MODERN CHEMISTRY AND ITS WONDERS

Photo, E.N.A.

A FUTURE CENTRE OF CHEMICAL INDUSTRY.

Kaieteur Falls.

The most wonderful in the world. With a height of 741 feet and a breadth of over
... [illegible]estic scener[illegible] in the Potaro River in British Guiana, this fall

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

NEW YORK
D. VAN NOSTRAND COMPANY
TWENTY-FIVE PARK PLACE
1915

PRINTED IN GREAT BRITAIN

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.

CONTENTS

LIST OF ILLUSTRATIONS

PLATES

MODERN CHEMISTRY AND ITS WONDERS

CHAPTER I

THE WONDERLAND OF MODERN CHEMISTRY

"And Nature, that 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 to read 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 Wordsworth 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

[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

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*

[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,

(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

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]

[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.

Pàradoxical 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

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

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

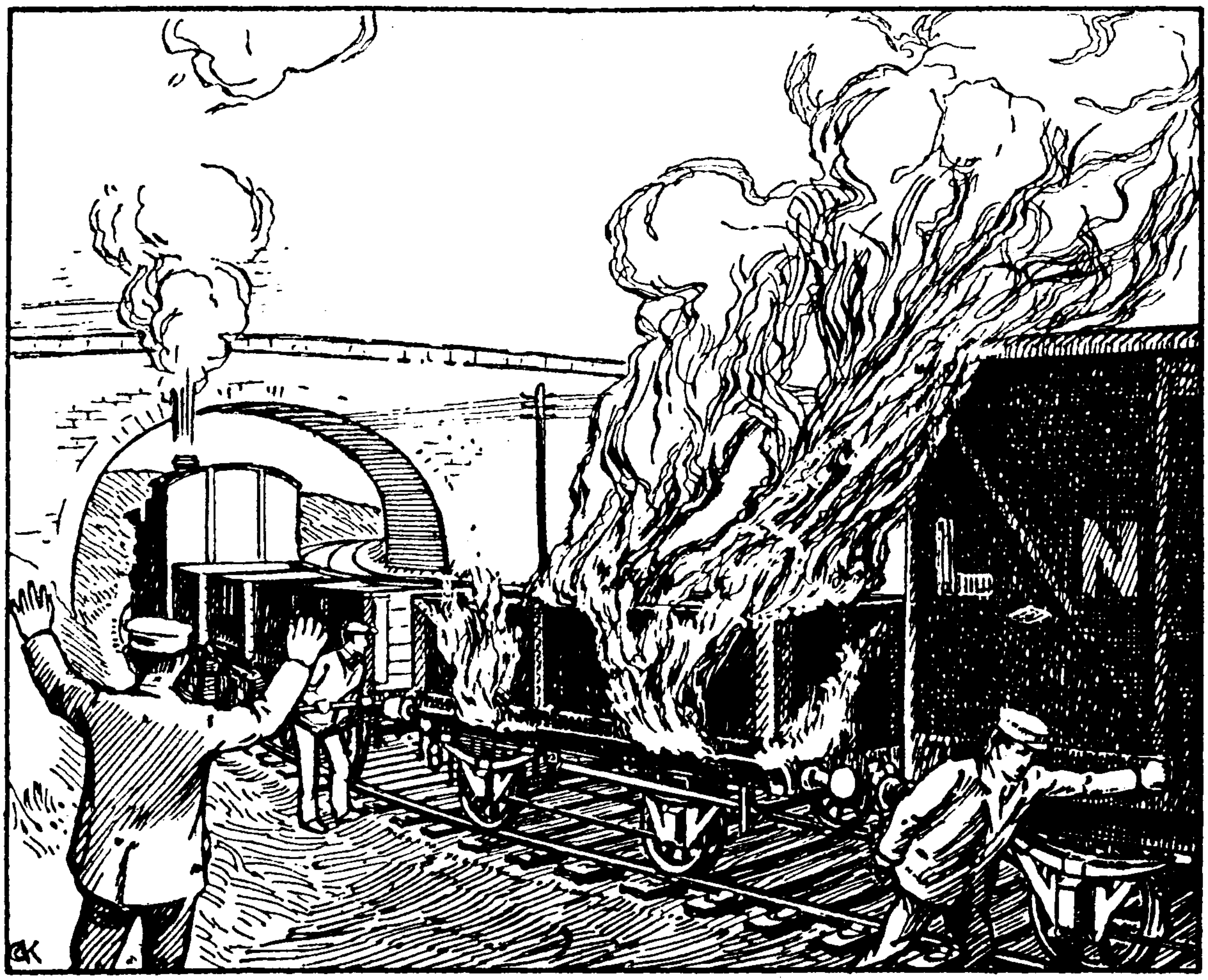


FIG. 1.—Railway trucks set on fire by nitric acid.

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 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]

[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

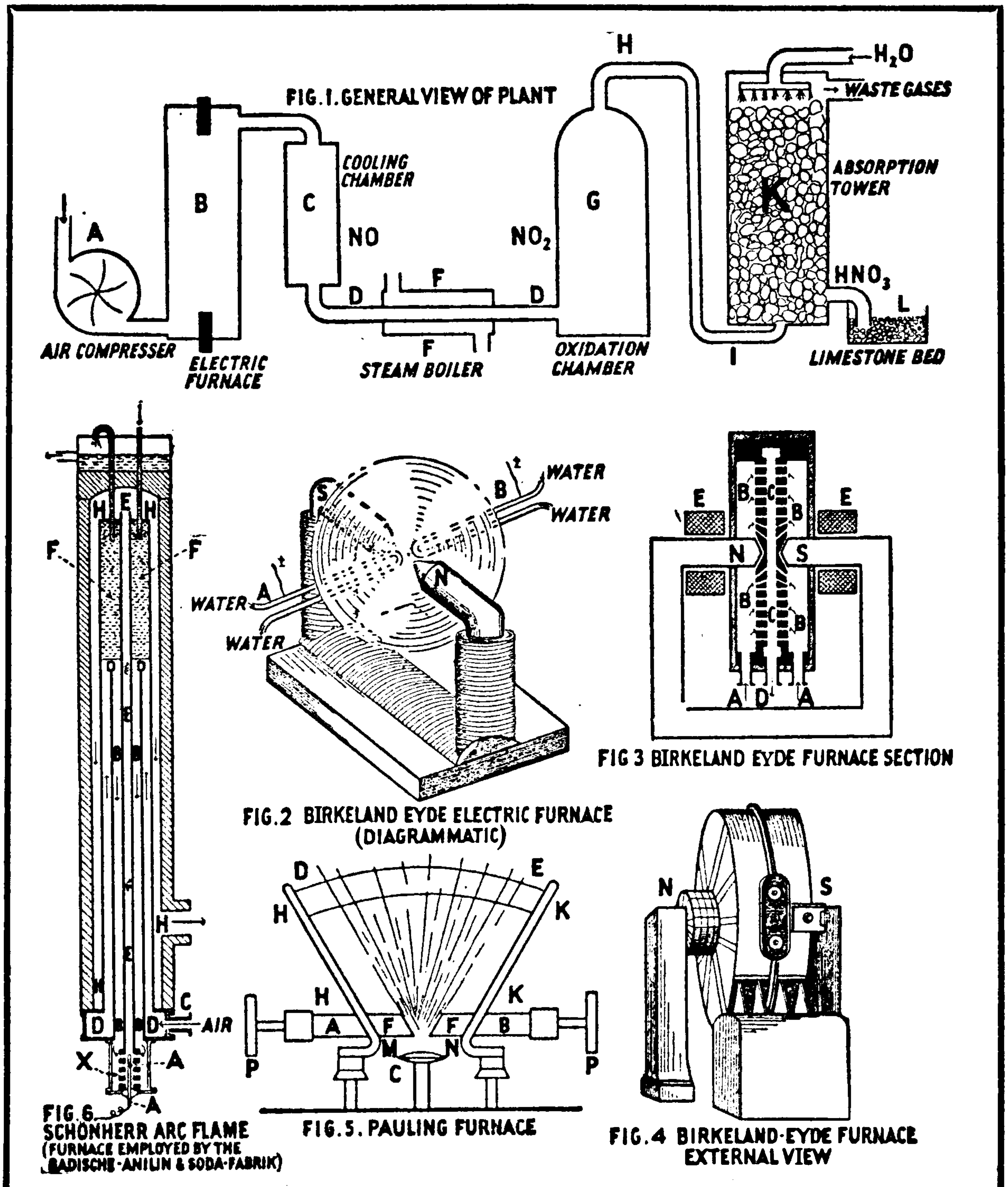


FIG. 2.—Nitric acid from the atmosphere.

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-

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

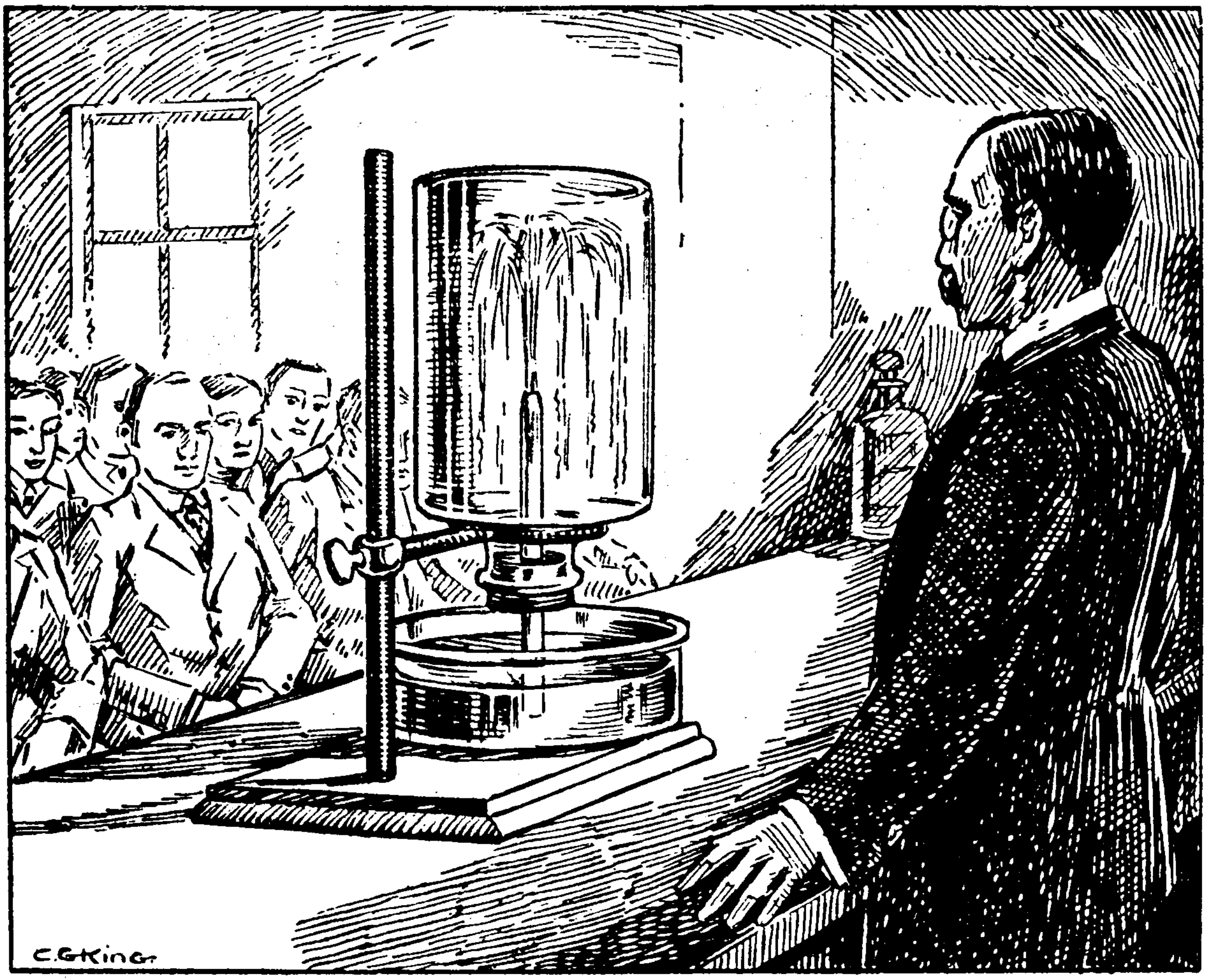


FIG. 3.—Solubility of ammonia in water.

