone," which has an overpowering smell of violets, and forms the basis of all violet scents. It is made by condensing citral with acetone in the presence of alkali, and so powerful is it that the contents of one small bottle is sufficient to envelop a small town in an atmosphere of violet perfume! Perhaps the most remarkable achievement of synthetic chemistry in this direction, however, is the manufacture of artificial attar of roses. Although the natural oil from roses contains about twenty different perfuming substances, yet the chemists of the great scent factories at Leipzig succeeded, after laborious and costly research, in separating each component, making them artificially, and then reuniting them in the exact proportions in which they occur in the natural product. Even the most sensitive nose cannot distinguish between natural and artificial attar of roses. Not only has the odour of violets and of roses been successfully reproduced by artificial products, but also that of jasmine, of heliotrope, of vine blossoms, lilac, lily-of-the-valley, and numerous others, and Germany alone now turns out scents to the value of £2,000,000 annually.

Between sweet-smelling perfumes and death-dealing explosives one would think that a deep gulf was fixed; and yet both substances are derived from coal-tar. Thus phenol is a substance obtained in large quantities from coal-tar, and from phenol some of the most valuable explosives are made by treating it with nitric acid, whereby it is changed into trinitrophenol or picric acid, thus:

$$\underset{\text{Phenol}}{C_6H_5OH} + \underset{\text{Nitric acid}}{3HNO_3} = \underset{\text{Picric acid}}{C_6H_2(NO_2)_3OH} + \underset{\text{Water}}{3H_2O}$$

Similarly, by treating various other substances obtainable from coal-tar with nitric acid, a whole series of explosives is obtained, which when mixed with other substances form the basis of many of the smokeless and safety explosives used at the present time.

Lyddite and mellinite are typical coal-tar explosives, and only those who have seen a lyddite shell strike a hillside and shatter it into a mass of flying rock, can realise what stupendous energy lies dormant in tar.

And now we come to the reproductive arts, in the development of which coal-tar products have played a large part. For example, inks for printing and writing are now largely made from coal-tar colours, while in photography nearly all the developers are coal-tar preparations. By the addition of certain aniline dyes to photographic emulsions they become enormously sensitive to light, and thus can be used for instantaneous photography ; thus Kodak fiends and living picture palaces are direct offshoots of the coal-tar industry !

Lastly, but not least, I will mention the sudden rise into importance of a whole new industry of varnishes, shellacs, ambers, artificial horn, and electrical insulators, which are now produced directly from phenol and cresol, bodies contained in coal-tar. By mixing phenol or cresol with formaldehyde (an indirect product of the wood-distilling industry) a whole series of wonderful acid-proof and inert shellacs, varnishes, and hard insulators are produced, which are now on the market under the name

"Bakelite," the American chemist Baekland being largely instrumental in securing their commercial utilisation. Soft woods, for example, can be impregnated with the material, and when heated under pressure become covered with a beautiful varnish equal to the most expensive Japanese lacquer. Cardboard, paper, fibres of all sorts, on heating, produce a hard, polished material which can be used as an insulator like ebonite. Some of the substances thus produced are enormously strong, a few having the same tensile strength as cast iron—namely, 10,000 lb. on the square inch! Bakelite can be obtained as a transparent, insoluble, infusible, and immensely strong substance, which will resist temperatures up to 300° C., and thus is far superior to any of the ordinary bone substitutes on the market. Moreover, unlike celluloid, it is non-inflammable. Bakelite resists nearly all chemicals, such as concentrated hydrochloric acid and boiling dilute sulphuric acid.

It is also used for making ornaments and beads for jewellery, for pen and pencil holders, and has numerous other applications. In fact, a promising new industry in these products has arisen, and factories for their manufacture have been erected in the United States, in England, and in Germany.

But here we will stop. Enough has been said to show that out of coal-tar has arisen, not one industry, but scores of industries, all closely related and entering into our life in a way altogether hard to realise by those not conversant with the technical side of chemistry. And the lever which set all this complicated machinery of modern civilisation into motion was undoubtedly Perkin's discovery of mauve. The industrial impulse thus created has gone on gathering momentum and power every succeeding year, overturning whole industries and creating out of their ruins still mightier ones, until at the present time the origin of the whole gigantic industrial revolution is almost forgotten as it sweeps into the most remote branches of human activity, creating new conditions and problems with such rapidity that at the present time no single man can follow even approximately the ramifications of the mighty whole.

And still to-day at the Royal Institution in London may be seen the small bottle of benzene, the first pure hydrocarbon isolated from coal-tar by Faraday in 1825—then a chemical curiosity, now a world-wide product. "When standing before the small, but historically priceless bottle of benzene which Faraday first isolated," said Professor Duisberg in a speech at the Royal Institution in 1906, "a thrilling vision flashed before my mind's eye. I saw this tiny bottle expanded to an enormous vessel filled with millions and millions of gallons of this substance. I saw all those gigantic factories in which benzene is worked up into thousands of different products and applied to innumerable wonderful purposes. And then I pictured to myself the vast coal-tar industry which came into existence here some fifty years ago. Before me there swept in never-ending procession the countless numbers of products distilled from coal-tar, and the thousands and thousands of coal-tar colours, ranging through all the shades and nuances of the rainbow. . . . I saw the pharmaceutical industry, with its numerous drugs derived from benzene, commencing with carbolic acid, passing on to kairine, antipyrin, antifebrin, phenacetin, all the astringents and hypnotics, and to crown all, the serum products. I smelt the odours of the delicious perfumes produced from tar, from coumarin, the smell of fresh-mown hay, to sweet woodruff; from artificial vanillin and the sweet odours of roses, to that of the violet and vine blossom. Then I saw the photographic products, which though small in number and industrially not to be compared with the giants and valiant knights of the artificial dye-stuffs, are none the less important scientifically. . . . Here on English soil this vast industry started, here in the land where benzene and gas and tar had their cradles, this giant industrial revolution began."

The colour industry started in England some fifty years ago, flourished immensely for twenty years and then passed away to Germany, where now gigantic factories control the world's markets.

This loss of supremacy in a world-industry is a fact to make Englishmen sad and thoughtful, and those who have lived, as I have lived, in Germany, and have seen her numerous universities and great technical schools filled with eager students, know perfectly well the reason of this disaster. It is not so much the fault of our practical men,—who in energy and judgment and general sagacity are, despite all critics, splendid, full of bold enterprise,—as the *fault of our universities*, who have *failed entirely* to get into touch with practical men. Instead of encouraging research—and it was this that laid the basis of the German chemical industry—our university senates have done their level best by legislation to keep our best students off it, or to make it so unprofitable that they prefer to enter some other form of activity. Let me give an instance of how the greatest difficulties are placed by the universities before students attempting to undertake scientific research.

When a student enters an English, and still more a Scottish, university, he sees before him a long series of oncoming examinations. Almost every year he has to pass an examination of increasing difficulty, and the only subjects that count are the stereotyped ones, on which questions may be asked at some forthcoming examination. In an atmosphere of examinations he lives, breathes, and has his being. Finally, after some four to six years' hard work, he passes the B.Sc. examination, which is an examination of considerable difficulty. Now mark, up to this point he has only been learning what others have done before him. At no time has he reached the confines of knowledge, or advanced it in any way. His parents now step in. The father says, "My son, we have given you a good education; for four to six years we have maintained you at a university, and you have shown your ability by passing innumerable examinations of a highly complicated nature, and it is now time that you pass into the great world to earn your own living." And so the young man passes out of the university without ever being even introduced to methods of research, or ever touching the boundaries of human knowledge. Being a university man, he hardly ever passes into the great world of affairs, but retires into the badly paid and despised teaching profession—and the worst of it is that *it is our very best students who invariably turn to the sheltered ranks of the teachers. It is only students who fail to pass the Chinese-like wall of examinations who join the business world and enter factory or workshop.* Perhaps, however, the young man, in spite of every discouragement meted out to him by the university authorities by means of suppressive legislation, is resolved to remain on in order to do research work. He works hard for two years longer (for research work is difficult and laborious), and at the end of that time has discovered enough to produce a small paper—nothing more can be expected after two years' work. Then as a rule this single little paper is not considered sufficient by the university authorities to merit the highest academic recognition, and so he leaves the university with no reward for his extra work. The highest academic honours involving recognition of research work are thus in this country confined to one class of men—namely, to university teachers, who remain on in the laboratories working out problems in science often for years; and the business world, *where the highest inventive and practical ability is really needed*, never or very seldom receives men trained in methods of research. And so there is a great gulf fixed between the business world and the academic world in England. The heads of factory or workshops, and even the directors of huge industrial undertakings, have never been introduced themselves either to the spirit or practice of research, and so are entirely out of sympathy with it. In Germany, however, a different system prevails, and it *pays* a student to remain on in order to undertake research, as it helps him afterwards in obtaining a good position in the industrial world. Such men gradually rise to the top, become directors of firms, and hence a sympathetic view of scientific work has become a characteristic of the German industrial world. It is all a matter of university legislation, and in Great Britain it is hopeless for the average student ever to attempt to obtain high academic honours involving research, and so he does not try. If any research work is done in this country research students must be *paid* to do it, the payment taking the form of research scholarships! In Germany a celebrated professor can have as many helping hands as he desires to carry on his investigations, his students forming willing and unpaid assistants, who afterwards pass out into the industrial world, carrying methods of research and influence there also. Here, however, students in any numbers cannot be got to undertake or assist research going on in the university, for no good of it will come to them. There is nothing fundamentally different between the natures of German and English students. The difference in the enthusiasm for research, however, is that the legislations of the German and English universities are different, so that in Germany research work helps a student in getting a diploma, and so his living, whereas in this country it is of no practical advantage for a student to undertake research work.

Yet every authority speaks of the great value, commercial and otherwise, flowing from the free application of research. Perkin, the great discoverer of mauve, the founder of the gigantic aniline industry, thus speaks of the subject: "Artificial indigo is being produced in great quantities, and at a cost less than the natural product, so that the land used for its production in India has had to be utilised for other crops. This is a most remarkable example of the fruits of persevering scientific research, made both for its own sake and also in connection with industry. I speak of research made for its own sake, for do not let us, when we see the wonderful fruits connected with the coal-tar colours industry, forget that the origin of them all is research, made for the sake of getting a deeper knowledge of the laws and secrets of nature. Without these researches no coal-tar colours would have been discovered, and doubtless the active cultivation of research will not only advance our highest knowledge of things, but, judging from the past, also lead into paths yielding valuable kinds of fruit at present unknown to us."

Hoffmann's words, too, are emphatic on this point:

"The moral of mauve," he says, "is transparent enough. Whenever one of your chemical friends, full of enthusiasm, exhibits and explains to you his newly discovered compound, you will not cool his noble enthusiasm by asking that most terrible of all questions, 'What is its use? Will your compound bleach or dye? Will it shave? May it be used as a substitute for leather?' Let him quietly go on with his work. The dye, the leather, will make their appearance in due time. Let him, I repeat, perform his task. Let him indulge in the pursuit of truth—of truth pure and simple—of truth not for the sake of Mauve,—let him pursue truth for the sake of truth!"

CHAPTER XIII

THE ROMANCE OF COMMON SALT

ALL my readers are acquainted with common salt, that white, beautifully crystalline mineral; and no doubt only very few of them will ever have imagined that there is much that is interesting, and much that is very wonderful to relate about this substance. And yet this is the case, as I hope to show in the following pages.

Salt is one of the most widely distributed of all minerals. All rocks contain it. It occurs in all rivers, all brooks, and, in large amounts, in all sea-water. In fact, the saltness of the sea is one of the earliest natural facts which the children of sea-bordered countries learn, and, as we shall presently see, large quantities of salt are obtained merely by the evaporation of sea-water.

