THE MACMILLAN COMPANY
NEW YORK · BOSTON · CHICAGO
SAN FRANCISCO

MACMILLAN & CO., LIMITED
LONDON · BOMBAY · CALCUTTA
MELBOURNE

THE MACMILLAN CO. OF CANADA, LTD.
TORONTO

MODERN SCIENCE READER

WITH SPECIAL REFERENCE TO

CHEMISTRY

EDITED BY
ROBERT MONTGOMERY BIRD, Ph., D.
Collegiate Professor of Chemistry in
the University of Virginia

New York
THE MACMILLAN COMPANY
LONDON: MACMILLAN & CO., LTD.,
1911

Set up and electrotyped. Published September, 1911

Printed at
The NORWOOD PRESS
Berwick & Smith Company, Norwood, Massachusetts

CONTENTS

Page

The Romance of the Diamond........................ 1
William Crookes

Making Money out of Waste........................ 11
Day Allen Willey

Modern Explosives........................ 17
J. S. S. Brame

A Sketch of the History of Propellants........................ 28
Andrew Noble

Artificial Silk........................ 36
Joseph Cash

The Creators of the Age of Steel........................ 42
A Review

The Anatomy of a Steel Rail........................ 56
Henry Cook Boynton

The Nature and Treatment of Alloy Steel........................ 65
John A. Mathews

The Oxyhydric Process of Cutting Metals........................ 72
E. F. Lake

The Commercial Production of Oxygen........................ 81
Alfred Gradenwitz

Why a Flame Emits Light........................ 89
Robert M. Bird

Marvels of a Plant's Growth and the Chemistry of Decay........................ 103
Vivian B. Lewes

Coal, Its Composition and Combustion........................ 115
William H. Booth

PAGE

The Coal-Tar Dye Industry, Its Wonderful Rise and Importance ... 124

Natural and Artificial Perfumes ... 131
MAX HEIM

Scientific Developments in the Glass Industry ... 141
R. SCHALLER

What Electrochemistry is Accomplishing ... 148
JOSEPH W. RICHARDS

The Yeast Cell and its Lessons ... 169
W. STANLEY SMITH

The Chemical Regulation of the Processes of the Body 181
WILLIAM HENRY HOWELL

The Science of Chemistry and its Development ... 195
Selections from The *New International Encyclopaedia*

The Age of Science ... 230
IRA REMSEN

The Old and the New Alchemy ... 245
HERMANN KOPP

Radioactivity ... 270
MADAME CURIE

Visible Molecules, Corpuscles and Ions ... 279

The Electronic Theory of Matter ... 286
OLIVER LODGE

The Ether of Space ... 290
OLIVER LODGE

Unsolved Problems of Chemistry ... 305
IRA REMSEN

Regarding Additional Reading ... 322
THE EDITOR

PREFACE

This book provides a partial course of reading in Chemistry for college men and general readers, and indicates further matter of an interesting and instructive nature. It is the first volume of a series of Readers which will contain reprints of modern papers and addresses, gathered from many sources and edited to suit the purposes herein explained.

It is our experience with college men that parallel reading, more than any other influence, conduces to interest in text-book matter, *especially in first-year courses in science.* It broadens the student's views, enlivens the subject and shows its bearing upon the work and problems of life. We believe that some reading of good scientific literature in each distinct branch of Natural Science should be required of every undergraduate; this volume attempts to supply suitable matter for Chemistry. We seek to help teachers to introduce such literature and its authors to college students, and to acquaint students with the more easily available sources of reliable articles of a popular nature. It is hoped that these readers will be of special service to teachers of large classes, where the inspiration of personal contact is necessarily small; and also that they will help to awaken interest in science among those who think they have no aptitude for such branches of knowledge.

We have had in mind, also, persons who are seeking knowledge without the aid of a teacher. Definite information for reading and home study is given, such as the editor now wishes he had known how to obtain while in business, before going to college or expecting ever to have the time to do so. We wish to increase the service of popular science by aiding readers of such to find good matter. We do this because we believe that the widespread habit of reading the scientific contributions to magazines and newspapers is responsible in no small measure for the present-day quick acceptance of applications of pure research, and that it has also contributed greatly to the development of workers who apply the discoveries of science, and of business men who promote such applications.

We have selected articles which will whet the taste for knowledge without giving rise to unbalanced and unscientific ideas; which will contribute to contemplative habits of reading, and thereby help to develop that culture, efficiency, and capacity for productive thinking which wins success in any field. We have endeavored, particularly, to choose articles which are suggestive, which will broaden the reader's outlook on science by showing him the interrelations of its different branches, and which will impress upon him the advantage such a broad view gives in the solution of the problems of the business and professional man. The papers contain the information which permits them to be readily understood; they are popular in style, that is, they possess "human interest," and some have even a "once-upon-a-time" flavor; yet they are all of a scientific and dignified character.

We wish to express our thanks to the authors and original publishers for permission to republish the articles; likewise to the publishers of the *New International Encyclopædia* for permission to include some of the excellent chemical articles contained therein. We shall feel under obligations to any one who calls our attention to suitable papers not now included.

Later volumes will be devoted to other branches of science, and a bibliographical volume will contain interesting and inspiring sketches of the lives and work of some of the men who have either added to the stock of human knowledge or who have applied it to human needs.

R. M. BIRD.

University of Virginia,
January, 1911.

THE ROMANCE OF THE DIAMOND[1]

BY SIR WILLIAM CROOKES, D. Sc., F. R. S.

From the earliest times, the diamond has fascinated mankind. It has been a perennial puzzle—one of the "riddles of the painful earth." Speculations as to the probable origin of the diamond have been greatly forwarded by patient research, and particularly by improved means of obtaining high temperatures, an advance we owe principally to the researches of Professor Moissan.

There is one theory of the origin of diamonds which appeals to the fancy. It is said that the diamond is a gift from Heaven, conveyed to earth in meteoric showers. The suggestion, I believe, was first broached by A. Meydendauer, who said:

> The diamond can only be of cosmic origin, having fallen as a meteorite at later periods of the earth's formation. The available localities of the diamond contain the residues of not very compact meteoric masses, which may, perhaps, have fallen in prehistoric ages, and which have penetrated more or less deeply, according to the more or less resistant character of the surface where they fell. Their remains are crumbling away on exposure to the air and sun, and the rain has long ago washed away all prominent masses. The enclosed diamonds have remained scattered in the river-beds, while the fine, light matrix has been swept away.

According to this hypothesis, the so-called volcanic pipes peculiar to all diamond mines are simply holes bored in the solid earth by the impact of monstrous meteors—the larger masses boring the holes, while the smaller masses, disintegrating in their fall, distributed diamonds broadcast.

Bizarre as such a theory appears, I am bound to admit

---

[1] Published in *North American Review*, March, 1908.

that there are many circumstances which show that the notion of the heavens raining diamonds is not impossible. The most striking confirmation of the meteoric theory comes from Arizona. Here, on a broad open plain, over an area about five miles in diameter, have been scattered one or two thousand masses of metallic iron, the fragments varying in weight from half a ton to a fraction of an ounce. There is little doubt that these masses formed part of a meteoric shower, although no record exists as to when the fall took place.

Curiously enough, near the center, where most of the meteorites have been found, is a crater with raised edges three quarters of a mile in diameter and about six hundred feet deep, bearing exactly the appearance which would be produced had a mighty mass of iron struck the ground and buried itself deep under the surface. Altogether, ten tons of this iron have been collected and specimens of the Cañon Diablo meteorite are in most collectors' cabinets.

An ardent mineralogist, the late Dr. Foote, cutting a section of this meteorite, found the tools were injured by something vastly harder than metallic iron. He examined the specimen chemically, and soon after announced to the scientific world that the Cañon Diablo meteorite contained black and transparent diamonds. This startling discovery was afterward verified by Professors Moissan and Freidel; and Moissan, working on a piece of the Cañon Diablo meteorite, has recently found smooth black diamonds and transparent diamonds, in the form of octahedra with rounded edges, together with green hexagonal crystals of carbon silicide. The presence of carbon silicide in the meteorite shows that it must, at some time, have experienced the temperature of the electric furnace.

Under atmospheric influences the iron would rapidly oxidize and rust away, and the meteoric diamonds would be unaffected and left on the surface of the soil, to be found haphazard when oxidation had removed the last proof of their celestial origin. That there are still lumps of iron left in Arizona is merely due to the extreme dryness of the climate and the comparatively short time the iron has been on our planet. We are witnesses to the course of an event which may have happened in geologic times anywhere on the earth's surface.

Although in Arizona diamonds have fallen from the skies, confounding our senses, this descent of precious stones is what may be called a freak of nature rather than a normal occurrence. To the average reader it is now known that there is no great difference between the composition of our earth and that of extraterrestrial masses. The mineral peridot is present in most meteorites. Yet no one doubts that peridot is also a true constituent of rocks formed on this earth. The spectroscope reveals that the elementary composition of the stars and the earth are pretty much the same. The spectroscope also shows that meteorites have as much of earth as of heaven in their composition. Indeed, not only are the selfsame elements present in meteorites, but they are combined in the same way to form the same minerals as in the crust of the earth.

It is certain from observations I have made, corroborated by experience gained in the laboratory, that iron at a high temperature and under great pressure—conditions existent at great depths below the surface of the earth—acts as the long-sought solvent for carbon, and will allow it to crystallize out in the form of diamond. But it is also certain, from the evidence afforded by the Arizona and other meteorites, that similar conditions have existed among bodies in space, and that on more than one occasion a meteorite freighted with jewels has fallen as a star from the sky.

Many circumstances point to the conclusion that the diamond of the chemist and the diamond of the mine are strangely akin as to origin. It is evident that the diamond has not been formed *in situ* in the blue ground where it is found. The genesis must have taken place at vast depths under enormous pressure. The explosion of large diamonds on coming to the surface shows extreme tension. More diamonds are found in fragments and splinters than in perfect crystals; and it is noteworthy that, although these splinters and fragments must be derived from the breaking up of a large crystal, yet in only one instance have pieces been found which could be fitted together; and these occurred at different levels. Does not this fact point to the conclusion that the blue ground is not their true matrix? Nature does not make fragments of crystals. As the edges of the crystals are still sharp and unabraded, the *locus* of formation cannot have been very distant from the present sites. There were probably many sites of crystallization differing in place and time, or we should not see such distinctive characters in the gems from different mines, nor indeed in diamonds from different parts of the same mine.

Although my experiments are chiefly connected with the physical and chemical properties of diamonds, and with researches on the perplexities of their probable formation, it will be a kind of compensation for some of my theories if I bring before the reader the general character of the South African diamond mines and their surroundings.