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.

Pressure and cold turn it into a colourless liquid which boils at $-38{\cdot}5°$ 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.

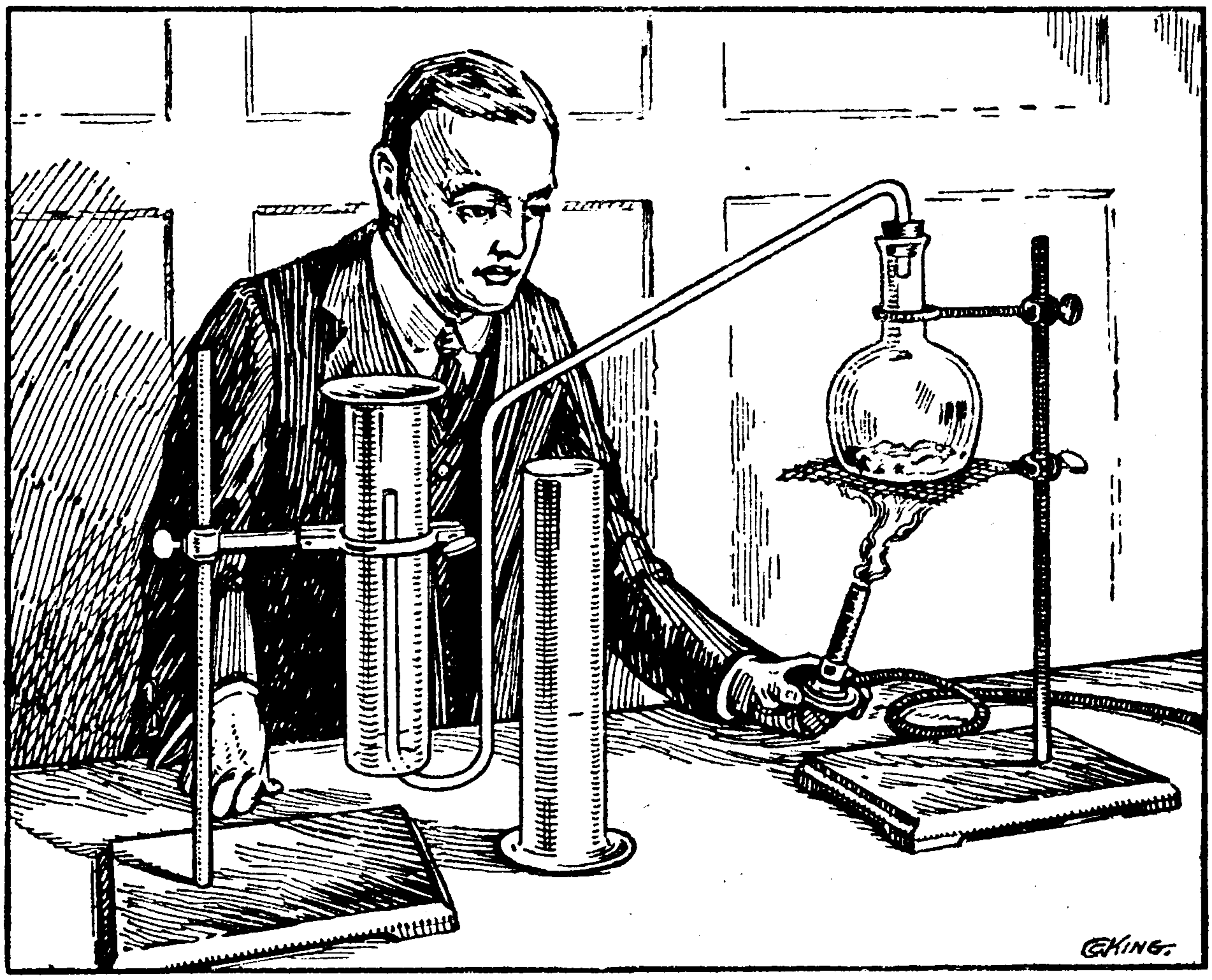


FIG. 4.—Preparing ammonia by heating lime and ammonium chloride.

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

$$2NH_4Cl \quad + \quad Ca(OH)_2$$

Ammonium chloride — Slaked lime (Calcium hydroxide)

$$= \quad CaCl_2 \quad + \quad 2NH_3 \quad + \quad 2H_2O$$

Calcium chloride — Ammonia — Water

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

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

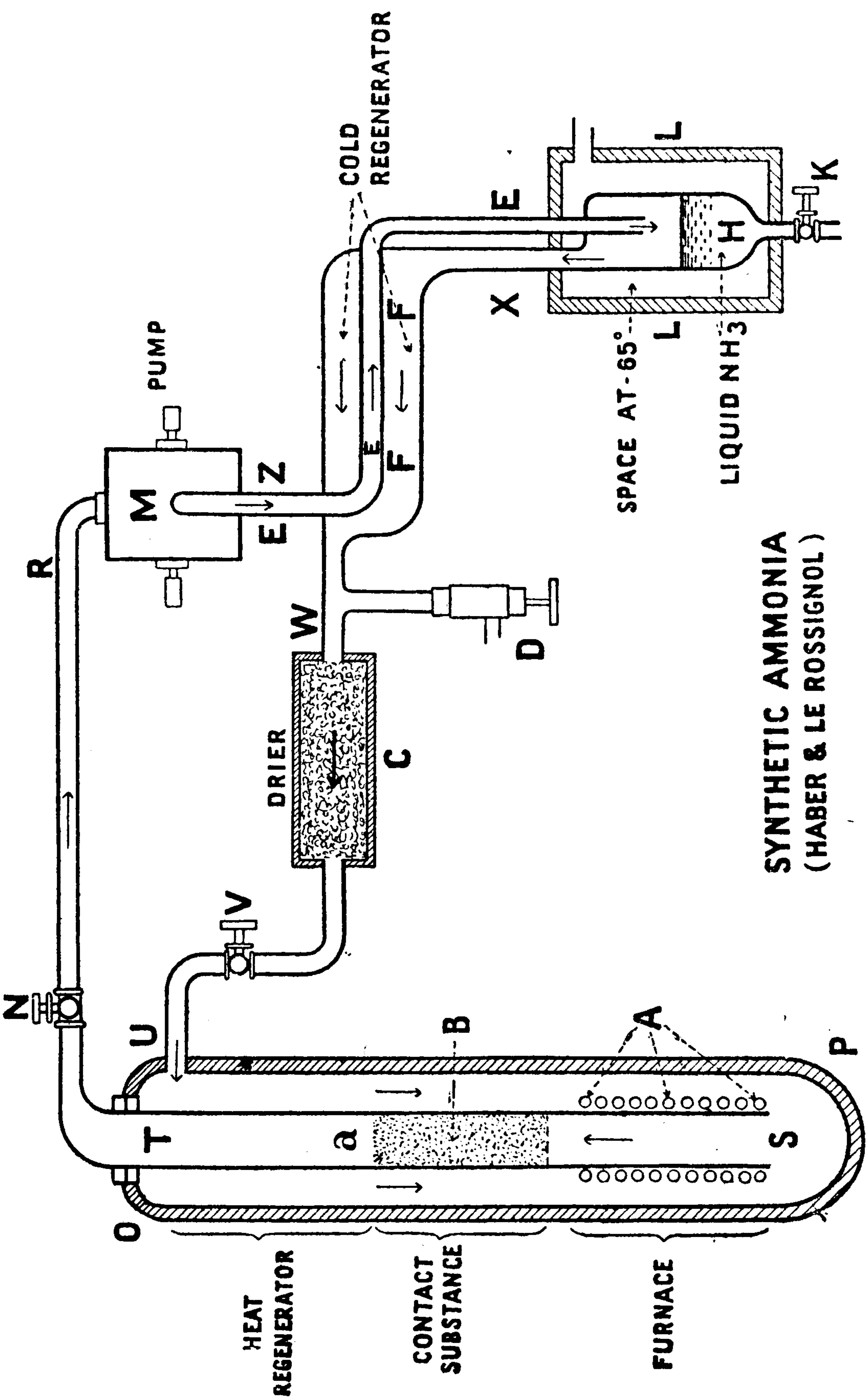

SYNTHETIC AMMONIA
(HABER & LE ROSSIGNOL)
COLD
REGENERATOR
PUMP
M
E
Z
R
W
DRIER
C
D
V
N
U
T
a
B
A
S
P
O
E
F
X
L
K
H
SPACE AT -65°
LIQUID NH3
HEAT
REGENERATOR
CONTACT
SUBSTANCE
FURNACE

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

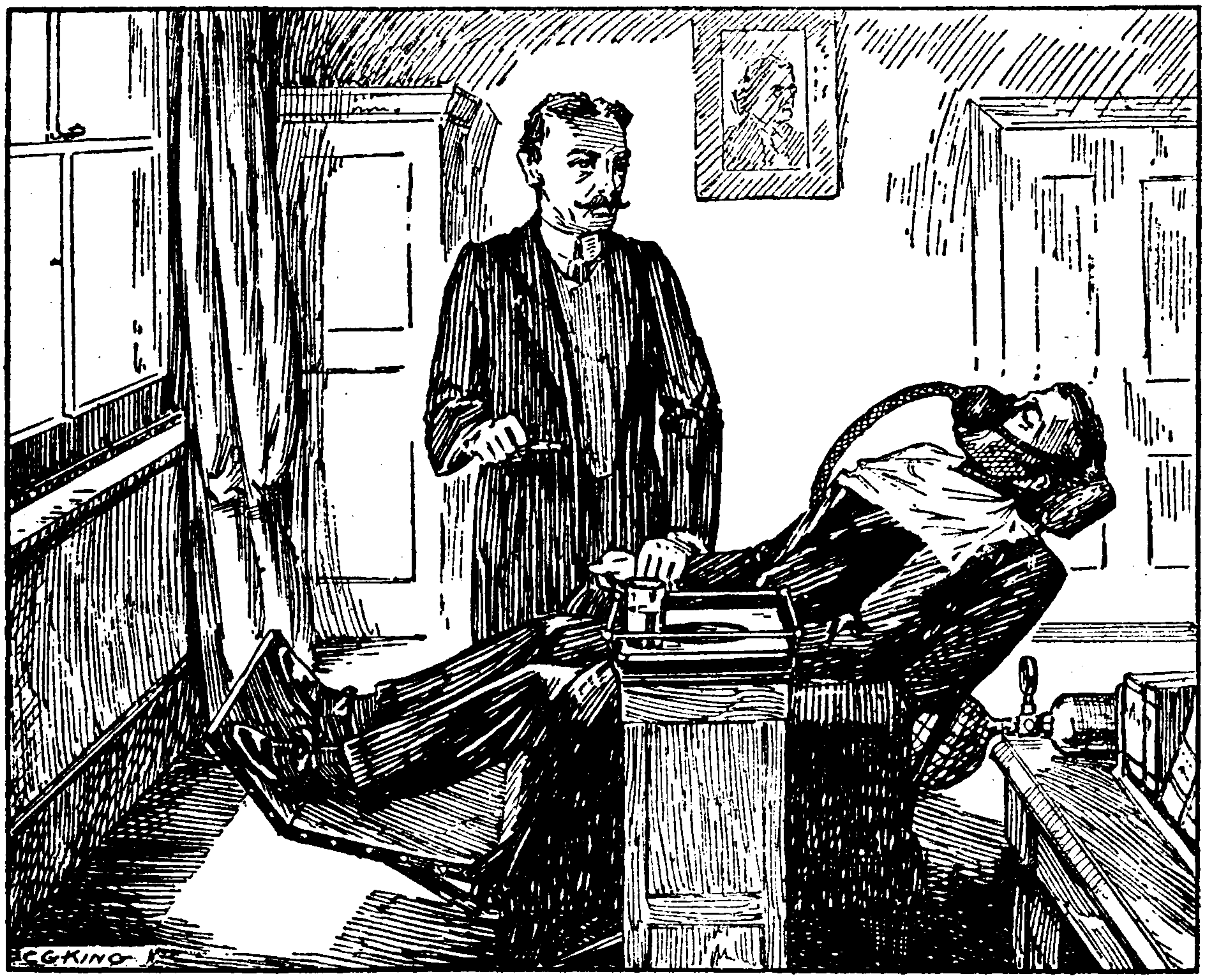


FIG. 6.—Dentist administering nitrogen monoxide to a patient.