How did salt get into the sea? For the full story of that we must go back to the very early history of our planet, when, if geologists are to be believed, it was but a great red-hot ball of molten, bubbling rocks. At this distant epoch the waters had not yet settled down so as to form the oceans, but hung aloft as vast masses of high-pressure steam, capped with enormous thunder-clouds, whence day and night poured down torrents of almost red-hot water. As this water fell so as to reach the hot surface of the earth, it was hurled aloft again in a series of vast explosions. That indeed was a time of turmoil and storm, such as at present can scarcely be realised by us who dwell under quieter conditions. However, the world cooled comparatively rapidly, and so the water condensed and began to cover our planet. But you will see that the waters that first condensed were practically distilled water, and so the very earliest seas could not have contained very much salt. In fact, many geologists assert that the very earliest seas were fresh-water seas, and only became salt in the course of ages in the manner I will presently explain. They assert that the process is still continuing, so that the oceans are becoming salter and salter every year. Let me explain how. The salt is supposed to be washed out of the rocks by the agency of running water. Few facts are more wonderful than the continual circulation of water over the surface of our planet.[1] From the time the first drop of water fell upon the earth until now, it has never ceased to circulate, changing the face of continents, wearing down mountains into plains, and plains into valleys. Whole continents are being slowly and remorselessly washed away into the sea by running waters, and this process has been going on ever since this hoary old world of ours began. This circulation is maintained by the heat of the sun. The sun evaporates the water of the oceans and causes it to rise in the form of invisible vapour, which then, in the cold of the higher atmospheric regions, condenses to clouds and falls upon the earth as rain. So that, as was long ago remarked, "the very rain that we see descending was thawed for us out of ice-bergs which have watched the polar star for ages, and lotus lilies sucked up from the Nile and exhaled as vapours the snows which lie on the summits of our hills."

There is thus continually going on a gigantic process of distillation, whereby the waters of the ocean arise as vapour, fall on the land as rain, and thence pour back into the sea as brooks and rivers. Geologists have calcu-

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[1] See the author's book *Triumphs and Wonders of Modern Chemistry*, 2nd edition, chap. v., "Water."

lated that every few thousand years the whole of the waters of our oceans pass into vapour, condense, pour upon the land, and thence run back into the sea again. Consider, for example, our own country. In one year there falls as rain about two feet of water over all Britain. So that in 9000 years there falls water nearly three miles deep over all the land—and the average depth of the ocean is barely three miles! Thus in the course of a few thousand years an ocean of water has distilled from sea to land, condensed, washed the land like a sponge, and poured back into the sea again. And when we recollect that the history of our world runs, possibly, to hundreds of millions of years, and that during all this immense interval of time this process of distillation has been continually proceeding, it will be clear that not hundreds of times, nor thousands of times, but *millions* of times in the past history of our world, have all the oceans of the globe been converted into vapour and fallen upon the land and again gone back to reform the great oceans. And so it is with no surprise that we learn that vast continents have arisen out of the sea, and then been swept away again into the sea, only to be replaced by other great continents, whose very memories and fragments have been dissipated and scattered ages before ever man arose upon the globe—a geological fact expressed by Tennyson as follows:—

"There rolls the deep, where grew the tree,
O Earth, what changes hast thou seen!
There where the long street roars has been
The stillness of the central sea.

The Hills are shadows, and they flow
From form to form, and nothing stands,
They melt like mist, the solid lands
Like clouds they shape themselves and go."

It is obvious, therefore, that water, the unconquerable and tireless scavenger, throughout all the ages which have elapsed since the world began, has been washing out salt from the land and accumulating it in the sea. You must remember that the amount of salt in the enormous masses of rock which make up the framework of the earth's crust is practically inexhaustible. The amount of rock, extending to miles beneath our feet, towering aloft in parts of the world in vast mountain ranges, four, five, or even six miles high, contains enough salt scattered through it completely to saturate the sea.

The salt of the sea is thus the salt of numerous forgotten continents, which, like the fabled Atlantis of old, have vanished ages ago beneath the sea. If the salt on the table could speak what a truly wonderful tale it could unfold—a tale of fair lands gone and forgotten ages before man appeared at all, of great monsters and strange forms of life now long extinct; nay, before that, it might tell us of a past so dizzily remote that the imagination reels at the thought, when it whirled through the incandescent mist of a world in the throes of birth; and before that, who knows of its origin, of whence it came, of the depths of space through which it journeyed before it reached our world at all? Truly, even historically considered, each particle of salt is a marvellous substance replete with interest.

Would you have thought, for instance, that by means of common salt we can actually estimate the age of the earth? Yet Professor Joly has shown us how to do that, and in a very simple manner. The method will be understood by what has been said above. It is assumed that the ocean, immediately after condensing, was practically a fresh-water expanse, containing but little salt, but that year by year salt was washed from land to sea by innumerable rivers and brooks, until it attained its present degree of saltness. Now Joly assumes that this process has continued at about much the same rate all the time. He first estimates how much salt is in the sea, and then finds out by analysing the waters of the chief rivers and brooks, how much salt is carried into the sea yearly. The question then is simply this: how many years would the sea require to attain its present charge of salt at the rate at which salt is now given to it annually? The answer comes out between 100,000,000 and 200,000,000 years; so that the world is certainly as old as that.

But the reader will think that if for ages salt has thus been steadily pouring into the ocean the latter must now be quite saturated with salt. This, however, is far from being the case. A hundred parts of sea water contain only between three and four parts of a mixture of salts (the exact proportion varying with the part of the sea whence the water is drawn), of which about 2·7 parts consist of ordinary common salt. Now if the ocean was quite saturated with salt it would contain between 30 and 40 per cent. of common salt, and the fact that it is not so saturated shows that it is not infinitely old.

However, the amount of salt in the sea is so great as to baffle the imagination. Let me make a little calculation. Sea water contains about 2·7 per cent. of common salt; and the sea covers about $\frac{3}{4}$ of the earth's surface. Taking the average depth of the Atlantic and Pacific Ocean at $2\frac{3}{4}$ miles, the reader can calculate that there is in the water underneath *every square mile* of its surface some 313,000,000 tons of salt! Now taking the area of water of the globe as, say, 145,000,000 sq. miles, we get as the amount of salt in the sea the enormous total of 45,400,000,000,000,000 tons. To give some idea of this amount of salt I might mention that if the ocean dried up there would be left a deposit of salt all over its bed some 200 yards thick. If all this salt was heaped up in a level layer over all Europe it would cover it with a white shining sheet to the depth of between four and five miles!

Of course there are some seas which are much richer in salt than others, especially smaller seas with no outlet. In the old world the Dead Sea is the best known example of this, the waters of which contain no less than 24·5 per cent. of salt. One consequence of this is that such water becomes much heavier than ordinary fresh or even sea water, and so its buoyancy is much greater. In fact the buoyancy of the water of the Dead Sea is such that a man cannot go much beyond his breast without being lifted off his feet. A similar sea, the Great Salt Lake of Utah, exists in the United States.

This latter is used as a bathing place, and it is claimed that no one can drown in it because bathers can float upon the water, lying on the back or chest with the head right above the water. Both these lakes owe their excessive saltness to the fact that for many ages rivers have been running into them, bearing with them salt, and that the waters, having no outlet, are gradually concentrated in the lake by the steady evaporation of the water under the fierce rays of a tropical sun. It is probable that both lakes are the remains of much more extensive seas which have now almost completely dried up.

It is stated that some underground river is draining off the waters of the Salt Lake of Utah more quickly than they are supplied by in-running streams, and so the waters are shrinking. Part of the bottom has the consistency of quicksand, and although hundreds of tons of rock and stones have been thrown in with the object of forming a solid bottom whereon to build a railway, yet these materials soon sink to unknown depths and cannot be

Plate 32.—Beautiful structures of crystallised salt, made by pouring saturated brine over wooden structures.

Plate 33.—The crystal cave in Wieliczka Salt Mine.

Large transparent blocks of salt crystals are here to be seen.

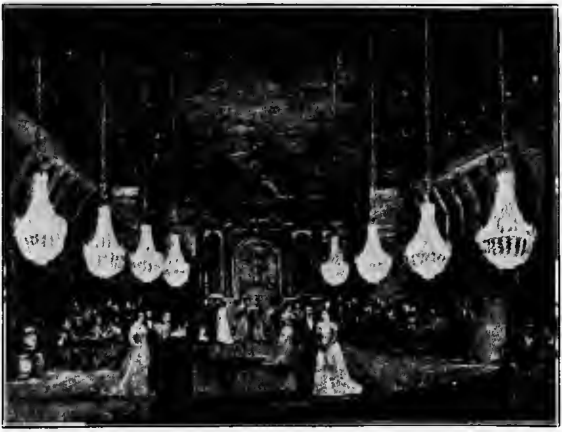

Plate 34.—A ball-room, hewn out of glittering salt, in the salt mine.

The chandeliers are masses of crystallised salt.

Scenes in Wieliczka Salt Mine.

reached by the sounding rods. The Salt Lake of Utah is some 75 miles long by 50 wide at its broadest part, and so it is quite a sea.

Now when lakes of this nature dry up they leave behind them great deposits of salt in a solid state, which after ages become covered up with layers of earth and rocks, and, buried deep below the surface of the globe, become transformed into what is known as "rock-salt."

And perfectly amazing are the deposits of rock-salt to be found heaped up in certain parts of the earth. Thus at Stassfurt in Germany there is a vast deposit ranging in parts from half a mile to a mile thick! Scarcely credible, I hear my reader say. But it is quite true. There exist in other parts of the world equally great deposits. One of the greatest of these is at Wieliczka in Austria, where in some parts the rock-salt is some 4600 feet thick almost in a solid sheet. The deposits are 500 miles long and 20 miles broad and average in thickness 1200 feet. At this place are, perhaps, the most wonderful salt mines on earth. Here the reader will find cut out of solid salt a series of great chasms, leading into the earth. In the interior, all scooped out of one vast rock of white glittering salt, are a series of great caverns, supported by lofty columns of gleaming salt, left at regular intervals to support the arched roof, the whole having the appearance, in some parts of the mine, of long aisles in a Gothic Cathedral. There are more than a hundred of these chambers, forming a perfect maze extending over 30 miles underground. Portions of the works, indeed, have not been entered for years. Massive and broad staircases lead into the mine, some cut in the rock-salt, others of wood, so that one can ascend or descend into it as leisurely as if one were on the staircase of a palace. Each of the mines consists of five and even more stories, and each of these stories of numerous arched chambers, or caverns communicating with each other by horizontal passages. The older parts of the mine are very picturesque, particularly where the roofs dividing the stories have fallen in, thus opening abysses to the view at which the spectator shudders. A visitor thus describes the aspect: "The torches and lanterns of the workmen lighted up the walls. One who stood in the highest gallery lighted a large piece of oakum and threw it down the shaft. It burst into a blaze and the blaze lighted up that glittering vault to its highest summits, and revealed fresh and unknown depths below." The newer parts of the mine are more regular and less striking. What will the reader say to a mine with a large chapel inside, all hollowed and carved out of glittering rock-salt, with images of saints, altars, niches, ceilings, pedestals, roof and doors hewn out of the same mineral? and yet such is the Chapel of St. Anthony, built in this mine in 1698.

The statues of saints found here, being composed of salt, are translucent and allow a light placed behind them to shine through.

Equally marvellous is a large ballroom hollowed out of salt, the walls of which are resplendent as with the lustre of thousands of diamonds, since the crystals which compose the salt reflect the lights in a marvellous way from the walls. Here are held subterranean fêtes, balls and dances, and on these occasions the illumination is said to surpass in splendour that of the most magnificent ballroom.

In some caverns immense chandeliers, cut out of the salt, have been hung up. In one, called the Great Hall, there is a chandelier some 35 feet in length and 60 in circumference, which when properly lighted up reveals the crystallised walls of this magnificent underground palace with a splendour which is stated to baffle description.

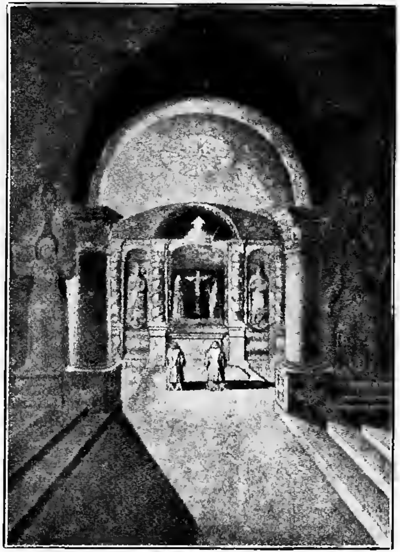

PLATE 35.—St. Anthony's Chapel, hewn out of solid salt.

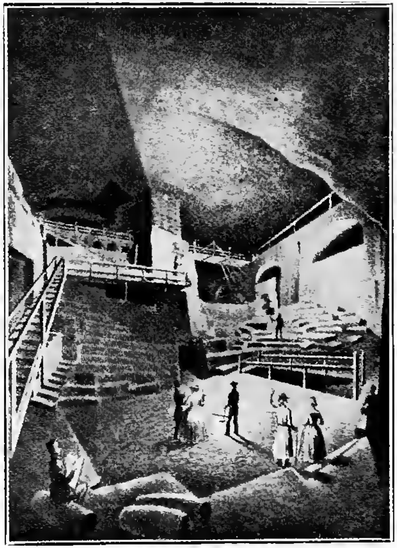

PLATE 36.—A chamber excavated in salt.