The most famous diamond mines in the world are Kimberley, De Beers, Dutoitspan, Bulfontein and Wesselton. Kimberley is practically in the center of the present diamond-producing area. The five diamond mines are all contained in a precious circle three and one half miles in diameter. They are irregular-shaped round or oval pipes, extending vertically downward to unknown depths and becoming narrower as the depth increases. They are considered to be volcanic necks filled from below with a heterogeneous mixture of fragments of surrounding rocks, and of older rocks, such as granite, mingled and cemented with a bluish-colored hard mass, in which famous "blue ground" the imbedded diamonds are hidden.

How the great pipes were originally formed it is hard to say. They were certainly not burst through in the ordinary manner of volcanic eruption, since the surrounding and enclosing walls show no signs of igneous action, and are not shattered or broken up even when touching the "blue ground." It is pretty certain that these pipes were filled from below after they were pierced, and the diamonds were formed at some previous time and mixed with a mud volcano, together with all kinds of débris eroded from the rocks through which it erupted, forming a geological "plum pudding." A more wildly heterogeneous mixture can hardly be found anywhere else on this globe.

It may be that each volcanic pipe is the vent for its own laboratory—a laboratory buried at vastly greater depths than we have yet reached—where the temperature is comparable with that of the electric furnace, where the pressure is fiercer than in our puny laboratories and the melting-point higher, where no oxygen is present, and where masses of liquid carbon have taken centuries, perhaps thousands of years, to cool to the solidifying-point.

In 1903 the Kimberley mine had reached a depth of 2,599 feet. Tunnels are driven from the various shafts at different levels, about 120 feet apart, to cross the mine from west to east. These tunnels are connected by two other tunnels running north and south. The scene belowground in the labyrinth of galleries is bewildering in its complexity, and very unlike the popular notion of a diamond mine. All below is dirt, mud, grime; half-naked men dark as mahogany, lithe as athletes, dripping with perspiration, are seen in every direction, hammering, picking, shovelling, wheeling the trucks to and fro, keeping up a weird chant which rises in force and rhythm when a greater task calls for excessive muscular strain. The whole scene is more suggestive of a coal mine than of a diamond mine, and all this mighty organization—this strenuous expenditure of energy, this costly machinery, this ceaseless toil of skilled and black labor—goes on day and night, just to win a few stones wherewith to deck my lady's finger! All to gratify the vanity of woman! "And," I hear my fair reader remark, "the depravity of man!"

Prodigious diamonds are not so uncommon as is generally supposed. Diamonds weighing over an ounce (151.5 carats) are not infrequent at Kimberley. I have seen in one parcel of stones eight perfect ounce crystals, and one inestimable stone weighing two ounces. The largest known diamond, the ''Cullinan,'' was found in the New Premier Mine. It weighs no less than 3,025 carats, or 1.37 pounds avoirdupois. It is a fragment, probably less than half, of a distorted octahedral crystal. The other portions still await discovery by some fortunate miner.

At the close of the year 1904, ten tons of diamonds had come from these mines, valued at $300,000,000. This mass of blazing gems could be accommodated in a box five feet square and six feet high. The diamond has a peculiar luster, and on the sorter's table it is impossible to mistake it for any other stone. It looks somewhat like clear gum arabic. From the sorting-room the stones are taken to the Diamond Office to be cleaned in acids and sorted into classes by the valuators, according to color and purity. It is a sight for Aladdin to behold the sorters at work. In the Kimberley treasure store the tables are literally heaped with stones won from the rough blue ground—stones of all sizes, purified, flashing and of inestimable price; stones coveted by men and women all the world over.

Where fabulous riches are concentrated into so small a bulk, it is not surprising that precautions against robbery are elaborate. The Illicit Diamond-Buying Laws are very stringent; and the searching, rendered easy by the ''compounding'' of the natives, is of the most drastic character. The value of stolen diamonds at one time reached nearly $5,000,000 a year. Now the safeguard against this is the ''compound.'' This is a large square, about twenty acres, surrounded by rows of one-story buildings, divided into rooms holding about twenty natives each.

Within the enclosure is a store where the necessaries of life are supplied at a reduced price, and wood and water free. In the middle is a large swimming-bath with fresh water running through it. The rest of the space is devoted to games, dances, concerts and any other amusement the native mind can desire. In the compound are to be seen representatives of nearly all the picked types of African tribes. The clothing in the compound is diverse and original. Some of the men are evident dandies, whilst others think that in so hot a climate a bright-colored handkerchief or "a pair of spectacles and a smile" is as great a compliance with the requirements of civilization as can be expected.

One Sunday afternoon, my wife and I walked unattended about the compound, almost the only whites present among 1,700 natives. At one part a Kaffir was making a pair of trousers with a bright nickel-plated sewing-machine, in which he had invested his savings. Next to him, a "boy" was reading from the Testament in his own language to an attentive audience. In a corner, a party were engaged in cooking a savory mess in an iron pot; and, further on, the orchestra was tuning up, and Zulus were putting the finishing touches to their toilet of feathers and beads. One group was intently watching a mysterious game. It is played by two sides, with stones and grooves and hollows in the ground, and appears to be of most absorbing interest. It seems to be universal throughout Africa; it is met with among the ruins of Zimbabwe, and signs of it are recorded on old Egyptian monuments.

A word as to the hardness of diamonds. They vary much in this respect; even different parts of the same crystal differ in their resistance to cutting and grinding. So hard is diamond in comparison to glass that a suitable splinter of diamond will plane curls off a glass plate as a carpenter's tool will plane shavings off a deal board. Another experiment that will illustrate its hardness is to place a diamond on the flattened end of a conical block of steel, and upon it bring another similar cone of steel. If I force them together with hydraulic power I can force the stone into the steel blocks without injuring the diamond in the least. The pressure which I have brought to bear in this experiment has been equal to 170 tons per square inch of diamond.

The only serious rival of the diamond in hardness is the metal tantalum. In an attempt to bore a hole through a plate of this metal, a diamond drill was used revolving at the rate of 5,000 revolutions per minute. This whirling force was continued ceaselessly for three days and nights, when it was found that only a small point, one fourth of a millimeter deep, had been drilled, and it was a moot point which had suffered most damage, the diamond or the tantalum.

After exposure for some time to the sun, many diamonds glow in a dark room. One beautiful green diamond in my collection, when phosphorescing in a vacuum, gives almost as much light as a candle, and you can easily read by its rays. But the time has hardly come when we can use diamonds as domestic illuminants! Mrs. Kunz, wife of the well-known New York mineralogist, possesses perhaps the most remarkable of all phosphorescing diamonds. This prodigy diamond will phosphoresce in the dark for some minutes after being exposed to a small pocket electric light, and if rubbed on a piece of cloth a long streak of phosphorescence appears.

For the manufacture of a diamond, the first necessity is to select pure iron—free from sulphur, silicon, phosphorus, and so forth—and to pack it in a carbon crucible with pure charcoal from sugar. The crucible is then put into the body of the electric furnace, and a powerful arc formed close above it between carbon poles, utilizing a current of 700 amperes at 40 volts pressure. The iron rapidly melts and saturates itself with carbon. After a few minutes' heating to a temperature above 4,000° C.—a temperature at which the iron melts like wax and volatilizes in clouds—the current is stopped, and the dazzling fiery crucible is plunged beneath the surface of cold water, where it is held till it sinks below a red heat.

As is well known, iron increases in volume at the moment of passing from the liquid to the solid state. The sudden cooling solidifies the outer layer of iron and holds the inner molten mass in a tight grip. The expansion of the inner liquid on solidifying produces an enormous pressure, and under the stress of this pressure the dissolved carbon separates out in transparent forms—minutely microscopic, it is true—but all the same veritable diamonds, with crystalline form and appearance, color, hardness and action on light the same as the natural gem.

Now commences the tedious part of the process. The metallic ingot is attacked with hot nitro-hydrochloric acid until no more iron is dissolved. The bulky residue consists chiefly of graphite, together with translucent chestnut-colored flakes of carbon, black opaque carbon as hard as diamonds—black diamonds, in fact—and a small portion of transparent colorless diamonds showing crystalline structure.

The residue is first heated for some hours with strong sulphuric acid at the boiling-point, with the cautious addition of powdered nitre. It is then well washed, and for two days allowed to soak in strong hydrofluoric acid in cold, then in boiling, acid. After this treatment the soft graphite disappears, and most, if not all, the silicon compounds have been destroyed.

Hot sulphuric acid is again applied to destroy the fluorides; and the residue, well washed, is attacked with a mixture of the strongest nitric acid and powdered potassium chlorate, kept warm—but not above 60° C., to avoid explosions. This treatment must be repeated six or eight times, when all the hard graphite will gradually be dissolved, and little else left but graphitic oxid, diamond and the harder carbonado or black diamond and boart. The residue is fused for an hour in fluorhydrate of fluorid of potassium, then boiled out in water, and again heated in sulphuric acid.

The well-washed grains which resist this energetic treatment are dried, carefully deposited on a slide and examined under the microscope. Although many fragments of crystals occur, it is remarkable I have never seen a complete crystal. All appear shattered, as if on being liberated from the intense pressure under which they were formed they burst asunder. I have singular evidence of this phenomenon. A fine piece of artificial diamond, carefully mounted by me on a microscopic slide, exploded during the night and covered the slide with fragments. This bursting paroxysm is not unknown at the Kimberley diamond mines.

MAKING MONEY OUT OF WASTE[1]

BY DAY ALLEN WILLEY

One of the most interesting phases of the world's development is the manner in which the people of civilized nations are utilizing so many things which were only recently considered as valueless—to be thrown away as worthless; while what we have thought was useless stuff, merely fit to be trod under the feet as so much dirt, has been converted into a product of great value. The increase in the population of various countries, and especially the increase in the number of inhabitants of great cities, has been one of the reasons why the genius of the inventor has contrived to make what we have called waste of worth to us by using it in various compounds and articles which have already become indispensable. The things that are thrown into the street, house-yard, and other receptacles for débris can be used in so many ways, that scarcely anything can now be considered refuse. For instance, old tin cans are melted to be molded into buttons, covers for luggage, and toys for children, which sell throughout the world at Christmas time. Discarded shoes and rubbers, also scraps of leather, have become of value in manufacturing various substances. Not a single bottle or other piece of glass need be thrown away, for mixed with certain kinds of earth and sand, it makes an excellent artificial stone for buildings. Not so long ago dead animals were buried, as it was not known that their bones, hide, and even parts of the intestines were of use. Much of the inflammable composition in the lucifer match is now obtained from such bones. Even the sweepings of the street pavement, containing as they do particles of horseshoes and other metal, are worth gathering; while

---

[1] *Scientific American Supplement,* April 10, 1910.

the bits which fall from the horse's hoof as it is being shod by the farrier make a most valuable dye when mixed with certain chemicals and metal scraps.