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]

"At the end of the session of laboratory work there

[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:

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

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.

$Pb(NO_3)_2$ =	PbO +	$2NO_2$ +	O_2
Lead nitrate	Lead monoxide	Nitrogen peroxide	Oxygen

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

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.

[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.

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:

$$\underset{\text{Potassium nitrate (saltpetre)}}{2KNO_3} + \underset{\text{Sulphur}}{S} + \underset{\text{Carbon}}{3C} = \underset{\text{Carbon dioxide}}{3CO_2} + \underset{\text{Potassium sulphide}}{K_2S} + \underset{\text{Nitrogen}}{N_2}$$

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

[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.

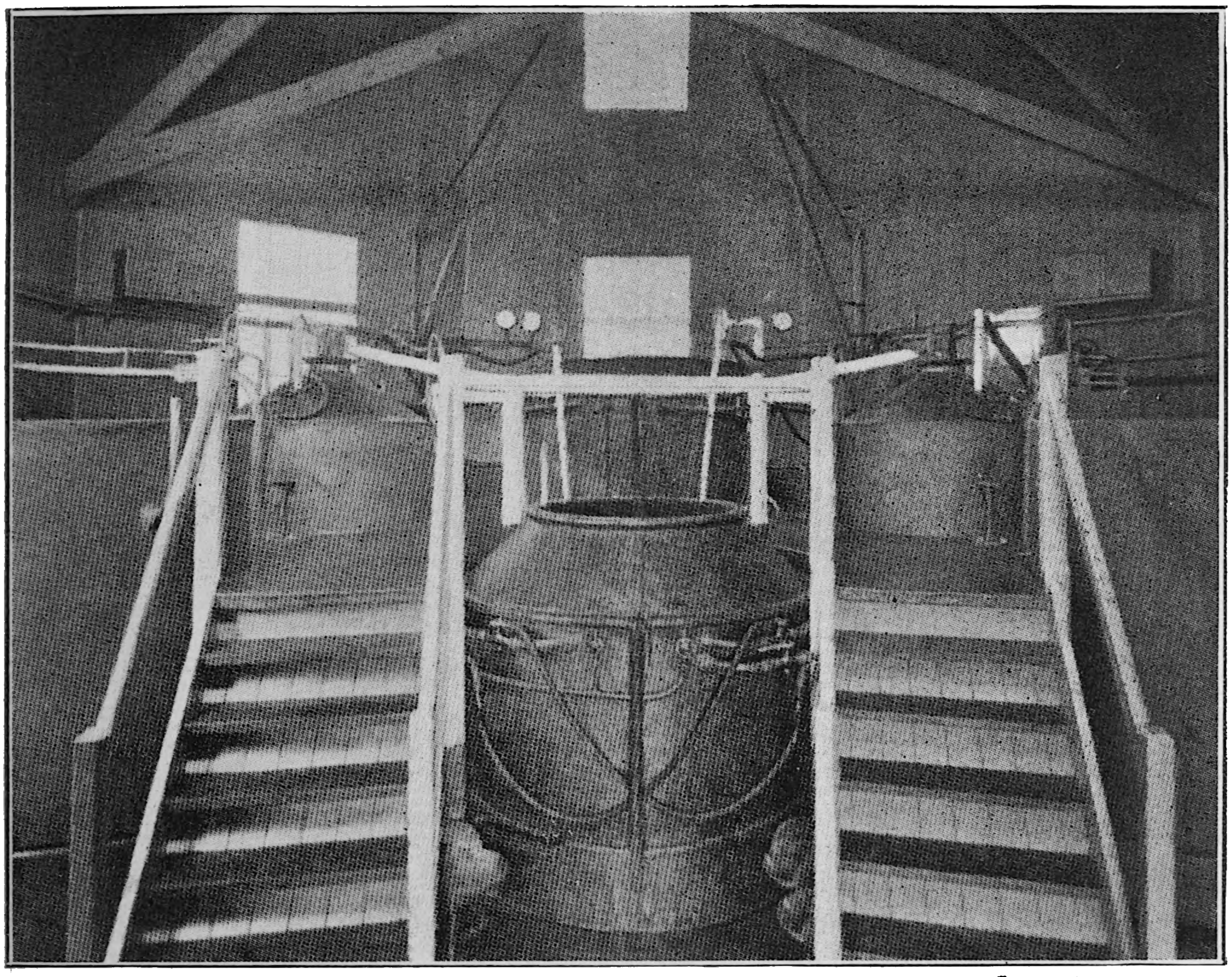
In order to make nitro-glycerine, the glycerine is sprayed in a very fine stream into a leaden tank (called a "nitrator") containing strong nitric acid, rendered more active by being mixed with sulphuric acid, and kept cold by a stream of cold water circulating through leaden coils in the interior of 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.

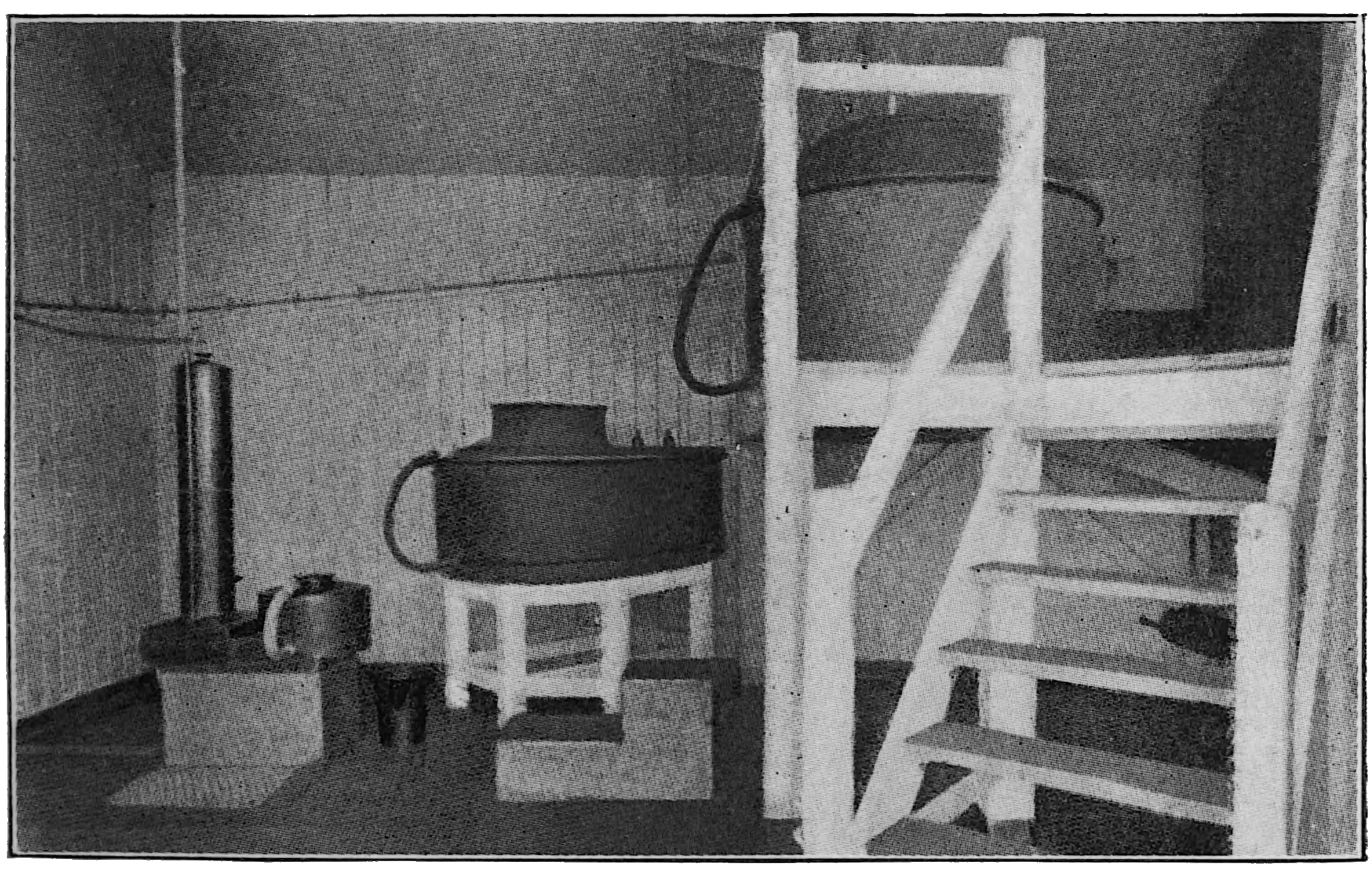
A visit to a large explosive works is well worth making.



From Cassier's Magazine.

Nitrators Forewash Nitrators

PLATE 1.—Manufacture of Nitro-glycerine.



From Cassier's Magazine.

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

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 nitro-glycerine. 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 nitro-glycerine 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 down-stairs 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

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.

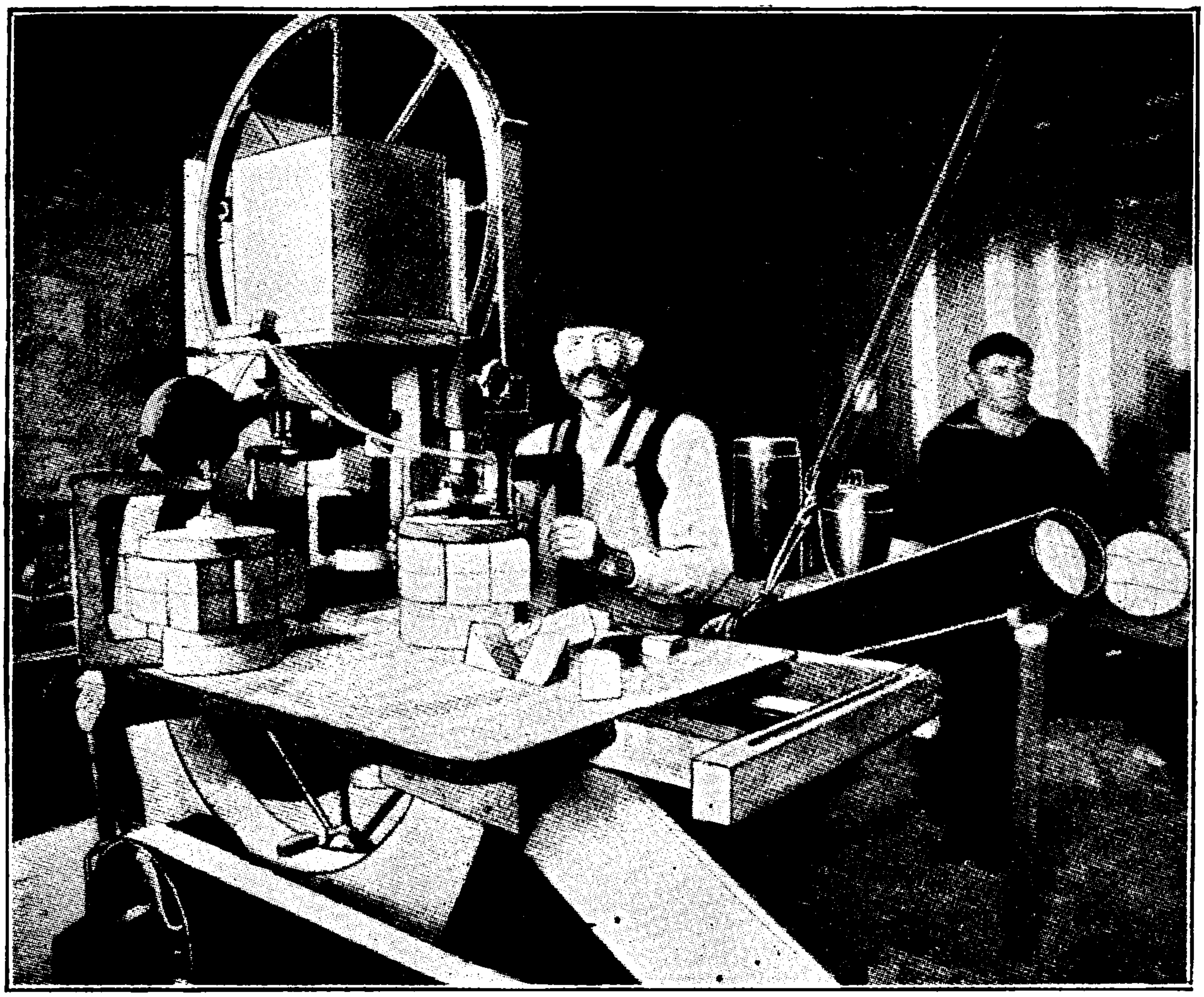
Multiply this velocity ten times and not even a boiler plate could withstand the resistance. Multiply the velocity once more by ten and we reach the speed with which the earth rushes round its orbit, about twenty miles a second. To a body moving with such a vast velocity the air at the surface of the 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!