SCENES IN WIELICZKA SALT MINE.

Some of the old salt caverns have been converted into stables, the stalls and troughs of the horses being also all of salt. In parts of the mine are subterranean ponds or lakes which have been described by some travellers as being the most wonderful of all the many wonderful spectacles which these salt caverns afford. On them float boats, and some of them are connected by canals several hundreds of feet in length, down which the boats glide from one lofty hall to another, the waters being some 20 feet deep in parts. One visitor thus records his impressions of his journey on these underground waterways:—"Never had a breath of wind troubled the surface of these waters; never had a swallow fluttered above them, or a lily bathed its petals in them. Moreover, as if by an invisible hand, the silent boat floated over the smooth, tranquil surface. We seemed as if in another world, for even the sounds which broke the silence were strange and unfamiliar. We had taken some pieces of salt with us, which we dropped into the middle of the water, and the sound was as if we had struck the deepest bass chord of a harp. The echo lasted several seconds, but did not seem to come from the rocks around, but to be reverberated from the depths of the water." Another visitor uses even more graphic language. He compares the mine to a subterranean city, scooped out of rock salt, as bright and glittering as crystal; he describes how the blaze of lights in general use are reflected from the dazzling columns supporting the lofty arched roofs, which are beautifully tinged with all the colours of the rainbow, and sparkle with the lustre of precious stones, "affording a more splendid and fairy-like aspect than anything above ground can possibly exhibit." However this may be, it is the universal testimony of travellers that the salt mines of Wieliczka are the most beautiful as well as the largest on earth. Everything shines and glitters with the purest brilliancy, and occasionally large masses of salt are found which are as transparent and as pure as the finest plate glass. Plates 32–36 show the Wieliczka mines.

The method adopted in building up out of salt the structures shown in these mines is simple and ingenious. The blocks of salt are cut out and built up in the usual manner and then water is poured over them. The water dissolves a portion of the salt and fills up all the joints, and in evaporating cements the whole together. In this manner walls and ceilings of the greatest solidity are constructed. The air in these mines is extremely dry, and in consequence often exercises a curious preservative effect on animal and vegetable matter. Thus dead horses have sometimes been thrown into abandoned workings, and years afterwards their bodies have been found in a very good state of preservation.

A large number of other salt mines are also known. Thus at Ischl are still shown some huge caverns, many of them being 12 or more feet high and some 10,000 to 12,000 feet in circumference, supported in the middle by massive pillars of rock salt.

At different times fresh water is led into these great chambers by means of pipes and allowed to stand until it has dissolved out a sufficiency of salt, when the waters are drawn off through a deep perpendicular shaft in the middle of the cave, and then conducted through pipes to the evaporating tanks, where they are evaporated for salt.

At Berchtesgaden in Eastern Tyrol, a large subterranean lake has been formed in a salt mine, the waters of which are quite saturated with salt. Over this lake visitors are ferried in their journey through the mines. The gloom of the huge cavern, whose darkness is only rendered the more apparent by the feeble lights of the miners, almost inevitably reminds the reader of the fabled waters of Charon and the River Styx.

There are some very extensive mines as well in America and also in Cheshire. In the latter region the salt is extracted by boring holes through the overlying strata to the salt bed below, and then water is pumped down. When the water becomes saturated with salt it is pumped up into large shallow pans, heated by hot air from a furnace, and allowed to evaporate until it crystallises out. As a rule the shafts of the mine are lined with iron or wooden casings to prevent the inflow of fresh water. In consequence of the dissolving away of extensive beds of salt in this manner the land has, in parts, sunk to an alarming extent, houses, streets, and drainage being involved in general ruin. Indeed quite extensive lakes have been formed on the sites of these salt beds, whole hills being turned into valleys. In countries such as France, very often sea-water is evaporated by being run into shallow lagoons and cut off from contact with the sea. Such salt is called "solar-salt."

But now a curious question will rise in the mind of the reader. He will recollect that I told him that if the whole of the mighty oceans, of average depth nearly 3 miles, were evaporated, they would but yield a layer of salt some 200 yards thick. But here and there we find accumulated masses of salt sometimes nearly a mile thick. From what mighty seas can such immense deposits have arisen? If three miles of sea water in evaporating will leave but 200 yards of salt, surely an ocean of water some fifteen to twenty miles in depth must have evaporated to yield a salt deposit of such immense thickness as those at Wieliczka and Stassfurt!

Such, however, is clearly an impossible explanation. A much simpler one is to hand. What has gone on in past ages at Stassfurt and Wieliczka is even now going on in certain parts of the earth, and so we can explain the immense thickness of these salt beds without making extravagant assumptions regarding the depth of water which has evaporated. On the East coast of the Caspian Sea lies the Kara Boghaz Gulf, a large expanse of water over 2000 square miles (German) in area. It is connected with the Caspian Sea by a narrow entrance some three to five feet deep and 150 yards wide, over which the sea flows in steadily at the rate of about 3 miles per hour. The entering sea contains less than 1 per cent. of salt, yet so great is the evaporation over this extensive body of water, that it is estimated that no less than 128,000,000 tons of salt are being deposited yearly, and that an enormous mass of salt is being formed on the bottom of the Gulf. We do not know for how many thousands of years the process has been going on, or for how many thousands of years it will continue. This is one of the most instructive deposits of salt in the world, since it shows us how, by continuous evaporation, even so weak a brine as 1 per cent. can be made to deposit salt. It is believed that the enormous deposits of salt to be found at Stassfurt and some other parts of the world were formed in a similar manner by the evaporation of shallow seas, the waters of which were continually renewed by more salt water even as the evaporation proceeded.

It is rather an interesting fact that it has been found possible to estimate the number of years it took for the Stassfurt beds of salt to deposit. It appears that every year of evaporation was marked by its own deposit of salt of a few inches in depth, which formed a sort of annual ring; and in the same way that the age of a tree can be determined by counting its rings of annual growth, so also the age of these salt deposits can be arrived at by counting the number of annual deposits. It works out at about 15,000 years.

Of course how long an interval has elapsed, during which the salt beds sunk to their enormous depth and became covered over with rocks and earth, is not given by this estimate. It only gives the time of formation of the beds.

In Africa great deposits of rock salt occur in the eastern part of the Sahara desert. At Tegazza it lies in extensive strata under a bed of rock, and is whiter than the purest marble. There is also an enormous deposit of salt in the Salt Plain of Abyssinia, near the country of Assa Durwa. It is a four days' journey in extent. For the first half mile or so the salt is soft, like snow; but as we penetrate deeper into the plain it becomes hard, and covers the ground like a sheet of crystalline ice.

As we shall see later, in small quantities salt is a necessity for animal and vegetable life, and is a needful constituent for vegetable soils. In large quantities, however, it acts as an antiseptic, destroying life. So that soils impregnated with too much salt soon become lifeless deserts. We read in the Old Testament of cities being destroyed and then strewn with salt so that they may become a desert. And so it is that in parts of the world vast deserts occur, which simply consist of soil too richly impregnated with salt to allow of vegetable life. Thus in Persia are enormous stretches of salt deserts, where all the lakes are salt and every considerable collection of water is impregnated with this mineral. Indeed these salt deserts are among the most striking objects of the scenery of that land; they relieve the general dreariness of the country by a saline efflorescence covering the soil and glistering in the fierce rays of the tropical sun. Every here and there over the white glistering immense plain a black rock protrudes, its image often contorted into a thousand varying shapes by the curious optical effects of the mirage. Similar desolate and forbidding plains exist in parts of America.

And thus it comes about that salt is frequently used as the symbol of sterility. And yet salt is an absolute necessity for life. A full-grown man of 165 lbs. contains about 1·1 lbs. of salt, and requires yearly some 15 to 18 lbs. of salt in order to maintain him in health. Deprive him of this salt and he will most assuredly die. We are told that the Chinese and also the people of Holland at one time killed their worst criminals by feeding them on bread deprived of salt. The gastric juice of the human stomach contains about 0·2 per cent. of hydrochloric acid —no doubt indirectly derived from salt consumed with the food, without which the process of digestion could not continue.

This physiological need for salt manifests itself as a craving for the substance, which becomes especially marked in countries so deficient in salt as to make the procuring of an adequate supply a matter of some difficulty. In such countries the salt becomes a luxury, a delicacy far more expensive and more highly prized than sweetmeats in countries more liberally endowed with salt. Such is especially the case in some parts of the interior of Africa, where the natives are either almost entirely deprived of it, or else can only obtain a scanty supply from time to time by long and costly land carriage. We are told that there is nothing that the Soudanese possess that they refuse to part with for a lump of salt. To them it is stated to be more valuable than gold itself.

The early travellers in Africa frequently refer to this love of salt. Thus Mungo Park wrote: "In the interior countries the greatest of all luxuries is salt. It would appear strange to an European to see a child suck a piece of rock-salt as if it were sugar. This, however, I have frequently seen, although in the inland parts the poorer classes of inhabitants are so rarely indulged in with this precious article, that to say a man eats salt with his victuals, is the same as saying he is a rich man."

In Burdell's travels we read of the valuable articles he bartered for salt, and on one occasion he was forced to send a long distance for a supply, remarking, "those who have never been in want of salt, will scarcely think this small quantity (about a gallon) worth a journey of ninety miles, or that when obtained it should appear to us a valuable and important acquisition." Elsewhere we read how salt is sought after by the children of African villages, and that "when the mother is engaged in preparing the food, the children will stand around her wistfully looking out for a morsel of salt, just as in England little silent gazers are attracted around their mother while making sweetened dishes, in hopes of obtaining a bit of sugar."

In the past, however, this physiological need of salt has led to graver consequences than these. We read of bloody battles between German tribes for the possession of salt springs; while despotic governments, early realising the necessity of salt to men, made a tax on salt the basis of part of a revenue scheme which fell with appalling severity on the poor. Wherever a system of taxation is framed with a view of raising the largest possible revenue, the heaviest burden invariably falls upon the necessities of life, and from almost time immemorial salt has had to bear a heavy portion of this load. In the Old France, before the revolution, the salt tax was enacted with a stringency that raised the price of salt to an enormous value and inflicted great hardships on the peasants.

In Italy, in Spain, and in most other countries the salt tax was enforced, and sometimes this led to extensive smuggling and bloody affrays between the Custom House Officers and the Salt Runners.

Not only is there a need of salt among men, but also among animals as well. The fondness of cattle for licking rock salt is well known, while certain mineral springs or salt marshes—"salt licks" as they are usually termed—are favourite places for ambuscading wild animals, many of whom travel hundreds of miles to get at the salt. Probably the most famous of these "licks" is the Big Bone Lick in Boone County, Kentucky. Thither for immemorial centuries animals have made their way to taste of its saltness, and it is certain that enormous numbers of them found untimely graves here. Most of them, no doubt, in their eagerness to get at the brine, forced their way in beyond their depth and were left sticking in the mud until they died of starvation; others, crowding on their bodies, were engulphed in the yielding morass and were suffocated. The locality appears to have been equally fatal to both large and small animals. In the superficial layers of the swamp we find the remains of animals which were already in the country when the first whites came from overseas to it. Deeper in the mire are found older bones of animals now long extinct, which once roamed in the wild forests of virgin America. Thus there occur the bones of fossil elephants, mastodons, musk-oxen and other animals, dwellers in the land at a time when the last glacial epoch covered the northern regions with a vast sheet of ice, and drove such animals southward. All these animals must be regarded as victims of a craving for salt, to satisfy the physiological needs of their bodies.

Although many animals, and even some men, do not seem to eat salt directly, yet they consume it all the same —or they will die.

They obtain it unconsciously in the food they consume; for salt is contained to a very considerable extent in the structure of all animal and vegetable food.