Over nearly every large city, especially such centers as London, Birmingham, and seats of other great countries, are enormous clouds of smoke, which so frequently darken the atmosphere that even at noontime it is necessary to have lights in the buildings. Yet this smoke if properly treated can be actually dissolved into several most useful elements —and the inventor has designed apparatus by which these elements can be secured at a small cost. It is a fact that smoke can be weighed and measured like so much earth and sand. Experiments which have been made in the United States show that a cord of ordinary fuel wood in burning generates 28,000 cubic feet of smoke. If the smoke from one hundred cords of wood is treated by this process, it will yield no less than six tons of the valuable chemical known as acetate of lime, besides twenty-five pounds of tar. But the smoke contains so much of the elements of alcohol, that this quantity will produce no less than two hundred gallons of spirit suitable for lighting, heating, or the operation of motors.

Usually perfumes and other useful odors are considered as being obtained principally from flowers. The oils coming from waste fruit, such as decayed pears, grapes, and peaches, however, can be substituted for some of the most costly floral odors after being treated with acids and other liquids which give them a remarkable fragrance. Perfume, soaps, even confectionery, are now manufactured, which are flavored with what is called the oil of bitter almonds, but which is extracted from the tar which is a refuse of gas-making plants such as are to be found in every large city.

The enormous production of iron and steel in various forms has caused great furnaces to be erected for smelting this metal in large quantities. Here again a study has been made of what can be done to use what was formerly waste. Even the gas which in the past has been allowed to escape in the air has been made prisoner, so to speak, and converted into a most valuable factor. The mixture left after the iron has been extracted from the ore—sometimes called slag—which represents the débris of the iron ore, is now one of the most valuable compounds coming from the blast furnace, although but a few years ago it was thrown away. In fact, blast furnaces have been built on the edge of swamps and bodies of water, so that the slag could be thrown into these places and used for filling them up. Very good glass is now made from this slag, as well as paving blocks and bricks, artificial porphyry, and a cement which is equal to the best. Ground with six per cent. of slaked lime, building mortar is also made from slag; and ornamental copings and moldings, window sills, and chimney pieces are fashioned of it.

Slag brick is stated to be quite as strong as ordinary brick, and much less permeable to moisture. To make 1,000 brick, 6,000 or 7,000 pounds of granulated slag, and from 500 to 700 pounds of burned lime, are consumed. Good bricks also can be made from granulated slag mixed with dust from slag, though the hardening process is rather slow. Slag is also used for steampipe and boiler wrappings, in which form it is called "silicate of cotton." Coal slag is a good structural material when mixed with slaked lime. Basic slag is used in large quantities by manufacturers of fertilizers, instead of phosphate rock.

The greatest metal industry in the world, which is now being built in Indiana, forming an entire city in itself, is provided with iron smelters from which the gas as it rises will be returned to the fires beneath the ore and used for heat. By this system the cost of coal to smelt the ore will be about one half the expense if the gas were not secured as stated. Waste gas has been utilized by inventors for the direct operation of engines so large that they have a force equal to the power of a thousand horses. As it issues from the smelter, the gas enters a large cover, as it might be termed, placed above the furnace. In the center of the cover is a pipe, through which the gas passes into a reservoir below. From this it is forced directly into the engine, and ignited by an electric spark. This causes it to explode, and the force of the explosion drives the engines and the other machinery.

One of the most important discoveries which has been made in connection with what we have called waste products is the value of sawdust. Usually sawmills produce such large quantities of the material, that it cannot be burned to advantage. It is then thrown away, so to speak, sometimes being piled in great heaps and left to slowly consume. A very good quality of alcohol, however, can be distilled from ordinary sawdust by an inexpensive process, in such quantities that two gallons of the liquid can be obtained from 220 pounds of dust. The sawdust from birch and some other species of forest trees will also yield a palatable sugar after it has been treated with certain chemicals. In America and in some parts of Europe an enormous quantity of the dust is sold, being vended about in wagons and in sacks carried on the backs of the venders. It is bought to sprinkle on the floors of cafés, butcher shops, and other places where it will prevent dirt from sticking to the floors. In recent years so many dolls and other "stuffed" toys have been made, that the sawdust is used very extensively for this purpose also. It is a fact that there are five hundred sawdust merchants in the city of New York alone, and that they sell what is generally called waste to the value of 400,000 pounds in a single year.

Since the slaughter of cattle, sheep, and other animals on a large scale was begun at the abattoirs in America, France, and other countries, the valuable articles and compounds which have been made from dead animals is really amazing. In some of the American abattoirs the carcass of a single beef may enter into no less than four hundred different articles, ranging from the beefsteak for the family table to the buttons sewed on the family clothing. Parts of the animals formerly discarded go into medicines, oils, soaps, brushes and combs, mirrors, household necessaries such as handles for tools, leather for harness and luggage covers. Even the teeth are fashioned into studs and buttons. A list of the slaughter-house by-products which are now utilized for commercial purposes includes hair, bristles, blood, bones, horns, hoofs, glands, and membranes—from which are obtained pepsin, thymus, thyroids, pancreatin, parotid substances, and suprarenal capsules—gelatin, glue, fertilizers, hides, skins, wool, intestines, neat's foot oil, soap stock, glycerin from tallow, brewer's isinglass, and albumen. Albumen is obtained from the blood of the slaughtered animals, and is used by calico printers, tanners, sugar refiners, and others. The bones coming from cooked meat are boiled, and the fat and gelatin which result are used, the former to make soap, the latter for transparent coverings for chemical preparations, and for other purposes. The uncooked bones are used in a variety of ways. From the bones of the feet of cattle are made the handles of tooth-brushes and knives, chessmen, and nearly every article for which ivory is suitable. Combs, the backs of brushes, and large buttons are made from horns, which are split and rolled flat by heat and pressure.

Hoofs are utilized according to their color. White hoofs are exported largely to Japan, to be made into various ornaments and imported back as "Japanese art objects." From striped hoofs buttons and horn ornaments are made; while black hoofs find service in the manufacture of cyanide of potassium for the extraction of gold, and are also ground up as fertilizer. From the feet neat's foot oil is extracted, and from various other portions of the body various other oils, all of which are highly valuable. Substitutes for butter, such as butterin and oleomargarin, are made by utilizing the fat of beef and hogs.

In the textile industry the making of value out of waste has been truly remarkable. In the modern woolen factory no fewer than five products are obtained by methods now in vogue, from the greasy excretions which, after circulating through the animal's system, attach to the wool of a sheep. These products are used as a base for ointments and toilet preparations, for dressings for leather, as a lubricant for wool and other animal fibers, and in conjunction with certain lubricating oils. At one large plant in America more than 200,000 pounds of wool are "degreased" every ten hours. From two million to three million dollars' worth a year of wool fat and potash are estimated to have been wasted in the United States before the solvent process of extraction came into general use.

In the industries of cotton manufacturing and cottonseed oil making, scarcely anything is allowed to go to waste. For many years the seed of the cotton plant was regarded as without value; now the cottonseed crop of the United States is worth about one fifth of the total cotton crop of the country. Among the principal uses of cottonseed oil are its part in making lard compound and white cottolene, both valuable food products. Cottonseed oil is also used as a substitute for olive oil, by soapmakers in the making of soap, by bakers, and also in the manufacture of washing powders.

The leather industry is equally saving in the matter of wastes. In the tanning of leather, there are developed as side products, scrap and skin, from which glue is made; hair, from which cheap blankets and cloths are manufactured, and waste liquors containing lime salts. By means of a special apparatus scraps of leather are converted into boot and shoe heels, inner soles, etc. What is called "shoddy" leather is made by grinding the bits of leather to a pulp, and then by maceration and pressure forming them into solid strips.

MODERN EXPLOSIVES[1]

BY J. S. S. BRAME

Of the Royal Naval College, Greenwich

THE subject of explosives is one which never fails to excite interest even under the most ordinary conditions, doubtless owing to the enormous potentiality of these substances, while at the present time more than usual attention is directed to them, it being scarcely possible to read a daily paper without finding some reference to the behavior of various modern explosives in the theater of war.

Explosion may be defined as chemical action causing extremely rapid formation of a very great volume of highly expanded gas, this large volume of gas being generally due to the direct liberation by chemical action, and the further enormous expansion by the heat generated. Explosion itself may, therefore, be regarded as extremely rapid combustion, while the effect is obtained by the enormous pressure produced, owing to the products of combustion occupying probably many thousand times the volume of the original body. The effect of high temperature is seen in the well-known case of explosion of a mixture of hydrogen and oxygen, where if the original mixture and the products of explosion are each measured at the same temperature above the boiling point of water, a less volume of gas (water vapor) is actually found. The explosion can only have been produced by the enormous expansion of this vapor in the first place by the heat of the reaction. Such an explosion when carried out in a closed bomb with the mixed gases under ordinary conditions of measurement produces a pressure of about 240 pounds to the square

---

[1] A lecture delivered at the London Institution on February 12, 1900. Published in *Scientific American Supplement* for May 12, 1900.

inch. A more practical illustration is seen with nitroglycerin, which Nobel found yielded about 1,200 times its own volume of gas calculated at ordinary temperatures and pressures, while the heat liberated expands the gas to nearly eight times its normal volume.

Clearly, then, a substance for use as an explosive must be capable of undergoing rapid decomposition or combination with the production of large volumes of gas, and further produce sufficient heat to greatly expand these gases, the ratio of the volume of gases at the moment of explosion to the volume of the original body largely determining the efficiency of the explosive.

Explosives may be divided into two great classes—mechanical mixtures and chemical compounds. In the former the combustible substances are intimately mixed with some oxygen-supplying material, as in the case of gunpowder, where carbon and sulphur are intimately mixed with potassium nitrate; while guncotton and nitroglycerin are examples of the latter class, where each molecule of the substance contains the necessary oxygen for the oxidation of the carbon and hydrogen present, the oxygen being in feeble combination with nitrogen. Many explosives are, however, mechanical mixtures of compounds which are themselves explosive, e. g., cordite, which is mainly composed of guncotton and nitroglycerin.

Two methods are in common use for bringing about explosions—ignition by heat, thus bringing about ordinary but rapid combustion, molecule after molecule undergoing decomposition; and detonation, where the effect is infinitely more rapid than in the first case; in fact, it may be regarded as practically instantaneous. The result may be looked upon as brought about by an initial shock imparted to the explosive by a substance—the detonating material—which is capable of starting decomposition in the adjacent layers of the explosive, thus causing a shock to the next layer, and so on with infinite rapidity. That the results are not entirely due to the mechanical energy of the liberated gas particles is shown by the fact that the most powerful explosive is not the most powerful detonator; neither is it entirely due to heat, since wet substances undergo detonation. The probability is that the result is brought about by vibrations of particular velocity which vary for different substances, the decomposition being caused by the conversion of the mechanical force into heat in the explosive, thus bringing about a change in the atomic arrangement of the molecule. According to Sir Frederick Abel's theory of detonation, the vibrations caused by the firing of the detonator are capable of setting up similar vibrations in the explosive, thus determining its almost instantaneous decomposition.