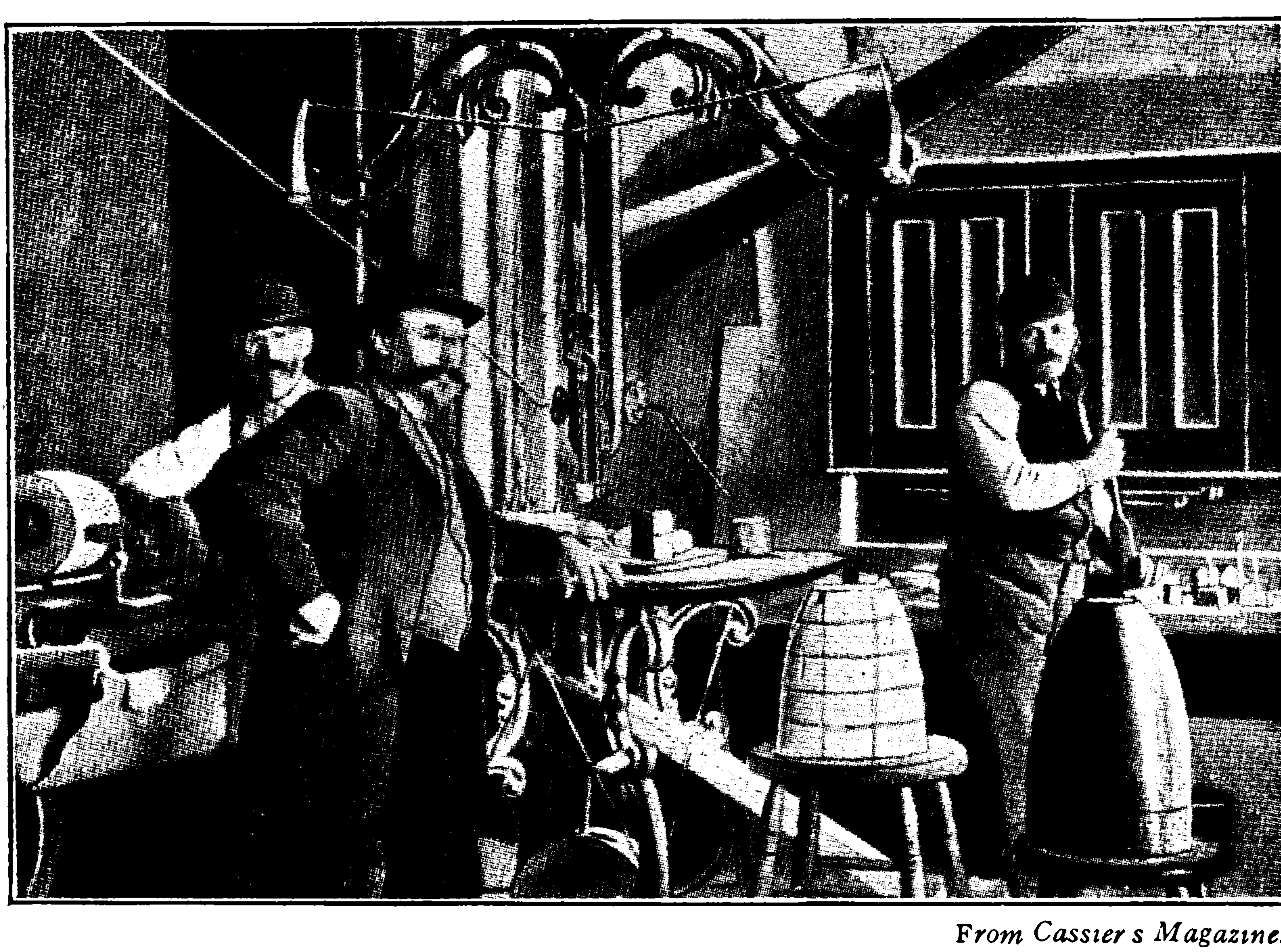
The next explosive that we will deal with is guncotton. This has a chemical composition somewhat similar to nitro-glycerine and is produced by the action of nitric acid on cotton. Pure cotton which has been freed from fat and grease by boiling with alkali is immersed in a mixture of concentrated nitric 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.

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

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.

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

day 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

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

[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.

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]

[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.

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.

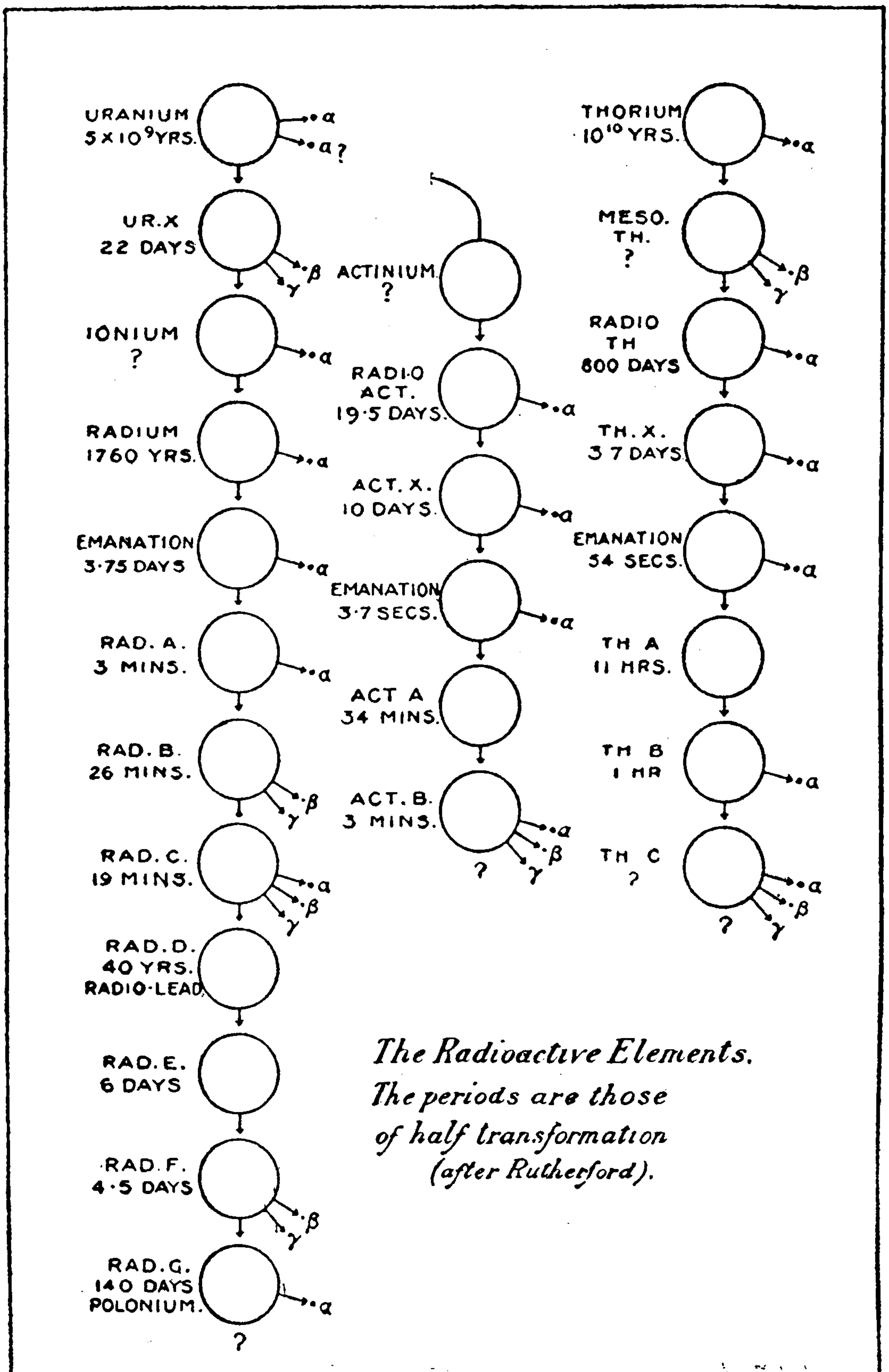
New stars appear and disappear, and some writers have supposed that matter can thus, under suitable conditions, explode into a mist of flashing ultra-atomic particles. Truly, the recent advances which science has made have revealed to us possibilities undreamt of by our forefathers, or even by the scientists 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 alph particles crash right through the atoms, and their collisio are rather with one or other of a number of circumscrib and powerful centres of force which exist quite inside atoms and act with great power when approached wi

and that from one gram of radium 136,000,000,000 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