The vital qualities of salt have long been recognised by

Eastern peoples, who often attach a semi-sacredness to it. By them it is sometimes termed the "Staff of Life" and used to consecrate federal engagements. From this use of it comes the old phrase about a man not being "worth his salt." It is well known that the Bedouin robber will not violate laws of hospitality towards a guest who has once partaken of his salt, and Price, in his *Mahommedan History*, relates a singular instance of this :—

"Yaakoob, the son of Eb-leys Es-Suffra, having adopted a predatory life, excavated a passage one night into the palace of Dirhem, the governor of Seestan ; and after he had made up a convenient bale of gold and jewels and the most costly stuffs, was proceeding to carry it off, when he happened in the dark to strike his foot against something hard on the floor. Thinking it might be a jewel of some sort or other, he picked it up and put it to his tongue ; and to his equal mortification and astonishment he found it to be a piece of rock salt ; for having thus tasted the salt of the owner, his avarice gave way to his respect for the laws of hospitality, and, throwing down his precious booty, he left it behind him, and withdrew, empty-handed, to his habitation. The treasurer of Dirhem repairing on the next day, according to custom, to inspect his charge, was equally surprised and alarmed at observing that a great part of the treasure had been removed ; but on examining the packages that lay on the floor, his astonishment was not less to find that not a single article had been conveyed away. The singularity of the circumstance induced him to report it immediately to his master ; and the latter causing it to be proclaimed through the city that the author of this proceeding had his free pardon, further announced that on repairing to the palace he would be distinguished by the most encouraging marks of favour." We are told that Yaakoob availed himself of the invitation, and, securing the favour of his master, rose to fame and power, and ultimately founded a dynasty.

The next question to be dealt with is the composition of salt. Of what is this body built up? I feel sure that the reader, without a previous knowledge of chemistry, would never guess, and will scarce credit me when I tell him that this white, beautifully crystalline substance, which is so necessary for life and health, consists of yellow gas and soft shining metal, and nothing more! And yet so it is, and the chemist can prove this to you so directly and so simply that you cannot deny the force of his logic and the convincing nature of his experiments. He can, by heating salt red-hot until it melts, and passing an electric current through the molten liquid, resolve it into this yellow gas and the shining soft metal, both of which are well known elements termed, respectively, chlorine and sodium. Then he can take the metal so separated, warm it gently to render it molten, and plunge it again in the yellow gas; and lo, it bursts into flame, and burns back again to pure white common salt, absolutely identical with the substance with which he started. The metal has united chemically with the chlorine to produce salt, according to the equation:

$$\underset{\text{Sodium}}{2\mathrm{Na}} + \underset{\text{Chlorine gas}}{\mathrm{Cl}_2} = \underset{\text{Sodium chloride, or common salt}}{2\mathrm{NaCl}}$$

Could anything be more convincing? I think not.

Of all the facts of chemistry nothing, to my mind, is more wonderful and more surprising than the way in which two elements unite, and as the result of their union bring forth a substance utterly different in every way from the component elements. You may look at salt until your eyes ache, you may examine it through the most powerful microscope yet invented, you may powder it until it is finer than the finest meal, and yet in it you will discover nothing akin to a yellow gas and a soft metal! This, indeed, is one of the strange facts of true chemical combination, and distinguishes a typical compound from a mere mixing or blending of elements.

The metal sodium is one of the most curious known to chemists, and usually delights the heart of the schoolboy beginning chemistry. Firstly, he finds that it is as soft as butter or soap, and consequently amuses himself by cutting it with his pen-knife into silvery shining slices. Then he finds that these silvery slices, when thrown into water, run violently about, evolving hydrogen gas, and often, especially when it comes into contact with some object, such as wet paper, which impedes its free movement over the surface of the water, bursts into furious flame, sometimes with a violent explosion.

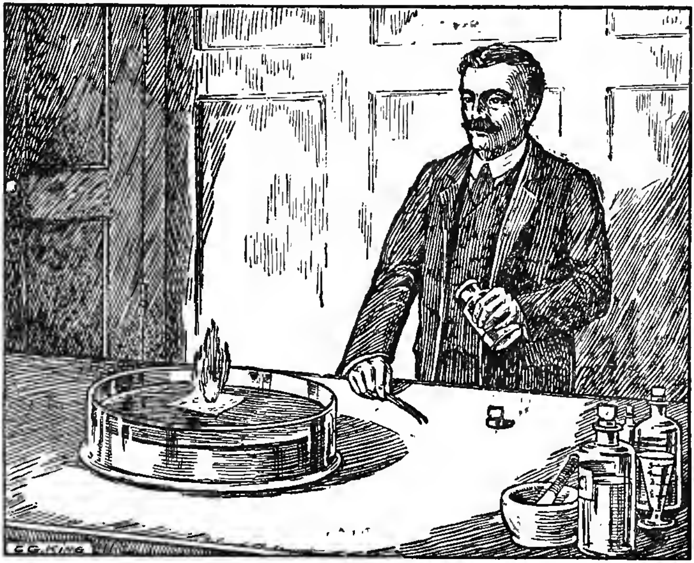

FIG. 22.—Sodium burning on water.

Sodium is now manufactured on a very considerable scale by passing an electric current through molten caustic soda. The sodium comes off at the negative pole, and floats to the surface of the molten liquid. If it were exposed to air it would soon oxidise and perhaps catch fire and burn furiously—for it is very inflammable. To prevent this an iron cap floats above the surface of the liquid, and into this the sodium ascends as it is liberated; the metal is skimmed off from time to time. The sodium thus obtained is used technically on a very considerable scale for making valuable chemicals, such as sodamide, sodium peroxide, sodium cyanide; it is also used for reducing purposes as well.

In large quantities, however, the metallic sodium is a dangerous substance, as is evident by the following event: There sailed from Treport on December 11, 1911, a steamer containing two tons of metallic sodium contained in twenty cases, and stowed in the fore-hatch. The ship encountered a storm; heavy seas swept aboard, and reached the sodium stowed below. Everyone who has handled sodium will know what now happened. Hydrogen was evolved in quantity and a series of violent explosions ensued. I have seen an ordinary pail of water into which a piece of sodium half the size of a man's hand had been cast, split suddenly by the force of the resulting explosion, while a column of water has been shot upwards to the height of a house. So the reader can imagine what took place when the waves began to dash into the two tons of metallic sodium. Now the Captain of the ship was quite ignorant of the nature of the substance (as chemistry is not supposed to help a sea-captain much in his profession) and so he promptly gave the order to play the hose on the sodium. This made matters far worse, and there then bursts forth flames and explosion owing to the inflammation of the escaping hydrogen.

At last the Captain decided to heave the lot into the sea. This was done, and the cases, there meeting with water in abundance, bounded up and down, followed by flaming explosions; many of the cases actually jumped aboard again, like flaming rockets. The vessel also carried tallow, and it melted. The sailors, consequently, were sliding all over the ship, and, to make matters worse, the hold caught fire and the sodium, getting into the engine-room, drove the engineers out. The ship being about to break up, all took to the boats, and shortly afterwards the vessel broke her back and foundered. Many of the men, including the Captain, were badly burned by the blazing, jumping, exploding pieces of sodium, which bounded along all over the ship

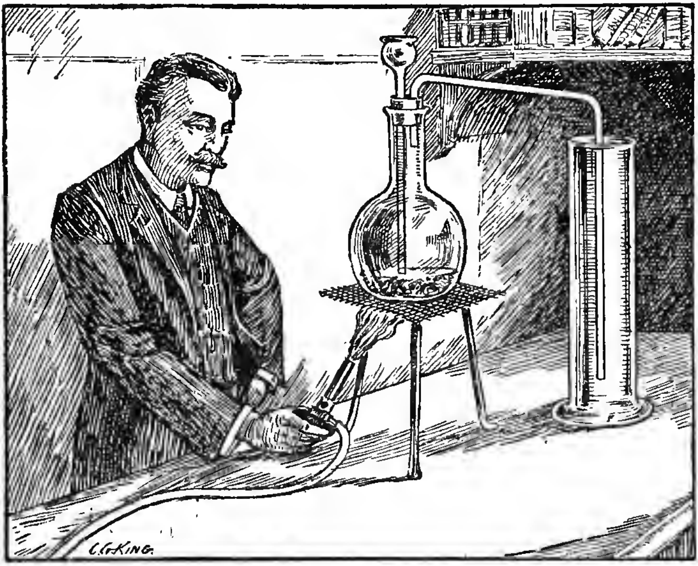

FIG. 23.—Making chlorine gas in the laboratory.

and the surrounding sea. The mate jumped overboard and was drowned.

It will therefore be seen that large quantities of sodium, if allowed to come into contact with water, may cause disaster.

I wish now to say a few words about the second element which builds up salt, namely, the yellow gas, chlorine,—a very strange element, as you will be ready to admit before we have finished.

First of all a word regarding its preparation.

The easiest method of preparing the gas is to heat together a black powder called manganese dioxide with strong hydrochloric acid, when it is rapidly evolved according to the following equation:

$$\underset{\text{Manganese dioxide}}{\mathrm{MnO_2}} + \underset{\text{Hydrochloric acid}}{\mathrm{4HCl}} = \underset{\text{Manganese chloride}}{\mathrm{MnCl_2}} + \underset{\text{Chlorine}}{\mathrm{Cl_2}} + \underset{\text{Water}}{\mathrm{2H_2O}}$$

The gas may also be prepared by heating together common salt, manganese dioxide, and sulphuric acid; when it is generated according to the equation:

$$\underset{\text{Common salt}}{\mathrm{2NaCl}} + \underset{\text{Sulphuric acid}}{\mathrm{3H_2SO_4}} + \underset{\text{Manganese dioxide}}{\mathrm{MnO_2}}$$

$$= \underset{\text{Chlorine}}{\mathrm{Cl_2}} + \underset{\text{Manganese sulphate}}{\mathrm{MnSO_4}} + \underset{\text{Sodium hydrogen sulphate}}{\mathrm{2NaHSO_4}} + \underset{\text{Water}}{\mathrm{2H_2O}}$$

Since the gas is very soluble in water it cannot be collected over that liquid. Usually advantage is taken of the fact that it is nearly 2½ times heavier than air and consequently is collected by merely allowing it to pour into an empty jar, when it displaces the air in exactly the same way that carbon dioxide or sulphur dioxide does.

The best way for the reader to realise the properties of the element so obtained is to imagine himself suddenly transferred to a planet similar in all respects to the earth, except that its atmosphere consists of chlorine gas. Of course we do not know whether planets really do exist with such an atmosphere, but there is no particular reason to suppose that some are not met with occasionally among the myriads thronging space. Indeed chlorine occurs in enormous quantities in the bound state upon the earth. This will appear evident to the reader when we tell him that every hundred tons of salt contains over sixty tons of chlorine, and that the sea itself has been calculated to contain 28,770,000,000,000,000 tons of chlorine[1] in a combined state, while even greater quantities are disseminated through the various rocks and soils which build up the crust of the earth. It is true that, so far as we know, chlorine never occurs in a free state upon the earth; but the reason of this is that the original nebula from which our world condensed contained so small an amount of chlorine relatively to the enormous masses of other elements capable of combining with it, that by the time the whole mass had cooled to the solid state, every scrap of chlorine in it had combined with metals to form compounds called chlorides, of which common salt is only one. Yet it would be folly to presume that this has been the case with every one of the myriads of planets which are known to exist in space. We do not as yet know, with certainty, the causes which determine the relative quantities of the different elements in world-forming matter, and, owing to some special local cause influencing the evolution of the elements in some particular region of space, it may well happen that here and there, scattered through the universe, we may meet with a planet containing such an abundance of chlorine, that this element not only saturates the solid crust of the globe, but also

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[1] Joly, *Radioactivity and Geology*, appendix B.

remains over in excess to form an atmosphere around the planet in much the same way that oxygen and nitrogen gases form an atmosphere around our planet earth.

However this may be, it will be most instructive to imagine the existence of such a world far in the depths of space. We can then predict with scientific exactitude many of the conditions prevailing on its surface, and as these will give the reader a vivid impression of the properties of chlorine, we will briefly relate them.

In the first place the inhabitants of such a world would look up into heavens of a dense yellow colour. Instead of a clear blue sky, like our own, nothing but yellow gloom would surround them.

Distant mountains and plains would show no purple or blue tints, like our own, but would appear of rich yellow tint. Even the seas and rivers, which on our own earth are usually blue, would all possess a heavy yellow colour. The prospect would be much the same as if one gazed through a deep yellow glass, and such a planet would truly merit the name of "The Yellow Planet."

The reason of this is that chlorine gas, even when seen in small quantities, possesses a beautiful greenish-yellow colour, and in very large masses, such as constitutes a planetary atmosphere, would have a much deeper colour, and would probably cut off such a large amount of light that the surface of our new planet would be enshrouded with a sort of gloomy yellow twilight. Indeed, if the atmosphere was very deep, the land below might be wrapt in Cimmerian darkness through which might creep strange forms of life—life which would necessarily be based on an entirely different chemical plan from that which underlies our terrestrial life. That this would be the case follows from the fact that no living being known to science could exist in an atmosphere of chlorine.