The most common and familiar of explosives is undoubtedly gunpowder, and although for military purposes it has been largely superseded by smokeless powders, yet it has played such an important part in the history of the world during the last few centuries that apart from military uses it is even now of sufficient importance to demand more than a passing notice.

Its origin, although somewhat obscure, was in all probability with the Chinese. Roger Bacon and Berthold Schwartz appear to have rediscovered it in the latter years of the thirteenth and earlier part of the fourteenth centuries. It was, undoubtedly, used at the battle of Crécy (1346). The mixture then adopted appears to have consisted of equal parts of the three ingredients—sulphur, charcoal, and nitre; but some time later the proportions, even now taken for all ordinary purposes, were introduced, namely:

Potassium nitrate	75 parts
Charcoal	15 "
Sulphur	10 "
	100 parts

Since gunpowder is a mechanical mixture, it is clear that the first aim of the maker must be to obtain perfect incorporation, and, necessarily, in order to obtain this, the materials must be in a very finely divided state. Moreover, in order that uniformity of effect may be obtained, purity of the original substances, the percentage of moisture present, and the density of the finished powder are of importance.

The weighed quantities of the ingredients are first mixed 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 traveling. After passing through a sieve, the mixture (green charge) is passed on to the incorporating mills, where it is thoroughly ground under heavy metal rollers, a small quantity of water being added to prevent dust and facilitating incorporation, and during this process the risk of explosion is greater possibly than at any other stage in the manufacture. There are usually six mills working in the same building, with partitions between. Over the bed of each mill is a horizontal board, the "flash board," which is connected with a tank of water overhead, the arrangement being such that the upsetting of one tank discharges the contents of the other tanks onto the corresponding mill beds below, so that in the event of an accident the charge is drowned in each case. The "mill cake" is now broken down between rollers, the "meal" produced being placed in strong oak boxes and subjected to hydraulic pressure, thus increasing its density and hardness, at the same time bringing the ingredients into more intimate contact. After once more breaking down the material (press cake) the powder only requires special treatment to adapt it for the various purposes for which it is intended.

Within the last half-century an enormous alteration has taken place in artillery, the old smooth bore cannon, firing a round shot, having gradually given place to heavy rifled cannon, firing cylindrical projectiles and requiring very large powder charges. This has naturally had its influence on the powder used, and modifications have been introduced in two directions—first, alteration in the form of powder, and second, in the proportions of the ingredients. As the heavier guns were introduced, a large grain powder which burned more slowly was adopted, but further increase in the size of the guns led to the introduction of pebble powders, which in some cases consisted of cubes of over an inch side. Such cubes having large available surface evolved the usual gases in greater quantity at the start of the combustion than toward the finish, since the surface became gradually smaller, thus causing extra strain on the gun as the projectile was only just beginning to move. General Rodman, an American officer, introduced prism powder to overcome this difficulty, the charges being built up of perforated hexagonal prisms in which combustion started in the perforations and proceeding, exposed more surface, the prisms finally breaking down into what was virtually a pebble powder.

In order to secure still further control over the pressure, modifications in the proportions of the ingredients became necessary; the diminution of the sulphur and increase of the charcoal causing slower combustion, and moreover the use of charcoal prepared at a low temperature giving the so-called "cocoa powders."

The products of the combustion of powder and its manner of burning are largely influenced by the pressure, a property well illustrated by the failure of a red-hot platinum wire to ignite a mass of powder in a vacuum, only a few grains actually in contact with the platinum undergoing combustion. The gaseous products obtained are carbon dioxide, carbon monoxide, and nitrogen, other products being potassium carbonate, sulphate, and sulphide. The calculated gas yield per gram at 0° C. and 760 mm. pressure is 264·6 c.c., while Nobel and Abel actually obtained by experiment 263·74 c.c., numbers agreeing very closely. At the temperature of explosion this volume is enormously increased.

In 1832, Braconnot found that starch, ligneous fiber, and similar substances, when treated with strong nitric acid yielded exceedingly combustible substances, and Pelouze, in 1838, extended the investigation to cotton and paper.

Schönbein announced in 1845 his ability to make an explosive which he termed guncotton, and a year later Böttger made a similar announcement, and on a conference being held between these chemists their methods were found to be identical. The method was not disclosed at the time, since it was hoped that the German government would purchase the secret, but in a very short time several investigators solved the problem, and attempts to make the new explosive commercially were common. Unfortunately the earlier product was unstable, and several disastrous accidents occurred which led to the abandonment of the experiments, except in Austria. General von Lenk, who continued experimenting in that country, showed that if sufficient care was taken to ensure complete nitration and to remove all traces of free acid from the finished material, the substance was stable. He introduced a method of manufacture which was improved by Sir Frederick Abel in 1865. The physical character of the cotton fiber is such that it presents every obstacle to the removal of free acid, since it is built up of capillaries, but by reducing these tubes to the shortest possible length, as in Abel's process, the removal of acid is facilitated.

Since water is a product of the reaction of nitric acid on cellulose, the nitric acid would become diluted, forming "collodion cotton" instead of the more highly nitrated guncotton, and, therefore, sulphuric acid is used with the nitric acid to absorb this water, the usual proportions being 3 parts by weight of sulphuric acid (1·84) to 1 part by weight of nitric acid (1·52). Cotton waste, which has been picked, cleaned, cut into short lengths, and dried, is dipped in 1¼-pound charges in the acid, removed after five or six minutes, the excess of acid squeezed out, and the cotton placed in cooled earthenware pots for some twenty-four hours for nitration to be completed. The guncotton now goes through the lengthy process for removal of all traces of acid, starting with the removal of the greater portion of the acid by a centrifugal extractor, washing in water till no acid taste can be detected, boiling in water till free from action on litmus, reducing to pulp in a hollander, and finally, the thorough washing of the pulp by more water. If the product now satisfies the tests of purity, sufficient alkali—limewater, whiting, and caustic soda—is added to leave from one to two per cent. in the finished guncotton. The pulp is drawn up into a vessel from which it can be run off in measured quantities into molds fitted with perforated bottoms, the water being drawn off by suction from below, and finally, a low hydraulic pressure is brought to bear on the semi-solid mass. The blocks are taken to the press house and submitted to a pressure of some five tons per square inch, after which the finished block will contain from 12 to 16 per cent. of water.

From its chemical reactions guncotton must be regarded as an ether of nitric acid, a view first suggested by Béchamp. The point of ignition of the substance has been found to vary considerably, ranging from 136° to 223° C., this difference being probably due to variations in composition. Good guncotton usually ignites between 180° and 184° C. The combustion is extremely rapid when fired in loose unconfined masses, so rapid, in fact, that it may be ignited on a heap of gunpowder without affecting the latter. When struck between hard surfaces guncotton detonates, but usually only in that portion which is subjected to the blow. The volume of permanent gases evolved by the explosion of guncotton, as stated by different observers, has varied greatly. Macnab and Ristori give for nitrocellulose (13·30 per cent. nitrogen) 673 c.c. per gram, calculated at 0° c. and 760 mm. Berthelot estimates the pressure developed by the detonation of guncotton (sp. gr. 1·1) under constant volume as 24,000 atmospheres, or 160 tons per square inch.

Various attempts have been made to adapt guncotton for use in guns, but the tendency to create undue pressure led to its abandonment. In 1868, Mr. E. O. Brown, of Woolwich, showed that wet guncotton could be detonated by the use of a small charge of dry guncotton with a fulminate detonator, and since it can be stored and used in the moist state, it becomes one of the safest explosives for use in submarine mines, torpedoes, etc.

Nitroglycerin is a substance of a similar chemical nature to nitrocellulose, the principles of its formation and purification being very similar, only in this case the materials and product are liquids, this rendering the operations of manufacture and washing much less difficult. The glycerin is sprayed into the acid mixture by compressed air injectors, care being taken that the temperature during nitration does not rise above 30° C. The nitroglycerin formed readily separates from the mixed acids, and being insoluble in cold water, the washing is comparatively simple.

This explosive was discovered by Sobrero in 1847. Nitroglycerin is an oily liquid readily soluble in most organic solvents, but becomes solid at three or four degrees above the freezing point of water, and in this condition is less sensitive. It detonates when heated to 257° C., or by a sudden blow, yielding carbon dioxide, oxygen, nitrogen, and water. Being a fluid under ordinary conditions, its uses as an explosive were limited, and Nobel conceived the idea of mixing it with other substances which would act as absorbents, first using charcoal and afterward an infusorial earth, "kieselguhr," and obtaining what he termed "dynamite."

In 1875, Mr. Alfred Nobel found that "collodion cotton" —soluble guncotton—could be converted by treatment with nitroglycerin into a jelly-like mass which was more trustworthy in action than the components alone, and from its nature the substance was christened "blasting gelatin." The discovery is of importance, for it was undoubtedly the stepping-stone from which the well-known explosives ballistite, filite, and cordite were reached. In 1888, Nobel took out a patent for a smokeless powder for use in guns, in which these ingredients were adopted with or without the use of retarding agents. The powders of this class are ballistite and filite, the former being in sheets, the latter in threads. Originally camphor was introduced, but its use has been abandoned, a small quantity of aniline taking its place.

Sir Frederick Abel and Professor Dewar patented in 1889 the use of trinitrocellulose and nitroglycerin, for although, as is well known, this form of nitrocellulose is not soluble in nitroglycerin, yet by dissolving the bodies in a mutual solvent, perfect incorporation can be attained. Acetone is the solvent used in the preparation of "cordite," and for all ammunition except blank charges a certain proportion of vaseline is also added. The combustion of the powder without vaseline gives products so free from solid or liquid substances that excessive friction of the projectile in the gun causes rapid wearing of the rifling, and it is chiefly to overcome this that the vaseline is introduced, for on explosion a thin film of solid matter is deposited in the gun, and acts as a lubricant.

The proportion of the ingredients are:

Nitroglycerin	58 parts
Guncotton	37 "
Vaseline	5 "

Guncotton to be used for cordite is prepared as previously described, but the alkali is omitted, and the mass is not submitted to great pressure, to avoid making it so dense that ready absorption of nitroglycerin would not take place. The nitroglycerin is poured over the dried guncotton and first well mixed by hand, afterward in a kneading machine with the requisite quantity of acetone for three and a half hours. A water jacket is provided, since on mixing the temperature rises. The vaseline is now added, and the kneading continued for a similar period. The cordite paste is first subjected to a preliminary pressing, and is finally forced through a hole of the proper size in a plate either by hand or by hydraulic pressure. The smaller sizes are wound on drums, while the larger cordite is cut off in suitable lengths, the drums and cut material being dried at 100° F., thus driving off the remainder of the acetone.