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,

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

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

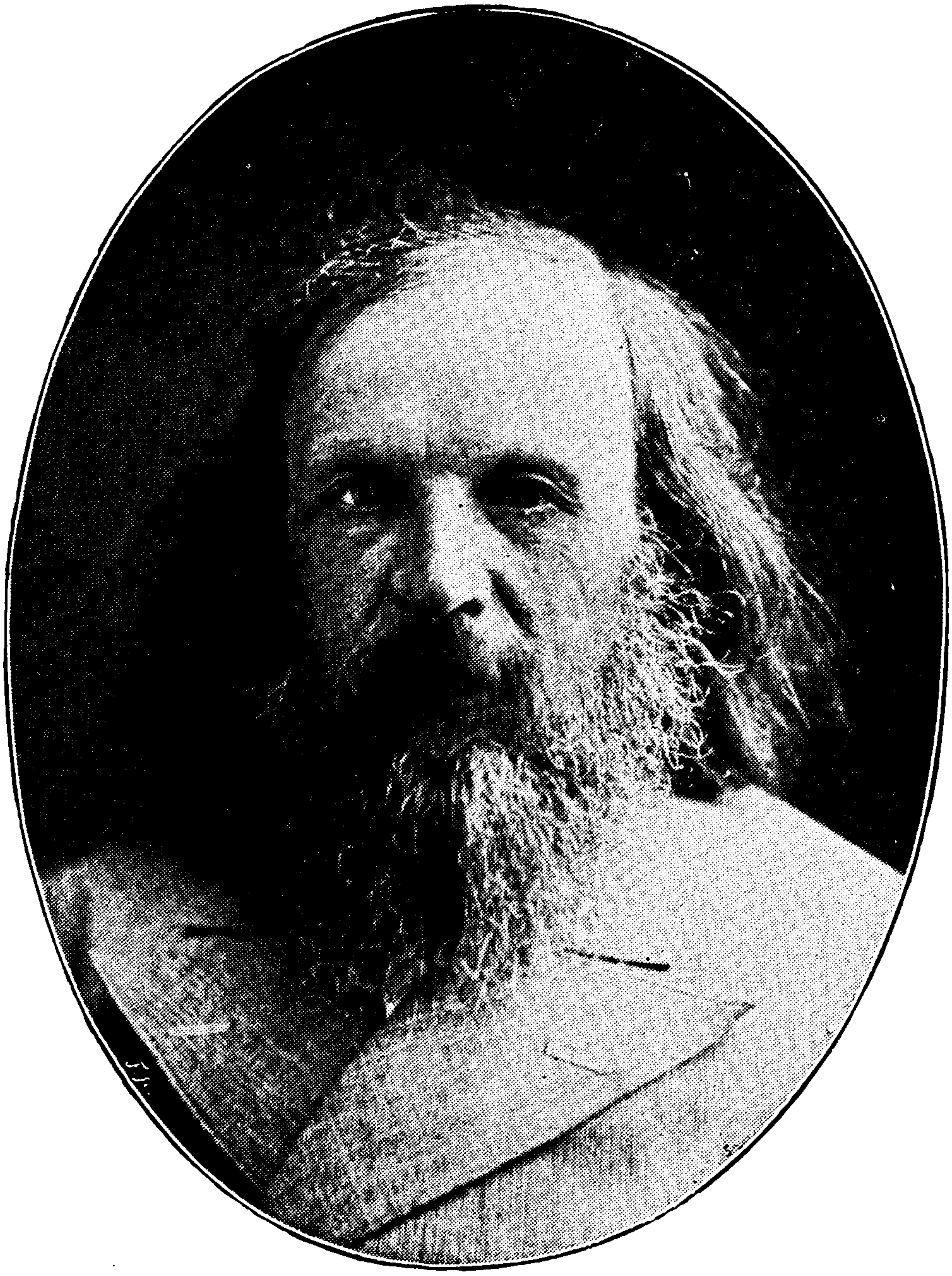
It was the immortal Wordsworth who sang of

"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 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.

"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 text-book 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.

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.

[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]

[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]

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

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

[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.

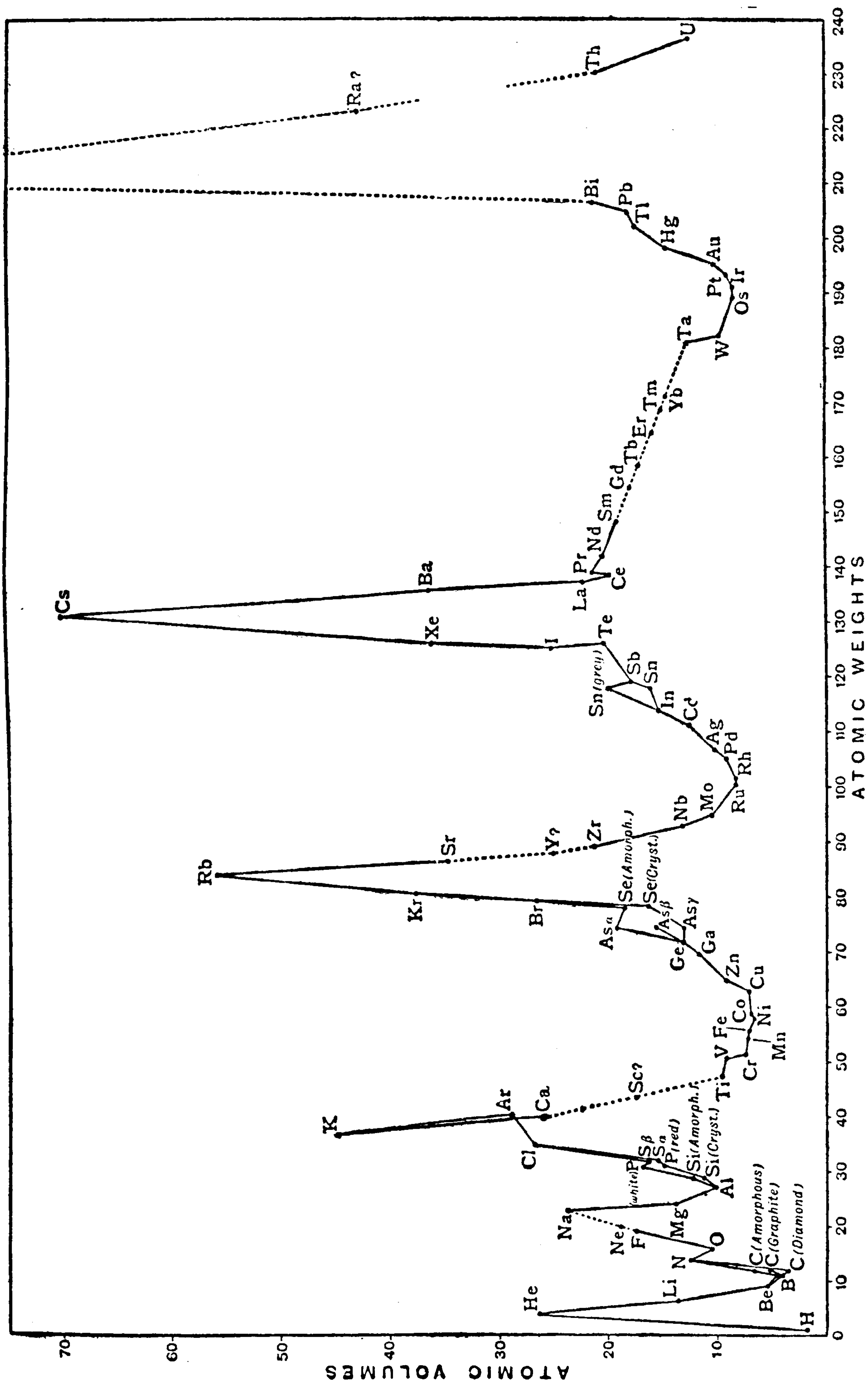


FIG. 8.—Curve of Atomic Volumes.

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

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.Em-anation 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

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

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

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]

[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.

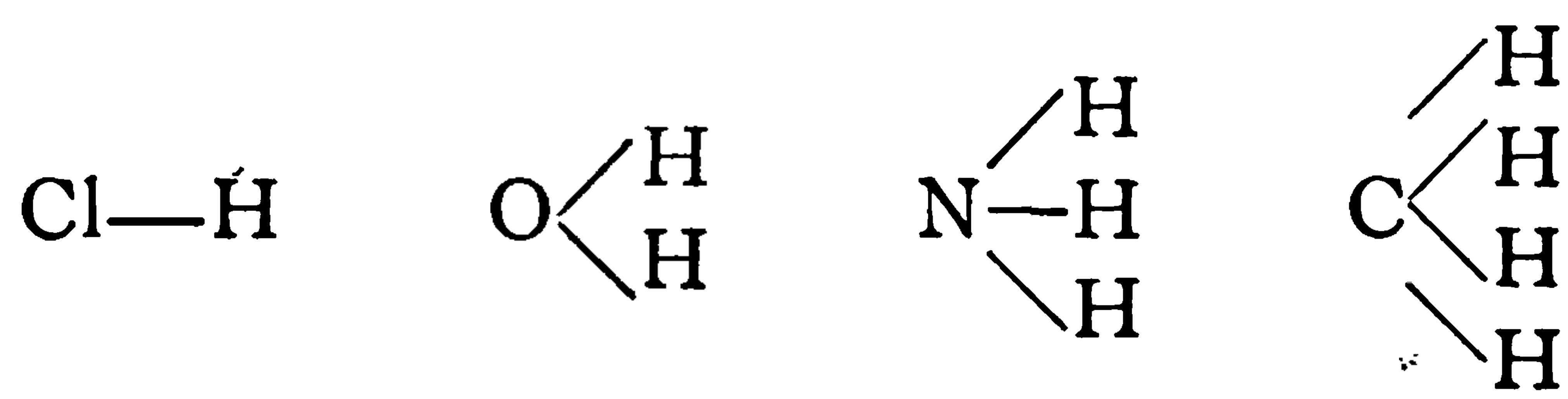
See also Geoffrey Martin, "The Chemical Conditions of the Elements," *Chemical News*, Nov. 10, 1905.

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 :—



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,"

[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: $C\equiv$, while the hydrogen atoms are supposed to have attached to them a *positive* charge, thus, $+H$.

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:

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

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

[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.

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;

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 radioactive 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

[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

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

[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

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

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

firmed, 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

[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.

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

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

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,

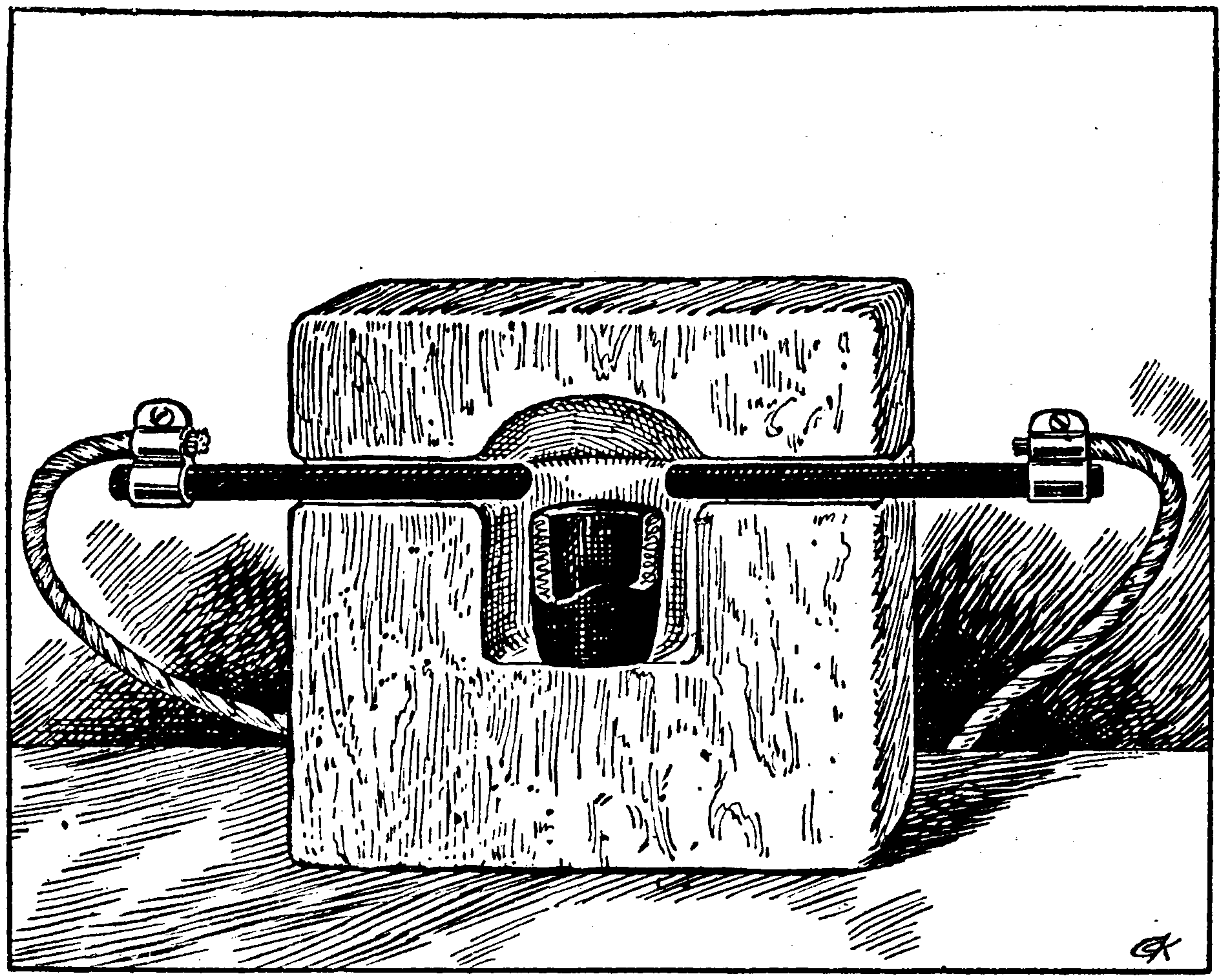


FIG. 11.—Moissan's electric furnace.