If, for example, we attempted to breathe in this chlorine atmosphere we would find that our mouths and nostrils would be immediately filled with suffocating, choking fumes, and we would perish miserably amidst the noxious gas—as indeed many workmen have done upon our earth itself by incautiously entering chambers filled with chlorine gas,[1] as sometimes occurs in the manufacture of bleaching powder (see below).

However, as we shall presently see, if there is water present on this planet, then there must also be free oxygen floating in the atmosphere and diluting the chlorine, and so a breathing apparatus which absorbed the chlorine or which was not sensitive to it, would enable forms of life which depended upon oxygen (as most forms of terrestrial life do) to exist. More probably, however, evolution would take such a form that kinds of life would come into existence which consumed chlorine (a very chemically active element) just as earthly forms consume oxygen. We will, however, not pursue such interesting speculations further, but will now come back to the statement we have

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[1] In the fighting at Ypres in April 1915, the Germans most barbarously caused vast volumes of chlorine to roll upon the British and French trenches and overwhelm the unfortunate soldiers. Observers state that about 4.30 in the afternoon a cloud of yellow-green vapour arose from the German trenches, and rolled on the breeze towards the British and French trenches. The greenish cloud did not rise more than seven feet from the ground, and when it reached the trenches suffocated a number of men. Many men not killed outright died from the after-effects owing to excessive irritation to the lungs. An officer (see the *Times*, May 7th, 1915), who visited the hospital after the affair, thus describes the horrible condition of the injured: "There were about twenty of the worst cases in the ward, on mattresses, all more or less in a sitting position, propped up against the walls. Their faces, arms, hands were of a shiny grey-black colour, with mouths open and lead-glazed eyes, all swaying slightly backwards and forwards trying to get breath. It was a most appalling sight, all these poor black faces, struggling, struggling for life, what with the groaning and the noise of the effort for breath. . . ."

The lungs fill up with a watery fluid, and the men slowly die of suffocation. The savages who deliberately introduced these methods of warfare posed as being the most civilised race of Europe.

just made, viz. that free oxygen must be present in the atmosphere provided only that our new planet contains water.

The reason is this: Water is composed of the two gases hydrogen and oxygen. Now chlorine gas has a very powerful attraction for hydrogen, and under favourable conditions will actually decompose water, setting free the oxygen gas and forming hydrochloric acid, thus:

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

This can be shown by quite a simple experiment. Chlorine gas is very soluble in water, the solution appearing yellow and tasting and smelling like the gas. Now if we fill a glass jar with this solution, and invert it in a large basin filled likewise with chlorine water, and if we place the whole apparatus in such a way that bright sunlight can fall upon it (best out of doors on a bright summer day) we shall distinctly see arising through the liquid small bubbles of oxygen gas, which gradually collect at the top.

That this gas is oxygen can be very easily proved by collecting a little and then testing it by means of a glowing splinter of wood, when the splinter should burst into flame. Other chemical tests can be applied which make the matter certain.

The reader, therefore, will now perceive that if the oceans which roll over the surface of this chlorine planet are saturated with chlorine gas, then any sunlight which falls upon such waters will in the course of time cause vast masses of oxygen gradually to accumulate in the atmosphere. Thus water cannot be a stable form of matter on this new planet.

The chlorine must be continually decomposing it, stealing its hydrogen, and setting free its oxygen. Consequently as time goes on the volume of waters will steadily diminish, but will not entirely disappear, provided the water contains enough chlorine, since it has been shown that when the amount of chlorine in the water exceeds a certain limit such water ceases to decompose further in sunlight.[1]

Moreover the seas will not be neutral liquids, like our seas. They will be all strongly acid, being nothing else than strong solutions of hydrochloric acid. Such waters could not be drunk by us, or other terrestrial creatures, without fatal results; however, strange to say, in our own stomachs quite appreciable amounts of hydrochloric acid occur, something over 0·2 per cent. being found in the

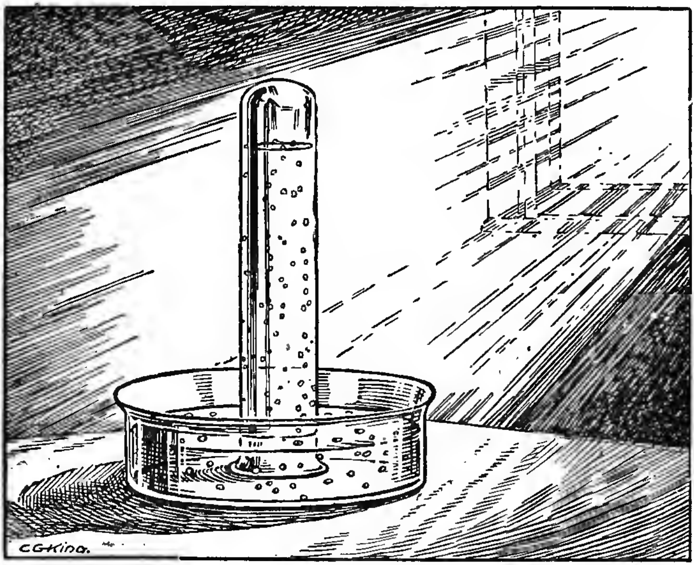

FIG. 24.—Sunlight decomposing chlorine water, oxygen gas being liberated.

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[1] See A. Pedler, *Trans. Chem. Soc.*, 1890, 57, 613.

gastric juice: it helps in some way in the digestion of our food. It must also be remembered that acid waters are not entirely unknown on our own earth. This is especially the case in volcanic regions. Enormous quantities of hydrochloric acid are belched forth by the volcanoes of South America, and from the sides of such volcanoes often there run out strongly acid streams. Thus, the waters of the Rio Vinagre in Mexico contain nearly 0·1 per cent. of free hydrochloric acid. And each year there runs to waste in this river no less than 14,000,000 tons of this acid.[1]

Some years ago at Santorin, near the little village of Vulcano in the Mediterranean, such large quantities of hydrochloric acid came up from below into the sea that the waters of a creek were quite acid, and ships used to anchor here so that the shellfish, &c., clinging to the bottoms and fouling them, were killed. This creek was later filled up with lava rising from the bottom of the sea.

However, what is on our world an isolated and rare phenomenon, would be in this "Yellow Planet" of ours the normal condition of affairs.

Another curious condition on this planet would be the absence of most organic colouring matters. The beautiful greens, blues, pinks and reds, which characterise our vegetation and flowers and give us a never-failing sense of satisfaction when we feast our eyes on them, would certainly be absent from this chlorine world.

The reason is simple. Chlorine gas, and also its solution, is one of the best bleaching agents known. A coloured piece of cloth, such as a red handkerchief or a carpet, is soon turned to a white colour when plunged into the moist gas, and this property is utilised in the preparation of bleaching powder. From this property of chlorine vast industries have arisen, in which thousands

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[1] See Boussingault, *Compt. rend.*, 1874, 78, 453, 526, 593,

of workmen are employed and millions of money are invested.

But this brings us to another point, which must be discussed here. Will the same chemical actions which take place on our earth still go on in this new chlorine planet? For example, would it be possible to light a candle or to smoke a cigarette? In many gases, such as the inert gas nitrogen, which forms the bulk of our own atmosphere, we know that under such conditions we could not light a match or make a fire (see the author's book, *Triumphs and Wonders of Modern Chemistry*, Chapter IX, where this point is discussed).

However, this would not be the case in an atmosphere of chlorine. A candle or oil-lamp would burn in it, but in a very remarkable way, showing a blood-red flame, something like the colour that the sun presents when setting through a fog on a cold winter's day.

Another curious thing that we would notice is that immense clouds of soot would arise from it. The reason is simple. Candle-wax and oil consist principally of combined carbon and hydrogen. Chlorine has a very great chemical attraction for hydrogen, and hardly any for carbon. Consequently it combines with the hydrogen, evolving heat and light and forming a flame, while carbon is set free as soot. Indeed this great affinity of chlorine for hydrogen is one of the most remarkable characteristics of the element. For example, turpentine oil is a harmless enough substance in ordinary air, but it is spontaneously inflammable in an atmosphere of chlorine. In the laboratory it is a favourite experiment to soak blotting paper in turpentine and then plunge the whole into a jar filled with chlorine, when it takes fire and burns in the way described. The reason is that chlorine possesses such an affinity for hydrogen that it withdraws this element from carbon, with the evolution of heat and light.

The action which takes place is explained by the following equation:

$$\underset{\text{Turpentine}}{C_{10}H_{16}} + \underset{\text{Chlorine}}{8Cl_2} = \underset{\text{Hydrochloric acid}}{16HCl} + \underset{\text{Carbon}}{10C}$$

The great chemical attraction of chlorine for hydrogen may be shown in another way. Returning, for instance, to the chlorine-saturated seas of our new planet, the reader will remember that I said that these waters would necessarily be strongly acid. Now acid solutions evolve hydrogen gas when iron is dropped into them (see under Hydrogen, *Triumphs and Wonders of Modern Chemistry*).

If therefore we dropped into such waters a large quantity of iron or other metal, hydrogen would be liberated and would react with the surrounding chlorine gas, causing a series of explosions. The water in the neighbourhood of the uprising hydrogen would become very hot, and might even be hurled into the air, with a violent explosion, provided that enough hydrogen was liberated. The reason is that it has been proved that hydrogen and chlorine gases in the presence of sunlight spontaneously unite at ordinary temperatures, forming hydrochloric acid gas, thus[1]:

$$H_2 + Cl_2 = 2HCl$$

Indeed the experiment may become dangerous. For example, if in the laboratory a mixture of equal volumes of hydrogen and chlorine be made in the dark, no immediate combination occurs. If now the mixture be brought out into diffused daylight a slow combination will take place; but if the whole be placed in bright sunlight, or even if a piece of magnesium wire be allowed to burn in the

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[1] As a matter of fact the mechanism of the changes which take place when hydrogen and chlorine gas unite under the influence of sunlight is by no means satisfactorily understood. Many curious results have been brought to light, and further research is urgently needed on this subject.

neighbourhood, the two gases, under the chemical stimulus of light, combine suddenly with a powerful explosion, and if the mixture be confined in a glass flask, will shatter it into a fine dust, while at the same time a deafening concussion will startle the experimenter.

The novelist has already seized upon some of these scientific facts to weave romances which often strike the man unacquainted with science as far-fetched—a curious illustration of the old maxim that "Truth is stranger than Fiction." One of the latest essays in this direction is a plot whereby the villain of the piece proposes to destroy his victims by sending them up at night in a balloon under which is fixed an envelope containing a mixture of hydrogen and chlorine. As soon as the sun rises and its

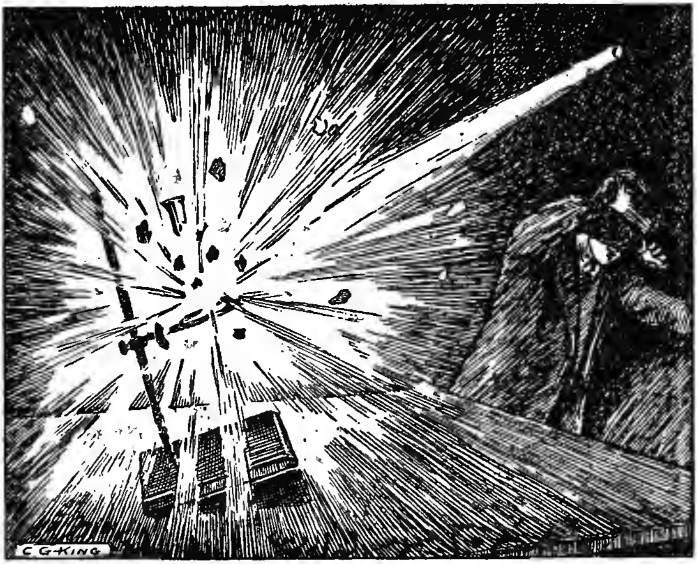

FIG. 25.—Explosion of hydrogen and chlorine gas by ray of sunlight entering through a hole in a shutter.

rays strike this envelope the explosion destroys with a vivid sheet of flame all evidences of the crime! Many of H. G. Wells' novels and also those of Jules Verne are remarkable illustrations of the facts of science being applied to create interesting situations. And it is safe to predict that, as scientific education becomes more widely spread, this class of fiction will be more and more read.

The affinity of hydrogen for chlorine can be shown in another remarkable way. If the reader fits up a hydrogen generating apparatus, provided with a fine glass jet through which the hydrogen issues into the air, then on lighting the jet of hydrogen and plunging it into a jar of chlorine, the hydrogen will continue to burn, forming hydrochloric acid gas.