Cordite varies from yellow to dark brown in color according to its thickness. When ignited it burns with a strong flame, which may be extinguished by a vigorous puff of air. Macnab and Ristori give the yield of permanent gases from English cordite as 647 c.c., containing a much higher per cent. of carbon monoxide than the gases evolved from the old form of powder. Sir Andrew Noble failed in attempts to detonate the substance, and a rifle bullet fired into the mass only caused it to burn quietly.

Lyddite is probably the explosive which has received most notice during the past few months. In 1873, Sprengel, in a paper read before the Chemical Society, stated that "picric acid alone contains a sufficient amount of oxygen to render it, without the help of foreign oxidizers, a powerful explosive when fired with a detonator. Its explosion is almost unaccompanied by smoke."

Picric acid was first prepared by Woulfe in 1771, by treating indigo with nitric acid. It may be made by the direct nitration of phenol (carbolic acid), but a better result is obtained by first dissolving the phenol in sulphuric acid, forming phenol sulphonic acid, which is dissolved in water, and nitrating this compound with nitric acid (1·4). On cooling, the picric acid separates out, and is purified by recrystallization from hot water, the yellow crystalline product being dried at a temperature not exceeding 100° C.

Picric acid containing as much as 17 per cent. of water can be detonated by a charge of dry picric powder; a thin layer may also be exploded by a blow between metal surfaces, its sensitiveness to shock being greatly increased by warming, for at a temperature just below its melting point a pound weight falling from a height of 14 inches will explode it.

The sensitiveness of picric acid can be reduced by converting the powder into larger masses, this being accomplished either by granulating it with a solution of collodion cotton in ether-alcohol, as in the earlier forms of mélinite, or by fusion, which takes place some twenty degrees above the boiling point of water, and casting directly into the shell, as in lyddite and possibly the mélinite of the present day. In any condition perfect detonation would yield only colorless gaseous products rich in carbon monoxide, but the bursting of a lyddite shell is frequently accompanied by a yellow smoke, probably formed by undecomposed acid in the form of vapor. The shells appear to burst in two distinct ways, in one case giving a sharp, powerful explosion with enormous concussion and no yellow smoke, and the other a heavy report with the yellow smoke, the two results appearing to be due to perfect decomposition in the first instance, while in the second partial decomposition only probably occurs.

Various mixtures of picric acid or its salts, together with some oxidizing agent, have been used from time to time, Abel's powder consisting of ammonium picrate, potassium nitrate, and a small quantity of charcoal.

It is impossible to deal with the numerous other explosives which are largely in use in such a survey as this, and, therefore, attention has been confined to those which play the most active part in modern warfare.

A SKETCH OF THE HISTORY OF PROPELLANTS[1]

BY SIR ANDREW NOBLE, D. Sc., F. R. S.

I PURPOSE, in this paper, to give a sketch of the history of propellants, pointing out how gunpowder for many centuries was the sole propellant employed, and which remained during these centuries with the mode of manufacture unimproved, while, even by very great men, the wildest and most divergent ideas were entertained as to the pressures developed by its explosion, and the energy which it was possible to realize.

The origin of gunpowder is, I am afraid, lost in remote antiquity. It was supposed to have been known, though not as a propellant, in China before the Christian era, but it was certainly known to Roger Bacon about 1265, who also was the first to suggest its use for military purposes. Its first employment in war was in the fourteenth century, and its composition and mode of manufacture during many centuries seem to have undergone but little change or improvement.

In England gunpowder consisted of 75 per cent. of saltpeter, 15 per cent. of carbon, and 10 per cent. of sulphur, while in France and some other countries the carbon and sulphur were in equal proportions, viz., about 12.5 per cent.

These differences in proportions affected but slightly the energies and pressures developed by fired gunpowder, but I do not know any physical fact with regard to which such

---

[1] Abstract of a paper read before the Institution of Engineers and Shipbuilders in Scotland, and published in the *Scientific American Supplement,* September 11, 1909.

wide differences of opinion were entertained by the many eminent men who have written upon the subject.

De la Hire, the first writer on gunpowder, in 1702, supposed that the propelling force of gunpowder was due to the elasticity of the air between the grains, and that the function of the powder was merely that of a heating agent.

Robins, however, who in 1743 read before the Royal Society of London a paper in which he described his experiments, pointed out that he had found that at ordinary temperatures and atmospheric pressure the generated gas occupied about 236 times the volume of the gunpowder, and that at the temperature of explosion—which, however, he much underestimated—the maximum pressure would be about 1,000 atmospheres (6.6 tons per square inch).

He considered, and cited experiments to prove, that the whole of the powder he employed must be fired before the projectile was sensibly moved from its seat, his argument being that, were this not so, a much greater energy would be realized when the weight of the projectile was materially increased; but this experiment showed that this was not so.

Hutton, in 1778, read before the Royal Society an account of his celebrated researches in gunnery, and detailed the experiments from which he deduced the maximum pressure of gunpowder to be about twice that given by Robins, or about 2,000 atmospheres.

Hutton, like Robins, saw that the energy of gunpowder was due to the elasticity of the highly heated gases generated by the explosion and, assuming that the powder was instantaneously ignited and that the pressure was as he stated, gave formulae for deducing the pressure of the gas and the velocity of the projectile at any point of the bore.

In 1797 Count Rumford communicated to the Royal Society his celebrated experiments on gunpowder, and these remained for many years the only experiments from which the pressure was deduced by actual measurement. In Rumford's case the weight lifted by the pressure of the exploded powder was assumed to be the correct measure of the pressure.

Rumford made two series of experiments, but the charges he employed were very small, his largest, with the exception of one by which his vessel was destroyed, being 18 grains or about 1¼ grams.

From the first series Rumford deduced that with a charge at a density of unity the pressure would reach 29,000 atmospheres. But, high as this result is, Rumford considered it much too low, and from a second series, the results of which were very discordant, he arrived at the conclusion that the tension of exploded gunpowder such as he employed, when filling completely the space at which it was inclosed, was about 101,000 atmospheres.

I may observe that the mode of firing the powder which Rumford was compelled to adopt, viz., the heating of the vessel in which the powder was confined by a red-hot ball, would materially increase the pressure, and he further accounted for the enormous pressures he gave not being realized in guns, by assuming that the combustion of powder in artillery and small arms was comparatively slow and approximated to the rate of combustion in the open air. From an examination, however, of Rumford's apparatus it is not difficult to conjecture both how he supposed his pressures to be so high, and also how some of his results were so discordant.

Passing over several experimenters or writers on the subject, I must refer to the researches of Bunsen and Shischkoff, who in 1857 published the results of their important investigations. The powder in their experiments was not exploded, but deflagrated by being allowed to fall in an attenuated stream into a heated bulb, in which, and in the connected tubes, the products of combustion were collected.

The transformation under these conditions would not be quite the same as if the powder had been exploded under pressure, but a careful analysis was made both of the solid products and of the gases. The weight of the permanent gases found by them represented only 31 per cent. of the weight of the powder, and occupied at 0° C. at atmospheric pressure only 193 times the volume of the unexploded powder. They fixed the temperature of explosion at 3,340° C. and computed that the maximum pressure which the gas can attain, which it may approximate to but can hardly reach, is about 4,374 atmospheres, or 29 tons on the square inch.

The very high tension of 101,000 atmospheres suggested by Count Rumford as the result of his latest experiments does not appear ever to have been accepted, but within my own time Piobert, who wrote in 1864, and who made a number of important experiments, appears to have accepted as tolerably correct Rumford's first series of experiments, and fixed the tension of gunpowder when fired in its own space at about 23,000 atmospheres, while Cavalli in 1867 arrived at nearly the same conclusion, making the tension about 24,000 atmospheres. On the other hand, I find that text-books in use at the Royal Military Academy, Woolwich, so late as 1879 placed the tension of fired gunpowder so low as 2,200 atmospheres, or, say, about 14 tons per square inch.

The authors who ascribed the enormous pressures I have named much underrated the rapidity of the combustion of gunpowder under pressure, and assumed that the combustion was comparatively very slow, and that due to this slow combustion the possible maximum pressure was never even approximated to in the bores of guns; but it has always struck me as remarkable that the authorities who accepted these high tensions did not test the accuracy of their assumptions by employing the simple test suggested by Robins, viz., to find what increase of energy would be realized when the weight of the shot was doubled, trebled, etc.

I myself, about a century and a half after Robins, repeated his experiment with means at my disposal far greater and more accurate than anything he could have employed, and the result with the old R. L. G. powder was as follows:

In a 6-inch gun with a shot weighing 30 pounds the initial velocity was 2,126 foot-seconds, and the energy realized was 972 foot-tons. With the weight of shot trebled—that is, increased to 90 pounds, the total velocity fell to 1,370 foot-seconds and the energy increased to 1,178 foot-tons.

Further increases in the weight of the shot to 120 pounds, 150 pounds, and 360 pounds gave energies practically identical, viz., 1,196, 1,192, and 1,192 foot-tons, thus entirely confirming Robins' view.

I think that I may venture to say that the question of the pressures developed by fired gunpowder was set at rest by the experiments made by myself and described in a paper by Sir F. Abel and myself in the transactions of the Royal Society. In these experiments I succeeded in determining for the three powders of the English service, pebble, rifle large grain, and fine grain, the tension of the exploded gas at all densities up to unity, and in altogether retaining the whole of the products of explosion, even of charges of several pounds, which filled entirely or nearly so the chambers of the explosion vessels. The results of my experiments gave for a density of unity a pressure of about 6,500 atmospheres. The temperatures of explosion of the different gunpowders varied considerably, but were generally between 2,000° C. and 2,230° C.

I have never been able to understand why the considerable proportion of sulphur was so long retained as a component of gunpowder. In the English service, shortly before the adoption of modern propellants, it was almost entirely dispensed with in cocoa powder, and with a view of studying the question I had in 1883 four experimental powders made; in two of these powders sulphur was dispensed with, or nearly so; in the third, the amount of sulphur was halved; and in the fourth, the percentage was increased. The powder without sulphur had its potential energy increased by about 13 per cent., while that with increased sulphur was decreased by 9 per cent.

The early methods for testing the potential energy and uniformity of gunpowder were very rude, and permitted in this country powders to be passed into the service which showed great variations in potential energy.

My attention was called to this point in 1860, when, being then an associate member of the Ordnance Select Committee and carrying out experiments for that body, I found that the variation in the energy developed by new powders of different makes occasionally amounted to 25 per cent.

The variation admitted at the present day in passing propellants is about 2.8 per cent.