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 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

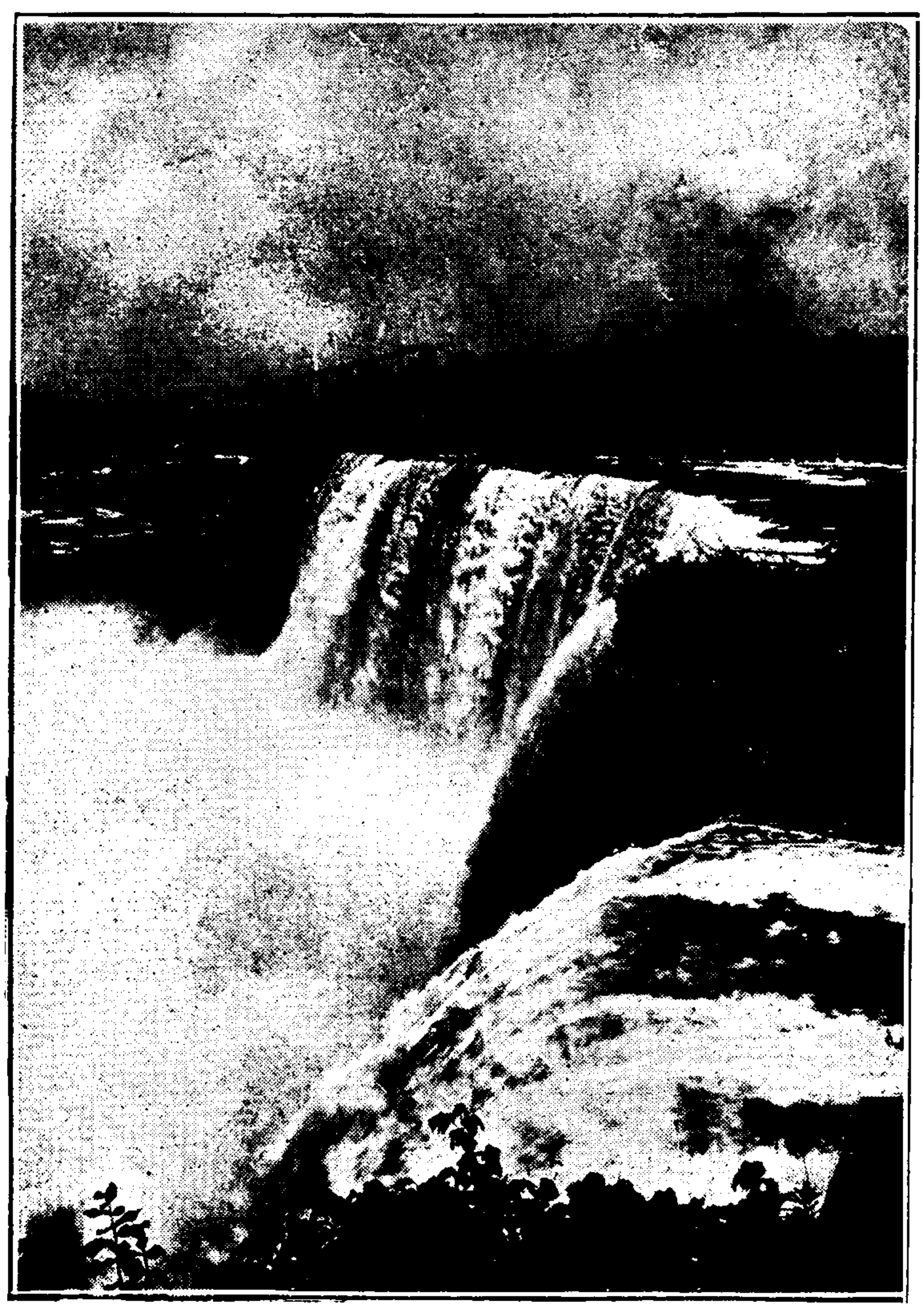
between the present time and 1935. Hence the general recourse of farmers to artificial nitrogenous manures. If the earth is to meet the ever-increasing demand for corn and food it must have more nitrogen.

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, L.N.A.

PLATE 9.—Niagara Falls.

FUTURE CENTRES OF CHEMICAL INDUSTRY.

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,

[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.

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

take many hours to perform. If two or three different metals are present in the solution the operation must be

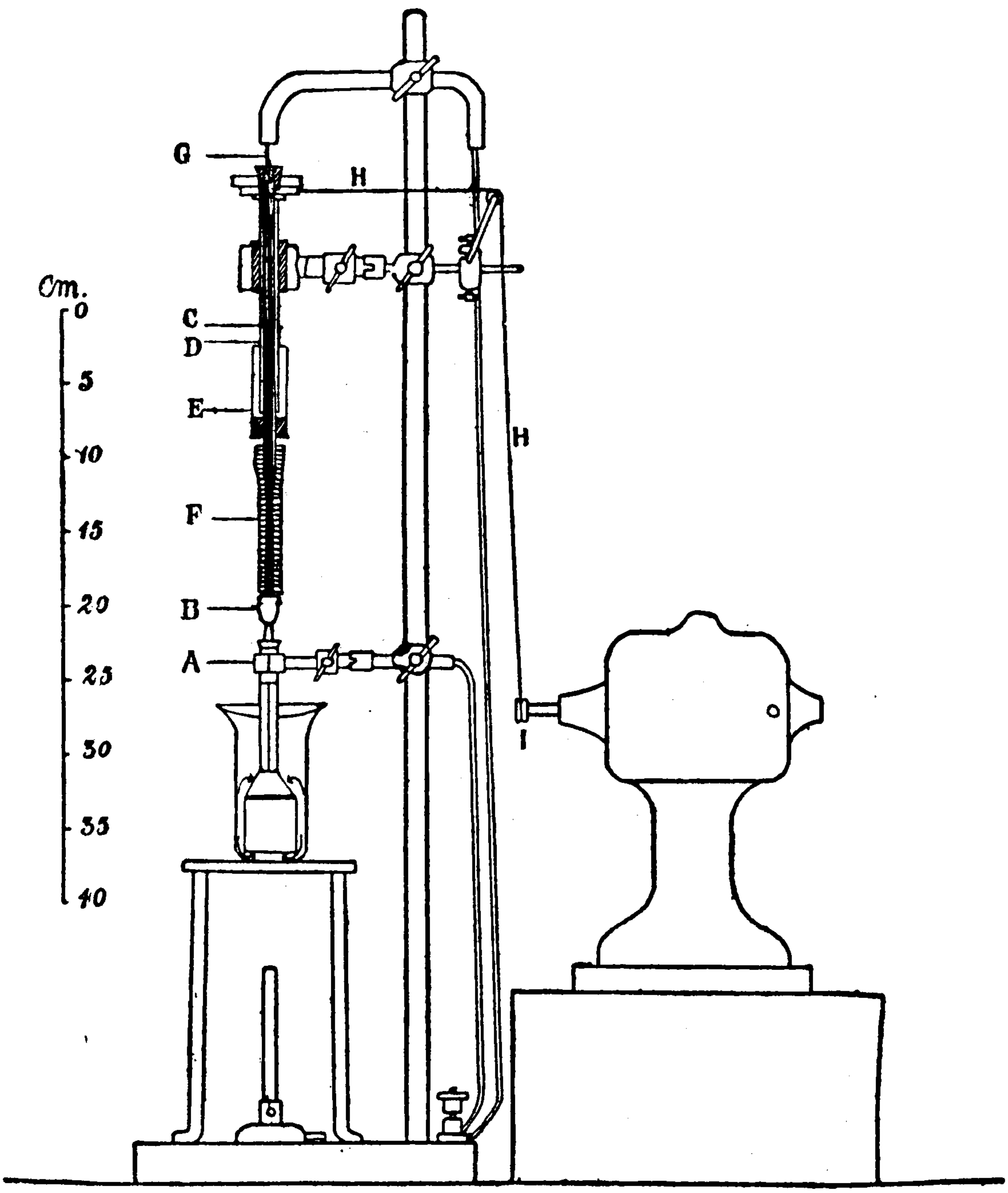


FIG. 12.—Section through Dr. Sand's Apparatus for Rapid Electro-Analysis.

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

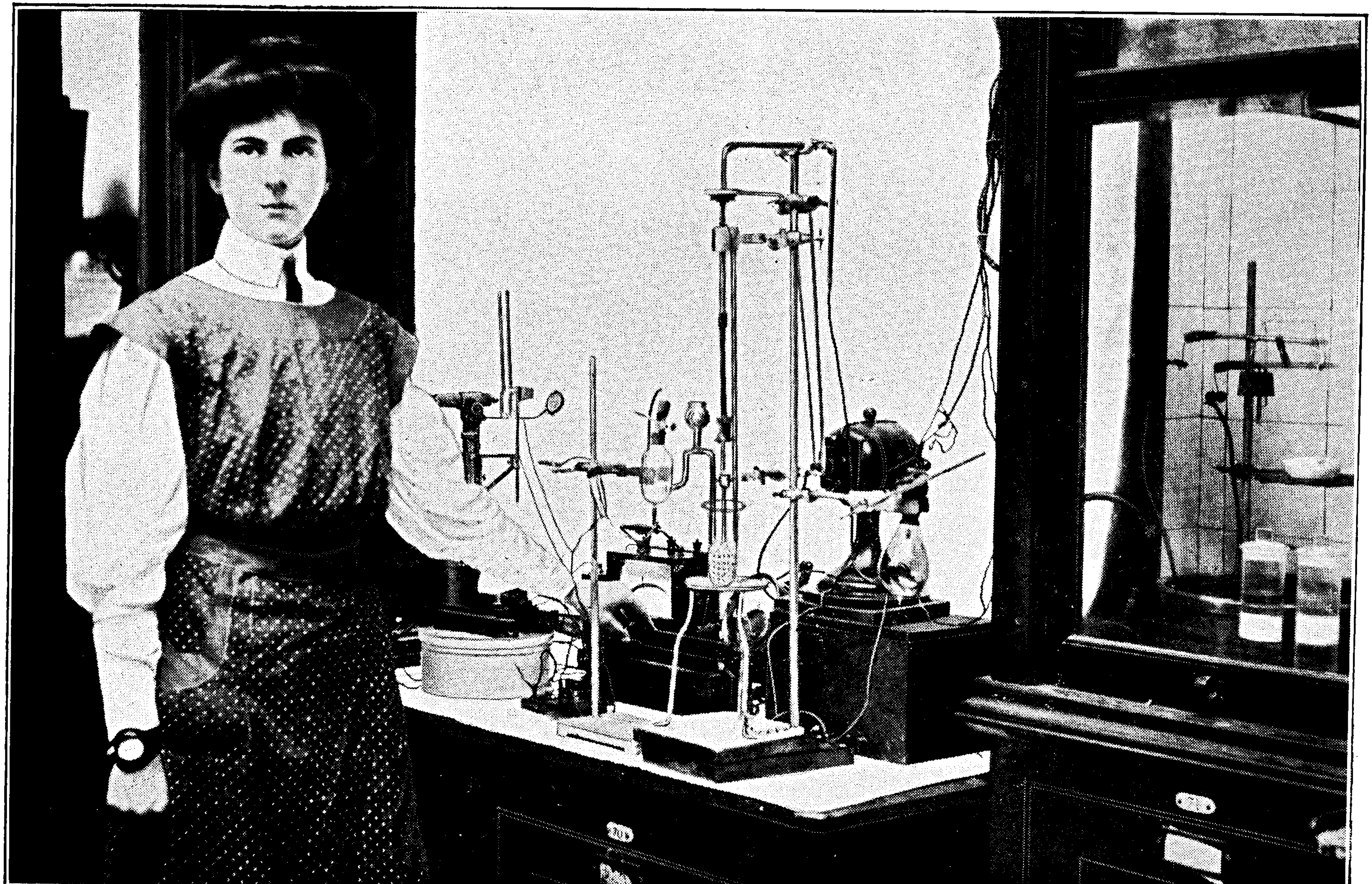


PLATE 12.—Dr. Sand's Apparatus for Rapid Analysis by means of the Electric Current. The operator is seen regulating the current intensity.