Chlorine is manufactured in very large quantities for making bleaching powder. Often it is compressed in a liquid form in iron cylinders and sold to manufacturers who need a supply of it. In order to make bleaching powder, its most largely used compound, lime is spread in thin layers on the floor of stone chambers and chlorine passed in. When the chlorine is nearly all absorbed workmen enter and turn over the lime so as to expose a new surface to the action, and the process of passing in chlorine is then repeated. When the lime is saturated with the gas, the manufacture is ready. The lime holds the chlorine in a more or less unstable form of combination, and when the whole is placed in water gives a solution which possesses strong bleaching properties, owing to the presence of complex chlorine compounds called hypochlorites. However, we cannot discuss here the subject further, and the reader interested in the process should consult one of the many treatises on technical chemistry now published.[1]

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[1] For example the author's work, *Industrial Chemistry*, vol. ii., gives a full account of the whole subject.

Chlorine, of course, forms many important and interesting compounds.

One of the most interesting of these is hydrochloric acid, to which we have frequently referred in the preceding pages. Hydrochloric acid, HCl, is a heavy colourless gas. It is immensely soluble in water, forming a corrosive acid solution known under the names "hydrochloric acid" and also "spirits of salt." It may be easily prepared by heating together common salt and strong sulphuric acid (oil of vitriol), when it is evolved according to the equation:

$$\underset{\text{Salt}}{NaCl} + \underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\text{Acid sodium sulphate}}{NaHSO_4} + \underset{\text{Hydrochloric acid}}{HCl}$$

This, too, is manufactured on a large scale during the preparation of "salt cake," or sodium sulphate, Na_2SO_4, which is a chemical much used for making glass, soda, &c. It is made by heating together in special furnaces sulphuric acid in salt in such proportions as roughly correspond to the equation:

$$\underset{\text{Salt}}{2NaCl} + \underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\substack{\text{Sodium sulphate} \\ \text{(salt cake)}}}{Na_2SO_4} + \underset{\text{Hydrochloric acid}}{2HCl}$$

A vast industry has now arisen out of this reaction, and yet in the early days the hydrochloric acid was allowed to escape freely from the furnace chimney into the open air, as it was practically worthless. As the industry developed, principally in England after 1823, these huge amounts of acid gases so contaminated the air for miles around the works that the vegetation died, nothing would grow, and the farmers began to bring actions for damages against the manufacturers. The latter sought to eliminate the effects by building enormously high chimneys, and in Lancashire, at St. Rollox, enormous stacks projected upwards into the air for over

450 feet. But all in vain. The heavy acid fumes sank downwards, forming dense clouds of acid smoke and mist, which involved the whole neighbourhood of the works in mist and gloom. What was worse, as the number of factories increased the amounts of hydrochloric acid thrown into the air steadily became larger, and so serious was the damage that Acts of Parliament were passed to forbid the free escape of acid fumes. Thus the manufacturers, faced with ruin, were compelled to trap their fumes. This was first done successfully by Gossage in 1836, by passing the gases up tall towers filled with coke, down which water trickled.

The water dissolved out the acid, while the purified furnace gases escaped into the air. So perfect at the present day is this condensation of the acid fumes that it is rare now (and also illegal) for more than 0·2 grain of hydrochloric acid to escape per cubic foot of gas issuing from the chimneys.

A practical consequence also sprang from this nuisance. The hydrochloric acid, at first a waste product and an intolerable nuisance to everyone concerned, was found to be very valuable for making chlorine gas as the latter was discovered to be absolutely necessary for bleaching various substances used on the large scale in industry. So that ultimately the manufacturers found it quite profitable to condense their acid and sell it, instead of wasting it as before.

Chlorine is one of a family of elements, all of which betray a considerable chemical resemblance to each other, which, however, decreases as the magnitude of the atomic weight increases. These elements are known as "The Halogen Group" and exhibit a regular and gradual change of properties.

Fluorine, atomic weight 19, very pale greenish yellow gas.

Chlorine, atomic weight 35·5, yellowish gas, of deeper tint than fluorine.

Bromine, atomic weight 80, dark red, easily volatile liquid.

Iodine, atomic weight 127, a blue black easily volatile solid.

Fluorine is altogether remarkable on account of the wonderful chemical activity it displays. It possesses much the same properties as chlorine but in a far more intense form. Thus it combines explosively with hydrogen in the dark, instantly decomposes water, evolving oxygen in the form of ozone, and liberates chlorine from its combinations. Sulphur quickly melts and takes fire in the gas. Iodine, bromine, phosphorus, arsenic, and antimony, combine with it with incandescence; crystallised silicon, amorphous boron,and even finely powdered carbon, such as charcoal or lampblack, take fire when plunged into fluorine and burn with the formation of fluorides. Metals like magnesium, aluminium, manganese, nickel, and silver when slightly warmed burn brightly in the gas. Gold, however, is not attacked at ordinary temperatures, but between 300° C. and 400° C. becomes covered with a yellow coating of gold fluoride. Even at the lowest temperatures attainable, fluorine retains its chemical activity largely unimpaired. Thus Moissan and Dewar immersed a tube of fluorine in liquid hydrogen, and when the fluorine had attained the surrounding temperature of the hydrogen (–252° C.) the tube was broken. Instantly a violent explosion took place with incandescence and complete destruction of the vessel containing the liquid hydrogen. Its combining power with other elements, however, is somewhat diminished at the lowest temperatures to which we can attain. Thus it does not liberate iodine from potassium iodide at these low temperatures, nor does it then combine with elementary iodine. Needless to say, a single breath of this intensely active gas would wreak such damage to the lungs as to cause death. Indeed, so chemically active is the substance that probably if a living creature were thrown into a large gasometer full of fluorine, the animal would take fire almost instantly and burn away. Glass vessels are rapidly attacked by the gas, and so it is very difficult to store for any length of time.

We could, if we had space, construct from the known properties of this wonderful element a picture of the conditions which would prevail on the surface of a planet whose atmosphere consisted solely of fluorine. However, we leave this as an exercise to the reader, and the wonderful results obtained will not fail to make him realise forcibly the remarkable features of the element.

But now let us return once more to common salt. We have in the preceding pages studied its occurrence, its properties, and discussed its constitution and the nature of the elements of which it is built up.

We have seen that it is indispensable to man and beast and herbs as part of their nutriment. But now a word regarding its industrial use. Salt itself is the basis of great industries, which maintain millions of people, directly or indirectly, in health and employment throughout the world. Thousands of factories, whose lofty chimneys rear themselves in the air, hum and throb with life on account of salt.

Let me mention, for example, some of the great world-industries of which salt is the raw material, the life-blood from whence streams almost endless wealth.

Let us take them in historical procession, as they arose to alter the civilisation of a world, to give rise to the modern age of industrial wealth. First of all came the manufacture of washing soda by the Leblanc Process. The salt is first heated with sulphuric acid, which converts it into sodium sulphate ("salt-cake") and hydrochloric acid is evolved—(from which springs the basis of chlorine manufacture for bleaching powder). The salt-cake or sodium sulphate is next heated in great furnaces with a charge of limestone and coal to form "black-ash," and the black-ash when treated with water yields soda or sodium carbonate on evaporating. Now, by causticising with lime, we can get the sodium carbonate converted into caustic soda, which serves as the basis of soap manufacture. By electrolysing solutions of salt we get bleaching fluids, chlorates, chlorine, hydrogen, caustic soda, and a whole series of similar products, which form the basis of giant industries. Cheap soap, cheap bleaching powder, cheap glass, and a thousand other chemical products of great importance all spring directly or indirectly from salt as the mother substance.

Think, too, of the vast amounts of salt used for seasoning food, for preserving meat and fish, for glazing common pottery, drainpipes and similar wares, and the reader will obtain some faint conception of the use that salt is to us.

Thus, in a thousand scarce dreamt of ways, salt directly or indirectly ministers to our comfort, our pleasures, our needs and our civilisation. Salt, in fact, is one of the most useful of chemicals.

And thus, I think, the reader will see that even a substance like salt, which at first sight seems an uninteresting and prosaic substance enough, is really, when properly viewed, one of the most interesting of bodies, with a romance as great as that attaching to almost any other substance. Salt, in fact, is interwoven with the history of man and beast and plant, in a way which, at first sight, would seem scarcely credible.

CHAPTER XIV

METALLIC FIRESTONES[1]

SOME thirty years ago Auer von Welsbach founded the rare earth industry by utilising thorium and cerium oxides for the manufacture of incandescent mantles.

Quite recently a new industry has developed out of this older industry, namely that of the so-called "pyrophoric alloys," which possess the extremely remarkable property of giving rise, when struck by a sharp or hard surface, to such a copious abundance of brilliant sparks, that cigars, cigarettes, gas and other combustible substances may be readily lighted by their aid. These alloys have now been placed on the market as a more or less successful substitute for matches, and the new industry is making rapid headway.

The originator and moving spirit of this new industry was again Auer von Welsbach, and the discovery arose in this manner.

It is well known that practically the sole commercial source of the thorium for incandescent gas mantles is monazite sand, which is a mixture of the phosphates of the rare earth metals, having the following composition :

ThO_2	5–7	per cent.
Ce_2O_3	25–35	,, ,,
La_2O_3 Pr_2O_3 Nd_2O_3	20–30	,, ,,
P_2O_5	25	,, ,,
SiO_2	1–4	,, ,,

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[1] Reprinted, with slight alterations, from *The Chemical World*, by kind permission of the editor, Mr. W. P. Dreaper.

It will be seen, therefore, that in this substance only a relatively small proportion of thorium is present—5 to 7 per cent.—the rest consisting of rare earths of the cerium group. Now the mixture of rare earths which gives the brightest light to an incandescent mantle consists of 99 per cent. thorium and 1 per cent. ceria, and consequently for the purpose of incandescent mantle manufactures all the thoria is extracted from the monazite sand, but there remains over a great bulk of useless rare earths, amounting perhaps to 75 per cent. of the whole, and consisting of Ce_2O_3, La_2O_3, Pr_2O_3, Nd_2O_3, &c. In fact outside the thoria factories little mountains of these waste rare earth oxides have accumulated in the course of years, and as about 3000 tons of monazite sand is now worked up yearly for thoria, it will be readily understood that the profitable utilisation of thousands of tons of these waste earth residues has long been a pressing industrial problem.

Welsbach turned his attention to the matter and in 1903 made the discovery on which is based this new industry. From the waste cerium residues he prepared the metals by the electrolysis of the fused alkali chlorides, using as negative pole a piece of iron wire. On this he obtained a lump of metal, which he then began to cut away with a knife. He now observed that the outer layers of metal, which consisted of practically pure cerium, cut away without any "sparking" effect, but that as he approached the inner core of iron a vivid display of sparks attended the cutting operation, and that moreover the nearer he approached the internal iron core the more pronounced became this effect. On investigating the matter he traced the "sparking" effect to the presence of iron in the cerium metals, the outer non-sparking layers consisting of iron-free practically pure cerium metals, while the internal layers were more and more contaminated with iron the nearer the central iron core was approached.

Perceiving the industrial possibilities of this chance observation, Welsbach at once set to work to prepare a series of alloys of the cerium metals with iron. He found that the greater the percentage of iron in the cerium metal the more pronounced is its property of giving an array of bright sparks when scratched or rubbed, the effect reaching a maximum with alloys containing 30 per cent. of iron. Similar effects were exhibited by alloys of nickel or cobalt with the cerium mixed metals—as the mixture of metals obtained by reducing the mixture of rare earth oxides left over after the separation of thoria is called—and in 1903 he took out his famous patent D.R. Patent, No. 154807, Klasse 4e (31st July 1903); British Patent 16853/03. Welsbach succeeded in selling this patent to the Pyrophoric Metalgesellschaft A.G. of Köln-Braunsfeld for the large sum of 600000M. (=£30,000) and also disposed of the foreign rights on advantageous terms, the English rights being secured by the British Pyrophoric Metal Co. of Leeds.

No sooner, however, had these new companies begun successfully to put these "fire stones" on the market than difficulties arose. In Germany as in other countries a new terror to civilisation has arisen in the clever "patent" lawyers, whose business it is to discover flaws in the patents of profitable inventions, and soon the Pyrophoric Metalgesellschaft was involved in the throes of most expensive litigation with rival companies, with the result that the patent was in part upset. Welsbach, however, who was under no obligation to return the purchase money if this patent was upset, obtained, what few inventors do, the full profits of his invention.