The early improvements in the old gunpowder were due to the labors of Major Rodman, U. S. A., who seems to have been the first to appreciate the importance of a suitable and uniform density of the powder, but also by the introduction of prismatic powder showed that it was possible considerably to reduce the very high and variable pressures which were common in the old guns, pressures which would not be permitted in the much stronger guns of the present day. He was also the inventor of a most ingenious instrument for determining the pressure developed by the explosion of the charge in the chambers or bores of guns, and Major Rodman's work was continued in this country by the labors of the first explosive committee, who not only determined with great accuracy the pressures of the propellants and the velocity of the projectiles at all points of the bore, but also increased the velocity by over 220 foot-seconds, thus increasing the energy developed by about 33 per cent., while the maximum pressure was reduced by about the same percentage—a matter of very great importance in the case of all, but especially of breech-loading guns.

But I fear I have detained you too long with the old gunpowders, and perhaps the easiest way of showing the striking difference between the old gunpowders and some of the modern propellants is to give you two tables[1] exhibiting, first, the volume of gas generated by the explosion; second, the units of heat generated; and third, the product of the units of heat and volumes of gas, which represents approximately the comparative potential energy of the explosives.

For cordite, the first modern propellant adopted in England, we were indebted to the labors of the late Sir F. Abel and Sir James Dewar, and the value of the propellant is sufficiently shown by the fact that with the same maximum pressure artillerists have been able to more than double the energy of the projectile.

It will be observed that the figures I give as representing the comparative energies of the old propellants vary from 200,438 to 179,478, while the similar figures for the modern explosives vary from 1,090,873 to 851,212, or more than four times as great, and the diagram I also show exhibits the comparative pressures developed up to the density of 5, thus at the density of 5 the pressure of gunpowder is about 1,700 atmospheres—amide powder 3,500 atmospheres—while the modern explosives at the same density lie between pressures of 8,600 and 7,200 atmospheres.

Turning now to the total volumes of gas generated and the units of heat developed by the explosion, I find in the various explosions I have examined the same general rules hold. With the increase of density the volumes of gas decrease and the units of heat increase.

Now, I have pointed out that with the increase of density there is in all cases a decrease, in most cases a considerable decrease in the volume of gas, and as the pressures developed increase much more rapidly than the density, it is obvious that with increase of density there must be a very considerable increase of temperature.

At a density of 0.5 I place the temperatures of the high

---

[1] See original publication if detailed information is desired.

explosives I have examined as varying between 4,000° and 5,000° C. I need not say that at less densities they are very much lower.

I have mentioned that the percentages of the several gases generated by the explosion vary greatly, dependent upon the pressure under which the explosion takes place, and I shall exhibit to you three diagrams, in two of which there are, with increase of density, large increases in volume, and in the third a considerable decrease.

All of the new propellants develop on explosion a very much higher temperature than did the old gunpowders, and the introduction of armored vessels has necessitated the employment of guns fifteen or sixteen times heavier than the guns in use fifty years ago, and capable of giving to their projectiles energies nearly fifty times as great.

Now, as regards the serious question of erosion, in the case of the very large guns it is important to remember that while the surface of the bore subject to the more violent erosion increases approximately as the caliber or a little more, the charge of the propellant required to give to similar projectiles the same maximum velocity increases as the cube of the caliber; and, consequently, unless special arrangements as to the projectile are made, or other means adopted, the life of the largest guns before re-lining must be short when compared with that of smaller guns.

It, therefore, becomes a matter of great importance that attention should be given to the best method of reducing erosion when very large charges are used, either by lowering the temperature of explosion of the propellant, or possibly by introducing with the charge some cooling agent.

As regards the first of these points some very considerable advance has been made, but I venture to think that the question of erosion has, at least in this country, hardly received sufficient attention, and that, in some respects, mistaken notions as to the amount of erosion with reduced charges are entertained.

ARTIFICIAL SILK[1]

BY JOSEPH CASH

It is a trite saying that all inventions are creatures of evolution. I shall give a short description, therefore, of a few attempts to produce the appearance of silk before the perfected artificial article of to-day became an established fact. Some were partially successful in effect and others have been a pronounced commercial success, adding greatly to the variety of the cheaper textile fabrics.

Spun Glass is probably the earliest production which resembles natural silk. The thread is perfectly flexible, possessing great brilliancy, and is produced in a variety of colors. The feel to the touch is soft and smooth; it can be woven into many textiles, and is specially useful in millinery articles where warmth is not a necessary adjunct.

Polished or Diamond Cotton is a lustrous-looking article, and in the fine sizes, or counts as it is called in the trade, is silky in appearance and soft to the touch. An enormous trade is done in this article for dress goods, as it is often used in combination with silk. The process of producing it is very simple, waxy and starchy substances being put on the thread in a liquid emulsion; the yarn is then transferred to a polishing machine with rapid-revolving brushes, which completes the process.

Mercerized Cotton. A process for giving a silky appearance to cotton has lately been brought to the notice of manufacturers with very satisfactory results. The process is practised by most cotton dyers, there being no valid patent. The name is derived from the inventor, John Mercer,[2] who discovered the process in 1844. The cotton

---

[1] Abstract, published in the *Journal of the Society of Arts*, 1899.

[2] Note the coincidence that a silk merchant is called a mercer in England.—Ed.

yarn is passed through strong solutions of caustic lye. The yarn must be at full tension during the whole operation, even until it is quite dry. Mercer's theory of the action of caustic soda is that received to-day, viz., that the mercerized yarn is a hydrate of cellulose, the first action being the formation of a compound of sodium oxide and cellulose. The subsequent washing replaces the sodium oxide by water, which is held by the cellulose like the metallic oxide. Such a theory as this gives us very little light on the matter, and does not explain the difference between the hydrate formed and the original cotton. It can be dyed any color without materially affecting the brilliancy which has been imparted to it by the mercerizing process.

Collodion Silk. Several persons have given their attention to the perfecting of the manufacture of collodion silk, among whom are Count Hilaire de Chardonnet, Dr. Lehner, and Nobel of cordite fame. The different systems vary only in detail, so I shall describe the most successful one, known as the Chardonnet silk. I first saw this artificial silk at the Paris Exhibition of 1889, where it obtained a "Grand Prix." Previous exhibits were made of artificial silk in 1878, but no commercial success was attained for many years.

A public company for the manufacture of artificial silk by the Chardonnet process has been formed in England. The factory, extending over two acres, is at Wolston, on the river Avon, near Coventry, and will be capable when filled with machinery of producing 7,000 pounds of silk per week.

The first stage of manufacture is the nitration of cotton or wood pulp, producing pyroxyline, discovered by Pelouze in 1838. The greatest care must be employed in conducting this operation, as it is the most important one in the whole process; mistakes sometimes occur even at the long established factory at Besançon in France. The process of nitration of cellulose is the displacement of a few molecules of hydrogen by nitric peroxide. There are several varieties of pyroxyline which are obtained by using different mixtures of acid. The highest nitro-cotton product, guncotton, or trinitrocellulose, is useless for the manufacture of artificial silk, as it is insoluble in a mixture of alcohol and ether. To obtain the pyroxyline or binitrocellulose suitable for the production of collodion for our purpose, a mixture of 15 volumes of sulphuric (H_2SO_4) and 12 volumes of nitric acid (HNO_3) is made; two pounds of bleached raw cotton is then taken and put into an earthenware jar with about three gallons of mixed acid; this is left standing for four to five hours, when the nitration is complete. The chemical reaction may be expressed by the following formulae:

$$C_6H_{10}O_5 + 2HNO_3 + H_2SO_4 =$$
$$C_6H_8(NO_3)_2O_3 + (2H_2O + H_2SO_4)$$

The object of the sulphuric acid (H_2SO_4) is to take up hygroscopically the excess of water produced, leaving the nitric acid (HNO_3), of which there is always an excess. The only known way of testing the quality of the pyroxyline is the use of the microscope in conjunction with the polariscope. A small piece of pyroxyline is taken from one of the jars, thoroughly washed in water and dried; it is then moistened with alcohol, when the colors exhibited should be in exact proportion which practice has proved to give the best results.

The pyroxyline is now taken out of the pots and subjected to pressure to extract all the acid possible. This extracted acid is not wasted, but is renovated with a mixture of new acid and used again for more cotton. From the press the pyroxyline is taken to the washing room and at once put into the washing machine, called a hollander, and similar to those used in paper making for washing pulp.

This washing continues for from 12 to 15 hours until the acid is thoroughly eliminated; from thence the material is removed to a centrifugal machine to extract the moisture, which must not exceed 28 per cent.; if too much water is present, the collodion will not be tenacious and therefore will not spin. The pyroxyline is now ready for dissolving in a mixture of alcohol and ether. The pyroxyline is placed in a cylinder, with a mixture of 40 parts alcohol and 60 parts ether; the cylinder is then hermetically sealed and made to revolve slowly for 12 hours, when, if the pyroxyline is good, all should be dissolved; the resulting mixture is collodion. The next process is the filtration. Upon this depends the amount of production from the spinning machinery, supposing the collodion be good. The filtering is to eliminate every particle of suspended matter which may exist in the collodion before it arrives at the spinning machines, as grit and seeds from the cotton, or suspended matter in the washing water, or even trinitrocellulose, which is insoluble in alcohol and ether, but this latter should never occur in good silk collodion. Each filter contains a sheet of cotton wool between calico. A pressure of 15 atmospheres is required to force the collodion through the filters; it is therefore first passed into a hydraulic press, by the aid of which it is forced through the filters and into the collodion reservoir, where it should remain as long as possible to allow any bubbles to rise to the top, for should they pass into the glass silkworms, the continuity of the thread would be broken.

A pressure of 40 to 45 atmospheres is required to force the collodion from these reservoirs to the spinning machines, which are constructed with pipes running on each side. Into these pipes are screwed a number of taps with a glass capillary tube fixed on the end, called a silkworm, through which the collodion is forced by the pressure before mentioned; immediately it comes into contact with the air it solidifies, enabling the operative to take hold of the thread or silk, as it can now be called, and convey it to the bobbin. From twelve to twenty-four of these threads are run together on to one bobbin, according to the size of silk required, as is the case with natural silk. The silk would soon dry by the evaporation of the alcohol and ether if left exposed to the air; it is therefore kept moist by damp cloths to facilitate the next process of throwing and twisting. This is accompanied by putting on the silk the required number of turns or twists per inch. The reeling or skeining of the silk into a given number of yards in each skein is the next operation. One thousand or two thousand yards is the usual quantity, and according to the weight of skein so is the size designated. The Chardonnet silk is about 30 per cent. heavier in S.G. than natural silk, so the comparison of sizes is easily arrived at. The silk is still damp, and should now have the remaining alcohol and ether dried out of it. The inventor claims this to be one of the most important points to give the silk good dyeing properties.

The silk at this point of manufacture is very inflammable and quite unfit for use in textile goods, therefore a process called denitration is next carried out which reconverts our product into cellulose, now very different in appearance from the raw cotton we commenced with, but practically the same in chemical composition.