I.

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

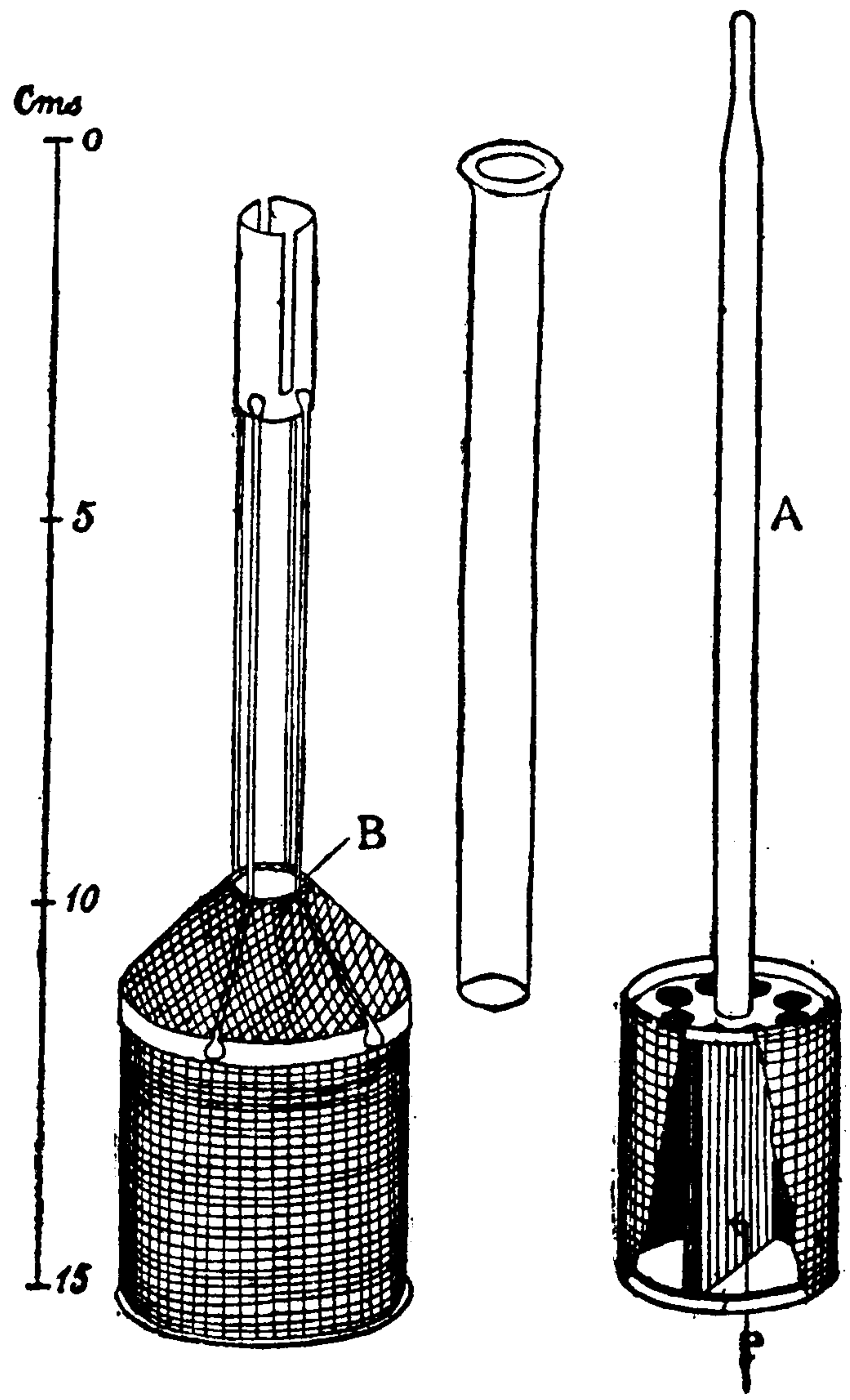


FIG. 13.—Dr. Sand's Electrodes for Electro-Analysis.

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 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.

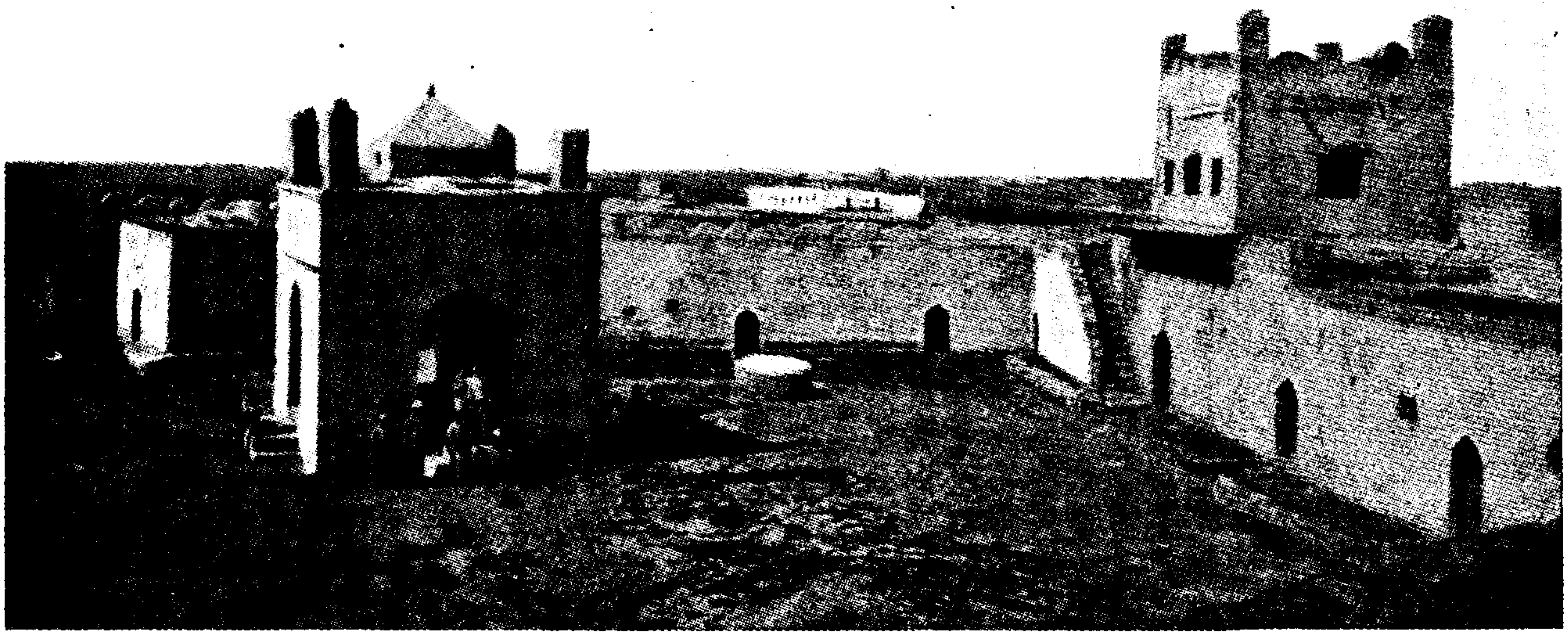
[1] "The Rapid Electro-analytical Deposition and Separation of Metals," by Dr. H. J. S. Sand, *Journal of the Chemical Society* (1907), vol. 91, p. 373.

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.

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.

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

[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

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

[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

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 of 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

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

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. F... example, Methane, or marsh gas, CH_4, obtained fr... the general formula C_nH_{2n+2} by putting $n=1$, Etha... 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,

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.

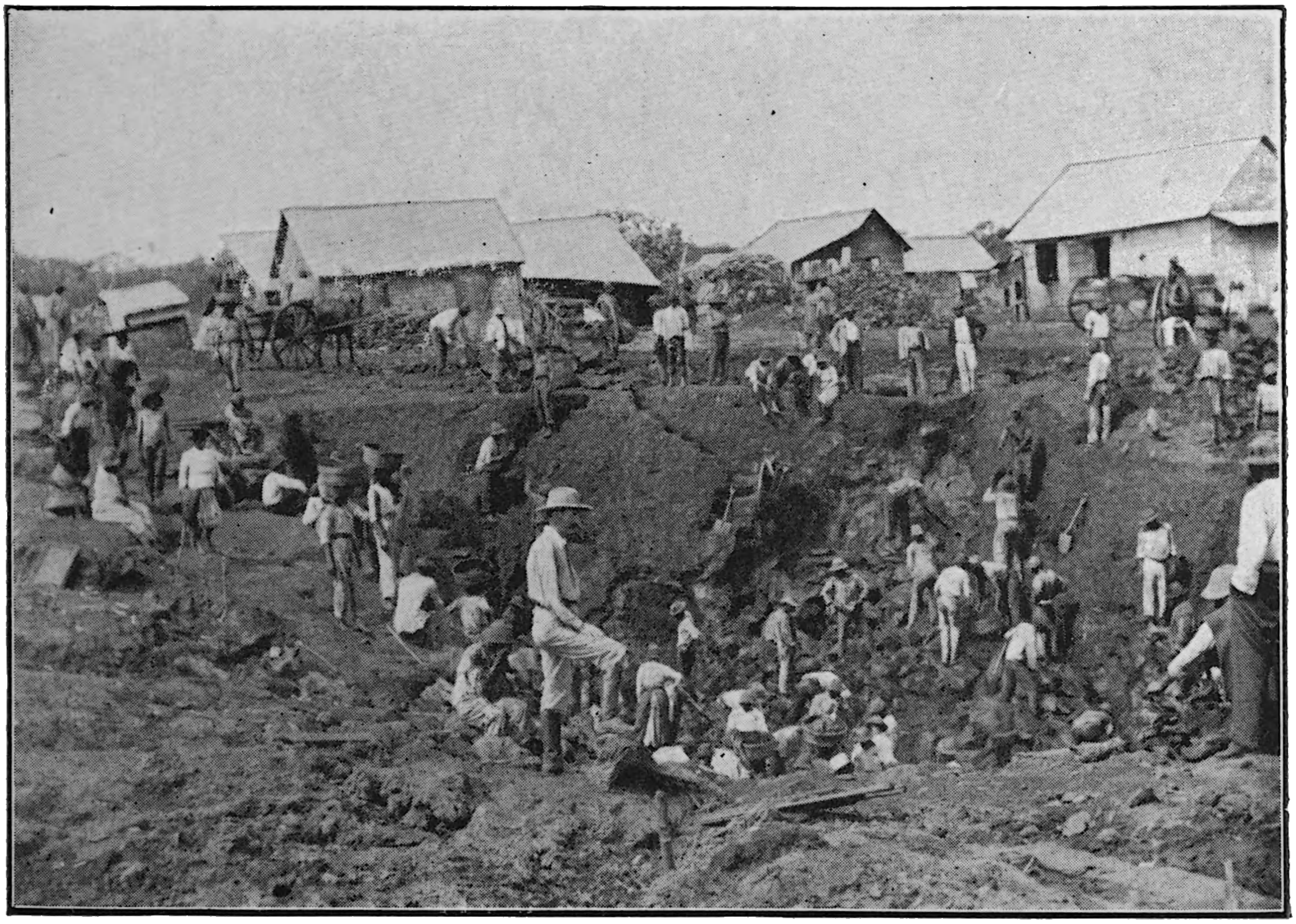


PLATE 19.—Village of La Brea, Trinidad.