It should be particularly noted that for the manufacture of these alloys pure cerium is never used, but "technical cerium" or "cerium mixed metals," which are an alloy of rare earth metals, consisting mainly of cerium, but containing a considerable amount of lanthanum, praseodymium, didymium and neodymium. Although a considerable sparking effect is attainable with alloys containing anything between 10 and 65 per cent. of iron, the alloys usually sold for the purpose contain about 35 per cent. of iron and 65 per cent. of the cerium mixed metals. The cerium mixed metal is usually obtained by the electrolysis of the molten chlorides, but every precaution has to be taken to exclude air, as the metal is extremely oxidisable. Cerium, in fact, is one of the most reactive metals known. It absorbs hydrogen and nitrogen quite readily, while when heated in an atmosphere of carbon dioxide or carbon monoxide it simply decomposes them, extracting their oxygen and depositing carbon. Consequently it is impossible to obtain a gaseous atmosphere (if we except the argon group of elements) indifferent to cerium. So reactive is it that it unites with antimony and arsenic with a violent explosion, and the temperature is so high that the bottom of the porcelain crucible melts, allowing the white-hot alloy to pour through in a blazing condition. Cerium, therefore, is a difficult substance to work with, and so only five years ago the cerium alloys were high in price. By means of processes, which naturally are kept secret, the process of manufacture has been so improved recently that the British Pyrophoric Metal Co. of Leeds was putting the alloys on the market at 42*s.* 6*d.* per lb.

The alloys of the cerium mixed metals with iron are usually known as "Auer-metal," sometimes as "cerium-iron," and for hardness or durability in air are among the best of such preparations. However, this "Auer-metal" soon encountered a serious rival in the "Kunheim" metal, which was cheaper and lighter. This latter alloy was patented by the firm Kunheim & Co. (Patent K. 39885, Kl 78f 25 Jan. 1909), advantage being taken in this patent of the fact that the cerium metals readily combine with hydrogen to form hydrides. First of all an alloy of the mixed cerium metals is made with magnesium and aluminium, and then this is heated in an electrically heated muffle furnace to a temperature of 500° C., while a stream of hydrogen is passed over the surface until no more is absorbed. Finally the alloy is allowed to cool in the stream of hydrogen gas. The quantity of hydrogen taken up corresponds to the complete transformation of the cerium metals into hydrides, 1 gram of the alloy absorbing 130 to 150 c.c. of Hydrogen gas. By means of this "hydrogenation" process the magnesium-cerium alloy is made very reactive as a sparking agent, and without this treatment the alloy seems to be technically unsuitable for the purpose. It is a curious fact that whereas the pure hydrides of the individual cerium metals rapidly oxidise in the air (and so become useless) and also lose a great part of their hydrogen at a red heat, the mixture of metals yields hydrides so stable that they can be heated in air to a red heat without losing much hydrogen. Also the temperature at which the mass is treated with hydrogen is very important, as the stability of the alloy in air is largely affected by this.

The composition of one of these "Kunheim" pyrophoric alloys is given as follows:—

Cerium	36 per cent.
Other Cerium Metals . .	49 " "
Magnesium . . .	10 " "
Aluminium . . .	1 " "
Iron	0·5 " "
Silicon	0·5 " "
Hydrogen . . .	1·3 " "
Traces of Be, Zr, Ti, &c. .	

The cause of the sparking is generally attributed to the fact that the cerium metals are readily oxidisable and when heated burn. When a piece of an alloy is struck with a sharp or hard surface, small particles are knocked off and the heat of friction raises these to their ignition temperature and they fly off burning brilliantly. The reason why the pure individual metals do not show this effect nearly so markedly as the impure alloys is stated by Kellerman to be due to the fact that when the pure metals are used relatively large particles are detached and the heat of friction is not sufficiently great to set these alight; whereas when impure alloys are used smaller particles are knocked off and the heat of friction heats these more highly than it can larger particles, so that they take fire and burn as they fly through the air.

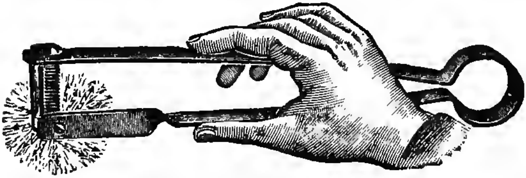

FIG. 26.—Simple gas-lighter.

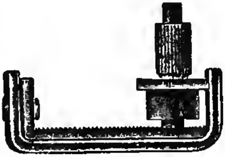

FIG. 27.—Section of gas lighter.

A few facts about the extent of this new industry may be interesting. In 1911, from 8000 to 10,000 Kg. of these "pyrophoric alloys" were placed on the market, and as from each kilogram of alloy from 3000 to 4000 "firestones" can be made, the number of "firestones" annually produced goes into tens of millions. One of these small "firestones" will give from 2000 to 6000 ignitions—and so is equivalent to from 2000 to 6000 matches—before being used up.

Their mode of employment is shown in Figs. 26 and 27, which illustrates a simple gas-lighter, Fig. 26 being a bird's-eye view and Fig. 27 a section. A piece of the pyrophoric alloy is affixed to the end of an arm movable by pressure like the arms of a sugar-tongs. When the arm is pressed the alloy is rubbed right across a file-like iron or steel surface attached at right angles to the end of the other arm, and the slight friction thus caused makes the pyrophoric alloy give out a brilliant shower of blazing sparks, which then ignites any gas in the neighbourhood.

Its use as a cigarette-lighter is shown in Fig. 28. At the top of a small metal box (sometimes shaped like a cigarette, sometimes of larger size), filled with oil and provided with a wick, there is affixed a small piece of pyrophoric alloy, and above this is a steel cogwheel, which can be pressed against the alloy. When the cogwheel is rotated by pressure of a finger, the rotating cogs strike against the pyrophoric alloy just below and detach a shower of brilliant sparks, which then lights the wick.

FIG. 28.—Cigarette lighter.

In some forms, the piece of pyrophoric alloy is placed in a box whose lid is actuated by a powerful spring. When a knot is pressed, the lid flies open and the spring simultaneously sets into rapid motion a steel cogwheel with a rough edge, which while rotating strikes off a shower of sparks from the alloy and so automatically lights a wick.

In France, especially, where the match industry is a monopoly in the hands of the Government and consequently matches are dear, this new industry has made very considerable headway.

As regards its future development and the ultimate replacement of the ordinary match by such alloys, only a very bold man would care to make a definite prophecy. The invention, in fact, is a highly efficient revival of the old "flint and tinder" method of obtaining fire which was in use before the advent of the match, and now this long-dead industry appears without warning to have suddenly flickered up into life again.

The writer wishes to thank Mr. Wilson, of the British Pyrophoric Alloy Co., Leeds, for information regarding these alloys.

CHAPTER XV

ARTIFICIAL PRECIOUS STONES[1]

THE love of bright, glittering stones is a deep-seated instinct of human nature. As far back into the immemorial past as we can penetrate we always find that men and women loved to adorn themselves with vividly coloured gems, which they from time to time discovered in the sands, rivers, and rocks of the lands which they traversed. In fact we find that even in very early times a regular traffic in precious stones took place, and as the people who had the greatest power of purchasing them naturally belonged to the noble and wealthy classes, very large amounts were given for stones of peculiar beauty.

Now natural precious stones only occur rarely—indeed their value is largely due to their rarity—and the search for them in the rocks and earth is a matter of great labour and uncertainty. It is not therefore surprising that even at a very early stage of the world's history mankind has dreamt of the artificial production of precious stones as a means of rapidly acquiring wealth. The get-rich-quick spirit is no thing of modern growth, as is sometimes supposed, but is as old as human nature itself. We find plenty of evidences of it in the old civilisations of Egypt, Babylon, Greece and Rome.

Thus the ancient Egyptians only rarely cut their scarabs in genuine turquoises. The great majority were made in a blue pottery. The old Romans did a large

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[1] The illustration accompanying this article was taken from an excellent article on the subject by Mr. Noël Heaton, B.Sc., F.C.S., which appeared in the *Chemical World* for March 1912. Permission to reproduce the illustration was kindly given by Mrs. Heaton.

and flourishing trade in sham jewellery, by imitating the various transparent coloured gem-stones by coloured glass.

Pliny states that in Arabia it was the custom for the Arabs to boil agates in honey for seven days and seven nights, whereby they become marked by striæ, veins, and spots, and are thus rendered more beautiful as ornaments. He thought that the boiling in honey freed the stone from all earthy and impure materials. There is no doubt, however, that Pliny only knew half the secret. It appears that many agates are permeable to liquids, and the object of boiling the stones in honey was to saturate the stone with this substance, which on heating was carbonised, and thus black and brown veins and spots were produced in the stone itself. The Roman lapidaries kept this process very secret, and for many centuries they came to the valley of the Nahe (where rich agate-quarries existed and which is still a very important centre of the agate industry) and bought up badly coloured agates and coloured them at home, by boiling the stones in honey and then soaking them in sulphuric acid, whereby the sugar was carbonised and the agate artificially darkened. This process was revealed some years ago by a tradesman from Idar who, while imprisoned in Paris for debt, met a Roman lapidary, who betrayed the secret knowledge of his craft.

In a somewhat similar manner chalcedony can be so cleverly coloured a delicate green by impregnating it with chromium and nickel salts as to make it almost indistinguishable from the more expensive chrysoprase. Nowadays, too, the colours of some natural stones are altered by exposing them to radium emanations and also by heating; for example zircon (see list of precious stones, p. 340) is often decolorised by heating and is sometimes sold under the name "matura diamonds."

Swindlers often smear violet ink over the surface of a yellowish or badly coloured diamond, and so pass it off as a more valuable colourless gem.

In mediæval times a great deal of ingenuity and labour was expended on the artificial production of precious stones, but with practically no success, since an accurate knowledge of the composition and nature of the minerals was wanting, and the methods adopted were based on superstition. Much more success, however, was achieved in producing *imitations* of precious stones by means of different coloured glasses, and at the present time many such "pastes"—as these glittering glasses are called — are employed for the manufacture of sham jewellery. A few words, therefore, about this material may be interesting. The glass most extensively used is prepared by heating together to a molten mass a mixture of powdered rock crystal, red lead, and potassium carbonate, together with small proportions of borax, white arsenic, or saltpetre.

Varieties with very high refractive indices are made by replacing the potassium carbonate by thallium salts. All the materials must be perfectly pure, and the fusion must be carried out so that the molten liquid is free from bubbles or streaks. When it is required to colour the glasses the manufacturers add such things as gold chloride, cuprous oxide or purple of Cassius for imparting a *red* tint. *Blue* is achieved by cobalt oxide, *green* with cupric oxide or chromic oxide, while fine *yellow* tints are obtained by adding silver chloride or antimony oxides.

Marvellously clever imitations of the various precious stones are now made by means of these glasses, so that without examination they would be readily mistaken by a non-expert for the genuine article.

No expert, however, would for a moment be deceived even by the best modern "paste." He could detect such an imitation with certainty in a few seconds, Indeed, since mineralogy has become a science it is known that all such imitations are very inefficient. In the first place all gem stones are transparent crystalline bodies of high specific gravity and considerable refractive power; that is to say, light rays on entering them at an angle are widely bent from their original course. In fact, the index of refraction varies from 2·42 in the case of the diamond to 1·54 for amethyst and other varieties of quartz. Now it is possible to produce optical glass having a refractive index as high as 1·96; so that, with the sole exception of the diamond, it is possible to match the refractive index of every stone. However, it is now known that the refractive power of glass can only be increased beyond a certain limit at the expense of its hardness and chemical stability. So that these highly refractive glasses not only discolour to a dark leaden tarnish and corrode in air, but also can be readily scratched with a thimble; whereas your true gem stones are hard substances which cannot be readily scratched and do not alter in air.

Human beings, however, are very clever, and some of these defects of sham jewellery are eliminated by coating the glass with a harder material, such as rock-crystal or colourless topaz. This avoids the effects of abrasion in wear and the chipping and staining of the surfaces. Such counterfeits, of course, can be readily detected when the *unmounted gem* is viewed sideways, but when it is mounted in its setting detection is not quite so easy, since the brilliant glass beneath the facing gives its fine colour to the whole.

However, all glasses are amorphous, and hence are single refracting (*i.e.* bend the light equally no matter from which side the light enters the stone), whereas the natural gems are crystalline and are usually double refracting (*i.e.* bend the entering light differently according to the direction in which it passes through the stone) and this causes them to exhibit certain very pretty optical effects. The diamond, garnet and spinel, however, are single refracting.