One of the substances used for this purpose is sulphydrate of calcium, and the chemical reaction may be expressed by the following formulae:

$$C_6H_8(NO_3)_2\,O_3 + 2\,Ca\,H_2S_2 = \\ C_6H_{10}O_5 + 2\,Ca\,NO_2 + H_2S + S_2.$$

The silk, now it is finished, requires no precautions in manufacturing more than cotton, in fact less, as there should be no loose fiber which can detach itself from the thread.

The bleaching is carried out in the usual way for vegetable fibers with chloride of lime and acid.

Up to the present time artificial silk has always been used in conjunction with other fibers in textile goods; the friction of weaving has a tendency to split the threads if used in warps, but this objection will no doubt be overcome.

Mantles for the incandescent gas light are manufactured of artificial silk, it being found that the salts of the rare metals can be mixed with the collodion with greater economy than with any other thread.

For braids and such classes of trimmings it is much more brilliant; for covering electric wires and all electric work it is better. Large works are in operation at Besançon, in France, producing 7,000 pounds per week; but the demand is so great that they are making extensions to their works to enable them next January to produce 2,000 pounds per day. The production at Sprietenbach is 600 pounds daily. Other factories are about to be established in Belgium and Germany.

Collodion silk can never replace natural silk in articles where warmth is required, its composition being vegetable, and that of silk analogous to horn and hair or wool. The artificial product is to be preferred, being more durable than the natural when the latter is weighted in the dyeing up to 100 per cent. in colors, and as high as 300 per cent. in black.

THE CREATORS OF THE AGE OF STEEL[1]

BESSEMER, SIEMENS, WHITWORTH, AND THOMAS

THERE is more of truth than poetry in giving to the era beginning with the year 1850 the name of "The Age of Steel." The metallurgical inventions and discoveries which mark abruptly that period have effected a revolution in the industry of the world. Steel is to us what iron was to our grandfathers; what bronze was to the armies that sat in league before Troy; what stone was to the naked savages that dwelt in the caves of Gaul before the beginning of history. The very web and woof of modern civilization is woven out of steel. The production of steel in 1882 was as great as the crude iron product of 1850. The metal is omnipresent; it has replaced iron, wood, brass, and copper. The rails, ships, cannon, and machinery of the world are steel. The best definition yet given of man is that he is a tool-using animal; his tools are steel, and the tools wherewith he makes his tools are steel.

As Carlyle says, "We are to bethink us that the epic verily is not Arms and the Man, but Tools and the Man—an indefinitely wider kind of epic. Man is a tool-using animal. Weak in himself and of small stature, he stands on a basis, at most for the flattest solid, of some half square-foot, insecurely enough; he has to straddle out his legs lest the very wind supplant him. Feeblest of bipeds! Three quintals are a crushing load for him; the steer of the meadow tosses him aloft like a waste-rag. Nevertheless, he can use tools; can devise tools; with these the granite mountain melts into light dust before him; he

---

[1] A review published in the St. Louis *Globe-Democrat,* 1884.

kneads glowing iron as if it were soft paste; seas are his smooth highway; winds and fire his unwearying steeds.''

The conquest of the world man is achieving with steel, and who the men were that have put this weapon in the hands of man, Jeans tells us in the book whose title precedes this article.

The two first and greatest inventors in the trade reaped no reward. Dudley in 1618 learned a way to smelt iron with coal, and died in obscurity. Henry Cort, in the middle of the eighteenth century, invented the puddling process, and would have starved but for a pension of £200 given him by Pitt. Honors and wealth, however, were showered lavishly on the bright galaxy of men whose names are enrolled in the list of the creators of the age of steel. The story of their triumphs over matter and circumstance makes one of the most interesting chapters in the history of industry.

Sir Henry Bessemer.—Among the French refugees driven to England by the Terror was Anthony Bessemer. A learned and little man, he speedily accumulated a handsome property, the reward of an inventive ingenuity inherited and developed by his illustrious son. Among many other profitable processes the elder Bessemer discovered that an alloy of copper, tin, and bismuth was the best for type metal. His process he kept secret, claiming that the superiority of his type came from the angles at which it was cut. It lasted twice as long as the other types, and sold all over England. The youngest son of this gentleman was Henry Bessemer, born at Charlton in 1813. His first attack upon destiny was made in improving the stamps upon public documents. He invented a stamp which could not be duplicated or detached, which was adopted by the Government, and for which not a penny was ever paid to the young inventor. His next work was a machine for making patterns of figured velvet, a type-casting machine, and a type-composing machine. While working upon this latter machine he was struck by the fact that bronze powder when manufactured sold for twelve shillings a pound, while the raw material cost but eleven pence. The difference he knew must come from the process of manufacturing, a process which he at once began to study. The article came altogether from Nuremberg in Germany, and no one in England could tell him how it was made. For nearly two years he studied this problem, earning success in the end by his infinite industry. He had not learned to have confidence in the patent laws, and he determined to keep his invention a secret. A friend advanced him £10,000, works were erected, the machinery being made in different parts of England. Five operatives were employed, at large salaries, under pledge of secrecy, and the bronze was turned out at a cost of less than 4 shillings a pound. To this day, although forty years have elapsed, no one has surprised the secret. Sir Henry Bessemer has years since rewarded the faithfulness of his workingmen by giving them the factory and the business, and they too have made fortunes out of the trade.

Between 1844 and 1850 Bessemer patented machines for the manufacture of paints, oils, and varnishes; for the separation of sugar from molasses; for a drainage pump capable of discharging twenty tons of water per minute; a machine for polishing plate-glass, substituting a vacuum for the plaster-bed. Each of these was as meritorious as unique, and as profitable as it was ingenious.

This much will show the surprising versatility of the man, and enable the reader to grasp the character that revolutionized modern industry.

The Crimean war turned Bessemer's attention to ordnance; he produced a projectile which rotated without the aid of rifling from the gun, and made many improvements in the guns themselves. The English authorities ridiculed his improvements; the Emperor Napoleon was greatly struck with them, and requested Bessemer to continue his experiments at the expense of France. At one of the subsequent tests Commander Minie said: "The shots rotate properly, but if you cannot get a stronger metal for your guns, such heavy projectiles will be of little use.'' That remark produced the Bessemer process for making steel. He knew nothing, absolutely nothing, about metallurgy; he had no idea how any improvement was to be made, and yet he resolved to attack this problem of steel making and solve it.

Prior to 1740 the best steel was made in Hindostan, and cost £10,000 a ton. A watchmaker named Huntsman, after a long course of experiments in that year, produced equally good steel, which could be made at £100 a ton, and for a century Huntsman's process had been used without improvement. In the English process before 1740 the bars of iron were heated with a cement of hardwood charcoal dust, which added carbon to the metal, and made what is called ''blistered steel.'' The heating had to be continued several days. This was as yet unfit for forging, and the bars had to be broken into lengths of about eighteen inches, raised to a welding heat, and hammered with a ''tilting hammer,'' a process which produced good steel. Huntsman took the blistered steel, broke it up into bits, put it into crucibles with coke dust, fused the whole, and so made cast steel.

When Bessemer began his work, this process was the only one in use. The iron had first to be melted into pigs, the pigs heated with carbon into blistered steel, the blistered steel broken up and remelted with carbon into steel ingots in crucibles which could not hold more than thirty pounds each. Bessemer's experiment produced first a cast iron better and stronger than any known before.

At the end of eighteen months the idea struck him of rendering cast iron malleable by the introduction of atmospheric air. A great many experiments followed, all of them moderately successful. Mechanical difficulties almost insuperable stood in the way. At last he constructed a circular vessel three feet in diameter and five feet high, able to hold seven hundred-weight of iron. He bought a powerful air engine and ordered in a quantity of crude iron. This was at Baxter House, a place to be ever memorable in the history of the steel trade. The apparatus was ready, the engine was forcing streams of air into the openings in the fireclay-lined vessel, and the stoker was told to pour in the iron as soon as it was sufficiently melted.

The metal was turned, and a volcanic eruption ensued; such a blaze of dazzling fire was never seen in a workshop before. Coruscations of fire filled the chamber. The metal flowed down, and the air burst through it upward, breaking away in great bubbles of living glory. A pot-lid hanging over the blaze disappeared in the flame. All this time the air was rushing into the molten mass, and no one dared go near to shut it off. While they were debating the flame died down. Soon the result of this wonderful pyrotechnic could be examined. It was steel! Seven hundred-weight of steel made from melted pig without crucible, coke dust, or charcoal. Seven hundred-weight of steel born simply of fire and air![1]

The British Association met in the following week, and Bessemer read a paper describing his process, exhibiting at the same time his results. It was on the eleventh day of August, 1856, that this public announcement was made of the new method. The whole industrial world was aroused by the tidings. Bessemer's paper was reproduced in the *Times,* and the iron trade examined the discovery with infinite interest. Experiments were made in a great many foundries, and the sole talk of the hour was the new way of making steel. Within three weeks after reading his paper at Cheltenham, Bessemer had sold £25,000 of licenses to manufacture under his patent. The Dowlais Iron Company was the first to begin the manufacture. Bessemer personally directed the construction of the works. Again the molten iron was poured into the receptacle, again the air blast bubbled through the metal, the gorgeous display

---

[1] See Fig. 2 in the article "The Anatomy of a Steel Rail," which illustrates a modern Bessemer converter in blast.

of Baxter House was repeated, everything went well, but the result was not steel—it was nothing but a very good cast iron.

Those who had praised the new process now ridiculed it. The failure was inexplicable, but it was a failure, and exactly six weeks after the publication of the article in the *Times* a meeting of iron masters at Dudley condemned the Bessemer process as a practical failure.

The inventor was not dismayed. Patiently and hopefully he set to work to find the flaw that had spoiled his work. A long series of experiments followed before he found the cause of his failure. By a mere chance the iron used on the occasion at Baxter House when steel was made was Blænavon pig, which was exceptionally free from phosphorus. The metal used at the Dowlais works contained this element. Here he found the cause of his failure. He set to work to eliminate the phosphorus by the puddling process, but while doing this there arrived an invoice of Swedish pig iron, clear of the obnoxious substance. Under his original process this yielded steel of such a high quality that he at once abandoned the effort to dephosphorize ordinary iron, and began to manufacture from the Swedish import. Sheffield steel was selling at £60 per ton; he could buy Swedish pig for £7, and turn it into steel at a very small cost.

Steel is pure iron with a small percentage of carbon to harden it. The line of demarcation between steel and iron is a difficult one to trace. Following the discoveries made in India by J. M. Marshall, Bessemer introduced ferro-manganese into his converter, and the pure iron was at once carburized into steel.

The public, however, had lost confidence in Bessemer; he had spent his private fortune, he had made steel, the point was now to sell that steel. Through the assistance of Mr. Galloway, Bessemer bought in the licenses which he had sold, works were erected, and steel produced at a profit at £42 a ton—Sheffield was selling at £60. This argument was unanswerable—the Bessemer process had won, the ironmasters took out licenses under it, and the age of steel began.