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

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]

[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

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

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

[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

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

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

[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

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

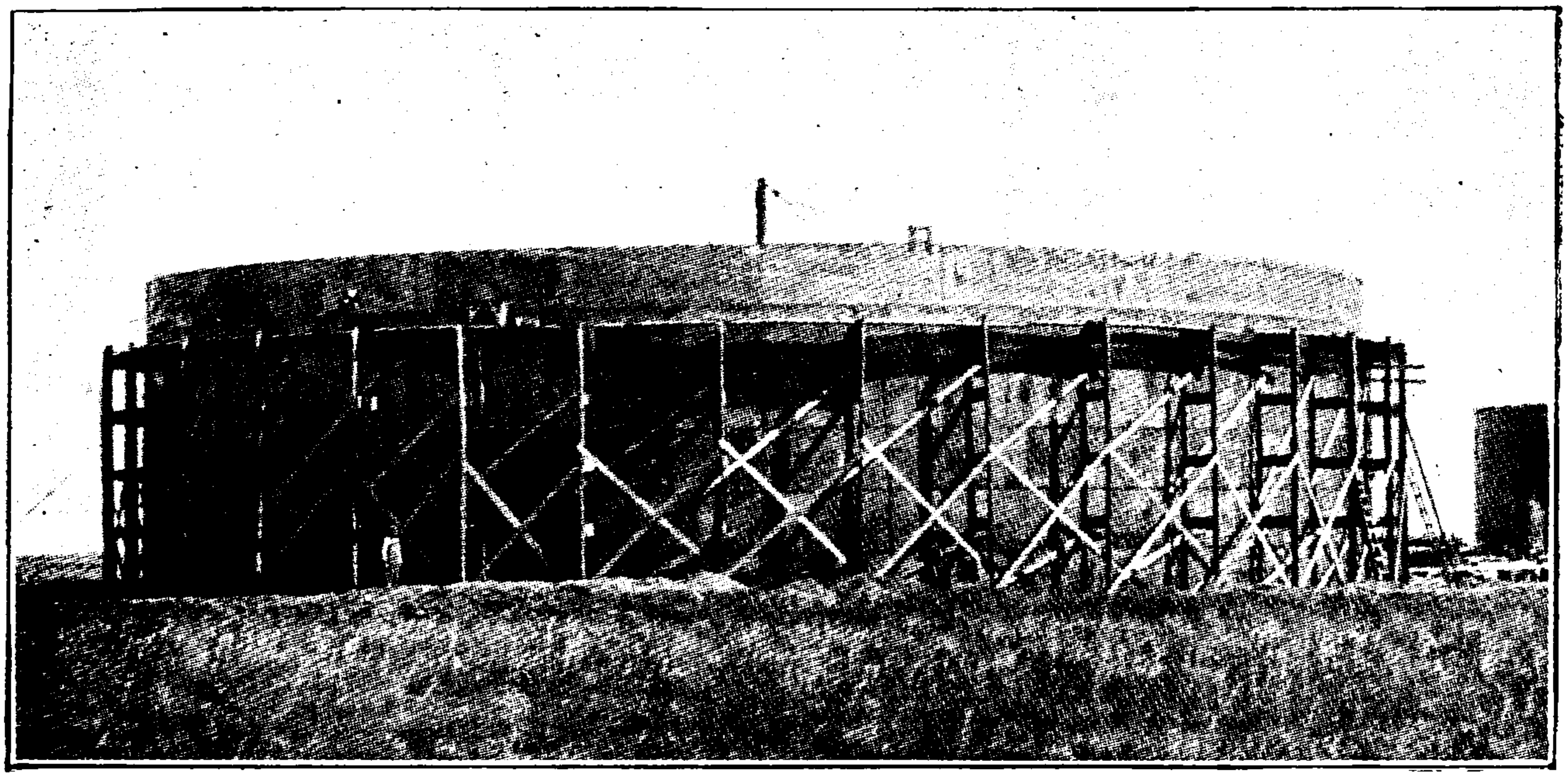


Photo by Trost.

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

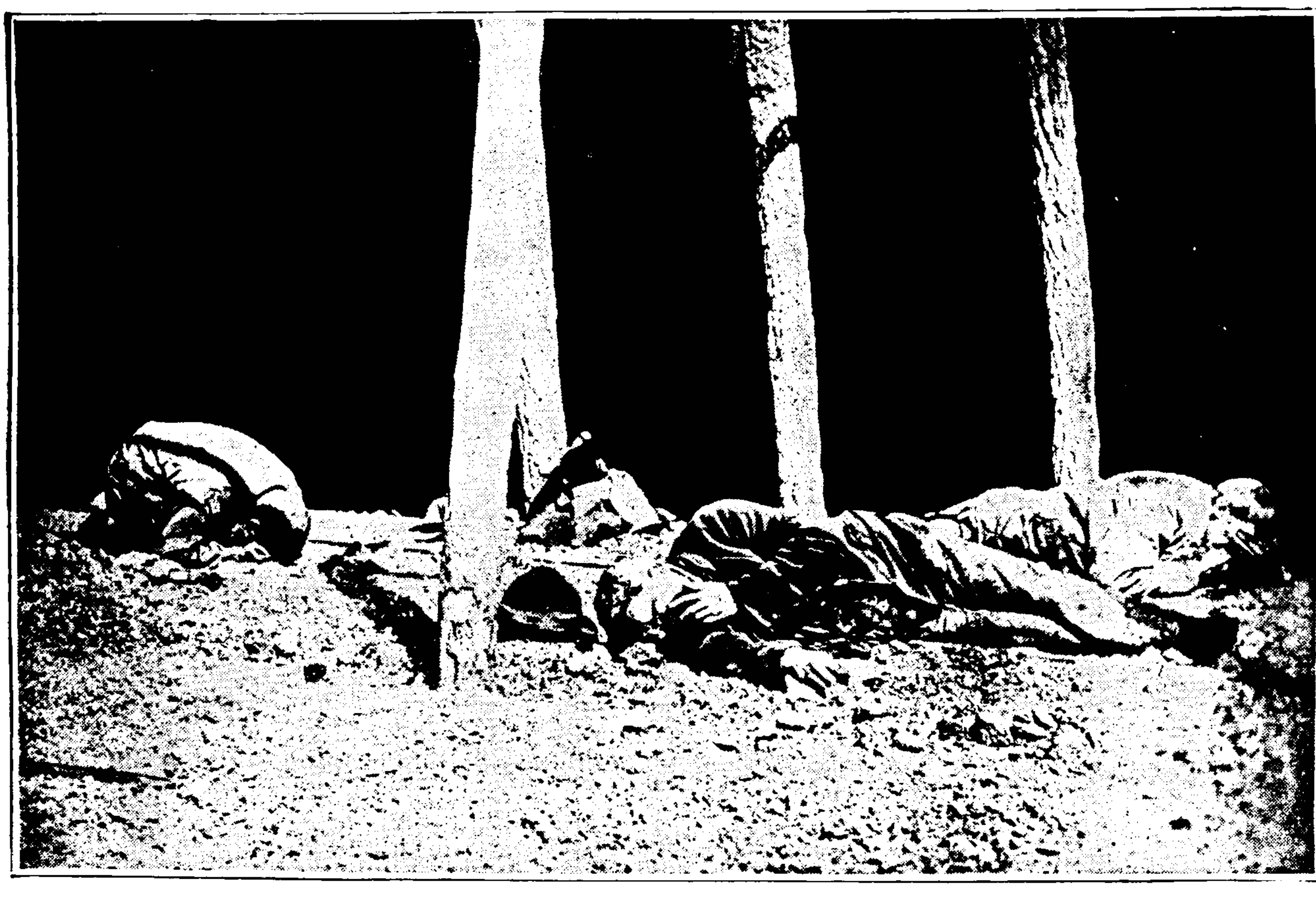


PLATE 22.—Dead miners, overcome by carbon monoxide (" after-damp "), after a coal-mine explosion at Pennycraig.

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

plosions, 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, 1½ 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

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

the subsequent fatty degenerations of the tissues which may result."

Perhaps the best way 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

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.

[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

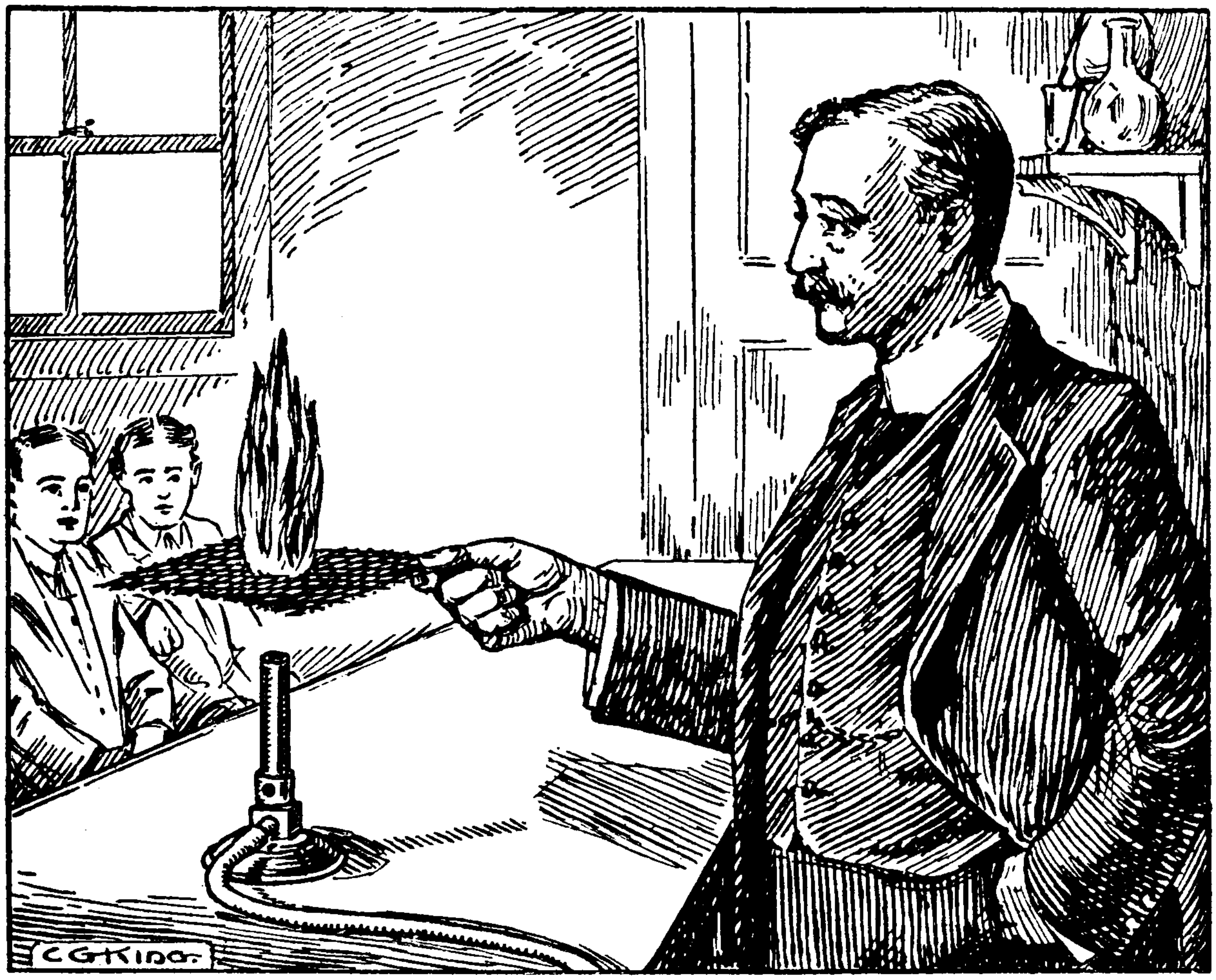


FIG. 19.—Principle of a safety lamp—a flame will not pass through wire gauze.

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 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

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 $21\frac{1}{2}$ 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.

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.