On account of these circumstances modern scientific research has been more and more concentrated on the artificial production of stones actually identical in composition with those occurring naturally.

Obviously, only those precious stones which command a high price are profitable to make artificially. It is no use producing stones so common that the natural variety barely differs in price from the artificial.

The following table shows the composition of some of the principal precious stones :

COMPOSITION OF THE PRINCIPAL PRECIOUS STONES

CHEMICAL TYPE.	SPECIES OF STONE.	VARIETY.	COMPOSITION.
Element	Diamond	......	Carbon.
Oxides	Corundum	Ruby Sapphire Oriental Amethyst	Aluminium oxide.
	Quartz	Rock Crystal Amethyst Cairngorm	Silica.
Silicates	Opal	......	Hydrous silica.
	Beryl	Emerald Aquamarine	Beryllium aluminium silicate.
	Topaz	......	Aluminium hydroxy fluo-silicate.
	Tourmaline	......	Alkali-lime alumina silicate.
	Sphene	......	Calcium titanium silicate.
	Garnet	Hessonite	Calcium aluminium silicate.
		Pyrope	Magnesium aluminium silicate.
		Demantoid, &c.	Calcium iron silicate.
	Spodumene	(Kunzite)	Lithium aluminium silicate.
	Olivene	(Peridot)	Magnesium iron silicate.
	Zircon	(Jargon) (Hyacinth)	Zirconium silicate.
Phosphates	Turquoise	......	Hydrated aluminium phosphates.
Carbonates	Pearl	......	Calcium carbonate.
Aluminates	Spinel	Balas Ruby, &c.	Magnesium aluminate.
	Chrysoberyl	Alexandrite Cymophane	Beryllium aluminate.

As the artificial production of the *Diamond* has been dealt with fully in my former book *Triumphs and Wonders of Modern Chemistry*, it will suffice to mention here that they were produced by Moissan (and some earlier workers) by saturating iron with carbon at the enormous temperature of the electric arc, and plunging the molten mass into cold water. After dissolving away the iron with acid, the diamonds were picked out from the residue by the aid of the microscope. The largest diamond so produced was barely visible to the naked eye, and so, from a commercial standpoint, we are as far removed from the artificial production of large diamonds as we were in the time of the alchemists. What the future holds in its bosom, however, no man can say.

Let us now take the precious stones occurring next in our list to the diamond, namely, those whose chemical basis is oxide of alumina, Al_2O_3, or corundum. The chief of these stones are the *Ruby*, the *Sapphire* and *Oriental Amethyst*. The ruby and sapphire are extraordinarily valuable and so their artificial production is a matter of considerable commercial importance. Technically the problem is not a difficult one. Oxide of alumina melts about 1800° C. under ordinary atmospheric pressure, and is so stable that it can be heated in the air without any change. Now the temperature of the oxyhydrogen blowpipe ranges well above 2000° C., so that it is the simplest thing in the world to obtain fused alumina, which, as a matter of fact, was produced as a scientific curiosity at the beginning of the nineteenth century. This method of production, however, was not developed for many years, because it was thought that the fused globules produced in this way would be merely amorphous masses, whereas, as we will see presently, they are really quite crystalline, and quite identical in properties with natural crystalline corundum.

It was only in 1904 that Verneuil brought the process to perfection, by introducing the aluminium oxide through the blowpipe itself as shown in fig. 29.

The oxygen for the blowpipe enters at the top into a funnel-shaped chamber. In this chamber is suspended a small sieve, filled with the raw material, the sieve being kept continuously shaken by means of a small hammer worked by an electro-magnet on the principle of the electric bell. From the sieve, therefore, there pours down a very fine cloud of alumina oxide dust right into the blowpipe flame. The hydrogen for the blowpipe enters as shown in fig. 29, and the flame plays downwards around the end of the oxygen tube. The dust fuses and falls as globules upon a small support, which can be gradually lowered by means of a screw attachment ; by this means, as the mass of corundum is gradually built up by the rain of fresh globules, the surface is kept at a constant level, and the portion already formed is removed from the heating zone, so as to allow it to solidify slowly. At the beginning of the operation the blowpipe is adjusted so as to give a comparatively cool flame, and the powdered aluminium oxide is only admitted slowly, whereby a small "stalk" of fused alumina is gradually built up on the support. This stalk insulates the support from the heat of the flame, and so preserves it from fusion. Once this stalk has been formed the full blowpipe blast is put on and the alumina dust is allowed to fall in more rapidly, so that a mass of fused alumina having the appearance of a pear is gradually built up, the masses being known as a "boule."

So perfect is this apparatus that within thirty minutes there can be built up a boule weighing thirty carats, and capable of yielding two cut stones of about six carats each. Moreover a single workman can control a dozen machines.

This blowpipe was first applied to make "reconstructed rubies," the raw material being chips and cuttings of natural ruby, which have been made into a fine powder.

At the present time, however, it is usual to make "synthetic rubies," the raw material being ammonium alum, $(NH_4)_2SO_4.Al_2SO_4.24H_2O$. Some authorities state that this, in a finely powdered form, is fed directly into the blowpipe; when, on reaching the flame, it decomposes to alumina, Al_2O_3, thus: $(NH_4)_2SO_4.Al_2(SO_4)_3.24H_2O = Al_2O_3 + 2NH_3 + 4SO_3 + 26H_2O$. Other authorities assert, however, that the ammonium alum is dissolved in water, treated with ammonia, and the precipitated alumina is filtered off and dried, and the dry powder is then fed to the blowpipe. The red colour of the ruby is produced by adding to the ammonium alum a small amount of chromium alum, 2½ per cent. chromic oxide giving the best results. Other colours may be produced by various metallic salts. If no colouring agent is used we get simply colourless "white sapphires," which are

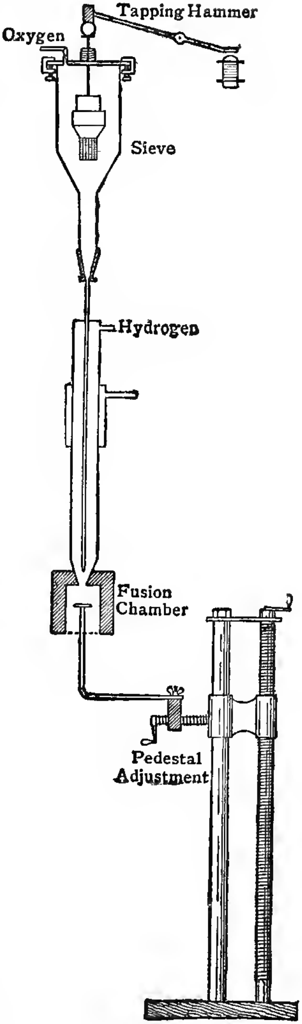

FIG. 29.—Verneuil's apparatus for making imitation rubies.

now much used for making hard bearings for watch wheels, gramophone points and similar machines.

For many years, however, all attempts to reproduce the fine blue colour of the sapphire failed, because cobalt was the colouring agent employed. Cobalt colours silicate a very fine blue colour because it produces quite readily a blue cobalt silicate.

It does not readily unite, however, with aluminium oxide to form a blue aluminate, and consequently it is impossible to produce a really satisfactory coloration of aluminium oxide (corundum) by its means. Finally, however, it was discovered that a little titanium oxide, TiO_2, when added to the alumina, yielded the required colour—a most unexpected result, because titanium minerals as a rule are not intense colouring agents.

At the present time, therefore, all manner of coloured stones can be produced from corundum, ranging in colour from the pure white of the "white sapphire" to the blood red of the ruby or the deep blue of the sapphire. The prices range from one shilling to ten shillings a carat.

In science it is the unexpected which often happens, and the production of these artificial gems furnishes a case in point; judging by analogy with other materials, it would have been expected that a mass of alumina fused in this way would either be a mass of small crystals or be an amorphous glass. For instance, if we fuse common salt to a mobile liquid and allow it to cool, it solidifies to a white mass of fine crystals. On the other hand, if we fuse silica (quartz or fine sand) to a liquid it solidifies to an amorphous glass—not to a crystal. In fact silica glass is now manufactured on an increasing scale for various scientific purposes. Now crystallographers are all agreed that in the case of alumina each of the "boules" is a single crystalline individual, with the major axis running roughly from the point of attachment to the pedestal, right to the top of the mass. The mass, in fact, forms a true crystal, not an amorphous glass.

Another curious scientific problem is the nature of the colours produced. For example, why does a trace of chromium give with alumina the magnificent red colour of the ruby? Is it due to traces of some synthetic inorganic "dye," whose colour arises from the complex nature of the arrangement of its component atoms, or is it merely an optical effect due to suspension of colloidal particles in solid solution? For example, the ruby colour of "ruby glass" has been proved to be due to very finely divided gold particles suspended in the mass. Such problems have not yet been satisfactorily solved.

Now, in consequence of the production of these synthetic rubies and sapphires—practically in all respects identical with the true natural article—it has become a matter of very considerable commercial importance to distinguish between one of these artificial rubies, worth a few shillings, and a real ruby, worth it may be thousands of pounds. This can be done by examining its structure under a microscope. The artificial crystal possesses the shape of a piece of solidified molten liquid. It has a drop-like structure, and any enclosed air bubbles (which are almost always present) appear as spherical bubbles when viewed under the microscope. Now in the natural ruby we also find a definite structure, the microscopic bubbles being drawn out into a series of parallel veins or streaks, all being in one plane and following one of the axes of the crystal. These natural bubbles in the artificial substance, however, do not appear as "globules" but form irregular cavities, with a decided tendency to a geometrical shape. There are other differences as well, so that in the hands of an expert, a careful microscopic and optical examination will always reveal the true nature of the stone. A man who is not an expert, however, can be easily deceived, and indeed, there are many cases on record where swindlers have made heavy hauls by foisting the artificial stones upon the unsuspecting public in lieu of the real gem.

The next group of precious stones on our list are those composed of silica, *e.g.* rock crystal, amethyst, and cairngorm.

These cannot be obtained artificially by merely fusing the silica, as in the case of the ruby and sapphire, because fused silica only yields an amorphous *glass*, not a true crystal, and so the optical qualities are wanting. In this case we have to adopt crystallisation methods, and all these stones have been produced artificially. Commercially, however, the subject has little interest, because the natural varieties are so abundant and so cheap that the artificial product greatly exceeds them in price.

The silicate group of precious stones is a very extensive one, as may be seen from the table on p. 340. Most of them, such as garnets, topaz, &c., have been produced artificially; commercially, however, their artificial production has no object, since the natural stones themselves are too common and cheap. The emerald, however, a very valuable stone, has not yet been made artificially in a suitable form. Fragments of emeralds have been fused into a coherent mass in Verneuil's blowpipe, as described under reconstructed rubies, but the product is a mere amorphous glass, devoid of double refraction and other optical properties, which depend upon the crystalline structure of the natural stone.

The *turquoise* is the next stone on our list, and belongs to an entirely different group to any previously considered. In the first place it is a *phosphate*, and in the second place it is non-transparent. All the other stones have been transparent, glittering gems. The turquoise has been produced a great many years ago by precipitating a mixture of aluminium and copper phosphates in the exact proportion to correspond to the natural stone, and then subjecting the damp mass to powerful hydraulic pressure for a long time. The artificial products so closely resemble the natural that it is difficult for an outsider to distinguish between them.

The *pearl* is also of an entirely different class from any of those previously considered, its chemical basis being calcium carbonate — the same mineral which composes chalk, marble and limestone. The beautiful lustre of the pearl arises from its peculiar structure. It is formed in the oyster by the deposition of the semi-transparent layers of calcium carbonate around some central object.

Innumerable layers are thus built up, and the light falling on these is partially reflected and partially transmitted, whereby the peculiar but very beautiful optical properties of the stone are produced.

It has so far proved impossible to produce artificially the peculiar structure of the natural pearl. The Japanese, however, have for years practised the growth of a sort of artificial pearl by inserting a mother-of-pearl shape between the shell and mantle of living oysters, and then leaving the oyster alone. The irritant foreign matter stimulates the oyster to deposit on it layer after layer of secretion, which convert the mother of pearl shape into a pearl.

To make the mass so produced resemble a true pearl the Japanese, after removing it from the oyster, back it with mother of pearl.

These artificial pearls, however, do not display the fine optical effects of pearls produced under normal conditions, and moreover they can be easily identified by examining the rear for the line of junction between the lustreless mother-of-pearl back and the pearl material.

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