The revolution spread over Europe and America; the process was especially popular in Sweden, where the Crown Prince superintended its first trial. In Prussia Herr Krupp, the great cannon maker, agreed to pay Bessemer £5,000 for a license. With Bessemer's papers Krupp applied to the Government for a patent, the patent was refused, and no royalty was ever paid to the inventor. Belgium and France appropriated the new process, and declined to recognize Bessemer.

Bessemer had attacked the problem of making steel for the purpose of having a better gun-metal than any then existing. Accordingly he returned to his experiments with ordnance. Steel cannon were cast with a tensile strength of thirty tons to the square inch, figures much greater than had been reached before. A number of tests were ordered at Woolwich, but through rank favoritism the matter was submitted to Sir William Armstrong, a rival cannon maker, and very naturally an adverse decision was rendered. The Government would not touch the new metals, and Bessemer, for the time being, let the matter pass, concentrating his attention upon the industrial uses of steel, a field large enough for the ambition of any man. In 1861 he induced the London and Northwestern Railroad to put down some steel rails as an experiment. In 1881 these rails were still in good condition—iron rails had to be turned once in nine months. The next step was the substitution of steel for iron in ship-building; the next, an invention of steel projectiles, which were found to penetrate the iron armor of ships as easily as the old iron balls went through wooden vessels. At this time Bessemer was receiving £100,000 a year from his business, but his inventive faculty did not lie dormant. The best known of his later devices was a ship built with an automatically balanced cabin in order to do away with sea-sickness. This was a theoretical success, but a practical failure. Henry Bessemer's life-work was the production of steel from cast iron; all the other many achievements of his mind were, after all, but side issues. In the first twenty years of the life of his invention he had saved to the industry of the world over a billion pounds sterling—that is, the work of one man did nearly twice as much to build the wealth of the world as the American civil war did to pull it down—indeed, figuring upon the actual saving made, Bessemer's invention had saved enough money to humanity by 1882 to pay for the American civil war, the Franco-Prussian war, the Austro-Prussian war, and the Italo-Franco-Austrian war of 1859. The inventor had been made a knight of the Order of Francis Joseph, he had been given the Grand Cross of the Legion of Honor, but the British Government declined to permit him to accept it. Out of the enormous benefits of his invention there has come to the inventor a fortune for himself. When his patent expired in 1870, he had been paid in royalties £1,057,748. Added to this, his Sheffield works divided in profits during their fourteen years' existence fifty-seven times the original capital, and the works sold for twenty-four times the original capital. In 1879 Bessemer was knighted by the Queen; honors were showered upon him. His services to humanity were recognized at home and abroad. All of the great cities of Europe conferred their freedom upon him, and, what caused the utmost pleasure to the inventor, a town in Indiana whose chief industry was based upon his invention was named for him, assuring him the only immortality that he desires—the constant record of his memory among the men for whom he worked.

Sir William Siemens.—Next to Sir Henry Bessemer among the creators of the age of steel stands Sir Charles William Siemens, who was the philosopher of the new era, as Bessemer was the inventor. After becoming a thorough student in electricity, Siemens' first exploit which attracted general attention was the invention with his brother of the system of anastatic printing, a process by which any old or new printed matter could be reproduced. This was rather a *success d'estime* than a money-making discovery, although it brought the young inventors into European notoriety. The method consists in applying caustic baryta to a page of printed matter, changing the ink to a non-soluble soap, and then applying sulphuric acid to precipitate the stearine. The paper was then pressed into a slab of zinc, making an intaglio from which copies could be easily taken.

Siemens next perfected a method for greatly increasing the heating power of furnaces by compressed air, the results being of immense practical value to the trade. The very high temperature which he was thus able to gain at a small cost of fuel naturally was applied to the working of steel. His method is called the "open hearth process." In this process the charge consists of pig iron, which is placed on the bottom and around the sides of the furnace. Melting requires four or five hours, then pure ore is charged cold into a bath in quantities of four and five hundredweight. Violent ebullition ensues, and when this ceases more ore is put in, the object being to keep the boiling uniform. Spiegeleisen or ferro-manganese is added, and the charge is cast. The result is steel. Siemens' first improvement was a rotating furnace, in which coal and iron are put together, and mixed and heated so thoroughly that the result is all that could be desired. So thorough is the process that the hitherto irreducible iron-sands of New Zealand and Canada can be worked to a great profit.

Coming into direct competition with the Bessemer product, the open-hearth steel has held its own, its consumption in the United Kingdom rising from 77,500 tons in 1873 to 436,000 in 1882. The Lindore-Siemens Company rolls the armor-plate for the British Admiralty, and the steel has been found to be even better than the Bessemer for general ship-building. In 1883 one fourth of the total tonnage of new ship-building was built of Siemens steel.

Sir William Siemens and his brother, Dr. Ernst Wernêr Siemens, of Berlin, have been called the pioneers of modern electrical research. The dynamo machine is theirs, and much of the development of the electric light. Siemens has put on record a series of experiments in electrohorticulture which show astonishing results. In the hostile English climate he has produced ripe peas by the middle of February, raspberries on March 1st, strawberries February 14th, grapes March 10th; bananas and melons showed similar results.

The German electric railway is one of the enterprises of the Siemens. They are the builders—the creators—of the Indo-European telegraphs, reaching from London to Teheran, in Persia. The history of this enterprise, with its dangers braved and its difficulties overcome, is one of the most interesting of this interesting book.

The Siemens laid the first submarine cable in 1847 from Deutz to Cologne, covering their wires with gutta percha. The services of Sir William Siemens to science as well as to the useful arts cannot be too highly appreciated. Besides his industrial triumphs, he constructed our theory of heat. Wealth and honors came to him, but in the midst of his career he was cut down. An accidental fall on a London pavement, November 5, 1883, ruptured the nerves of his heart, and he died a fortnight later, his death being mourned as a national loss in England and Germany.

Sir Joseph Whitworth.—Joseph Whitworth's first industrial exploit was the production of true plane surfaces in metals automatically, an achievement perfected in 1840. The old method was grinding with emery powder and water. He planed the metals with a steel plane. "So exactly can surface plates be made by his apparatus, that if one of them be placed upon another, when clean and dry, the upper will seem to float upon the under, without being actually in contact with it, the weight of the upper plates being insufficient to expel except by slow degrees the thin film of air between their surfaces. But if the air be expelled the plates will adhere together, so that by lifting the upper one the lower will be lifted along with it, as if they formed one plate.''

Whitworth was essentially a tool maker. No sooner had he perfected the plane, with its immense effect upon English industry, than he attacked the screw. His system of screws is now adopted all over the civilized world. Following up his improvements, he recognized the necessity for a more exact measuring machine than any then in existence, and supplying this want he devised a machine which would measure distinctly and practically to the 40,000th part of an inch, and theoretically to the 1,000,000th. To show to what exactness this was brought, we quote his own words in an address at Manchester in 1857: ''Here,'' said he, ''is an internal gauge having a cylindrical aperture 0·5770-inch diameter, and here also are two solid cylinders, one 0·5769-inch, and the other 0·5770-inch diameter. The latter is 0·0001 of an inch larger than the former, and fits tightly in the internal gauge when both are clean and dry, while the smaller 0·5769 gauge is so loose in it as not to appear to fit at all. These gauges are finished with great care, and are made true after being case-hardened. The effect of applying a drop of fine oil to the surface of this gauge is remarkable. It will be observed that the fit of the larger cylinder becomes more easy, and that of the smaller more tight. . . . It is thus obvious to the eye and the touch that the difference between these cylinders of one ten-thousandth of an inch is an appreciable and important quantity, and what is now required is a method which shall express systematically and without confusion a scale applicable to such minute differences of measurement.'' The Whitworth gauges have been adopted by the Government as standards of measurement.

The accuracy in mechanical processes rendered possible by Whitworth's inventions bore its first proof in a direction which the inventor little expected.

England was engaged in the Crimean war, and the Enfield rifle, a hand-made weapon, was the arm of her forces. It became necessary to have these guns in large quantities, and the burning question of the hour was how to make these rifles by machinery. The science of projectiles was then entirely empiric. Some guns shot well and some shot ill, but why these were good and those bad no one knew. Whitworth went before a Parliamentary committee, and told it that until the data of rifling were established good machine made guns would be impossible. It was necessary to find out what made an effective gun by continued experiment before anything else was done.

England needed a million rifles. To make these by the processes then in use would have taken Birmingham twenty years. It was agreed that the Government should bear the expenses of Whitworth's experiments.

A gallery was set up at Rusholme, 500 yards long, furnished with tissue paper screens in order to track the bullets throughout their flight, and with sliding targets. The experiments began in March, 1855. The Enfield rifle had a bore of 0·577-inch, and the rifling had one turn in 78 inches. The first result was that in every particular the Enfield was found to be wrong. Whitworth made barrels with one turn in 60 inches, one in 30, one in 20, one in 10, one in 5, and one in 1 inch. To be brief, he determined conclusively that the best rifle had one turn in 20 inches, a minimum diameter of 45 inches, and a rounded hexagonal instead of a circular bore. After beating all other guns at short ranges the Whitworth rifle had a deviation of about 4·62 feet at 1,400 yards. The Enfield could not hit the target at all. With a steel bullet Whitworth's rifle perforated plates of iron half an inch thick at an obliquity of fifty degrees, and easily passed through thirty-four half-inch elm boards.

Applying the same principles to artillery, Whitworth devised a gun which threw two and one-fourth hundredweight of iron six and a half miles.

To such a great superiority did he bring artillery, first by his invention of compressed steel, next by making the guns breech-loading, and finally by increasing the size of the powder chamber, that it began seriously to be doubted whether any armor could be made able to resist the crushing force of the square-headed Whitworth projectiles. Whitworth himself attacked the new problem, and in 1877 prevailed. He made plates of compressed steel, built in hexagonal, each of which was composed of a series of concentric rings around the central disk. The rings prevented the spreading of a crack beyond the one in which it occurred. Of this material a target was composed nine inches thick, supported by a wood backing against a sand bank. In front a horizontal iron tube was put to receive the fragments of the shot. Against this target a Palliser shell weighing 250 pounds was fired point blank from a nine-inch gun, with fifty pounds of pebble powder, at a distance of thirty yards. This shell would have passed through twelve inches of ordinary armor; against the new target it was shattered into innumerable fragments. The target was drawn back eighteen inches into the sand. The fragments of the projectile, escaping at the end of the tube, continued their rotation in such a manner as to cut through the planks in front of the displaced target. The only piece that survived the shock was a flattened mass of eight pounds, formed from the apex of the shell and left embedded in the target, where it had made an excavation of eight inches in diameter, and four tenths of an inch deep in the deepest part. The ring which received the shot was not cracked.

This experiment alone effected a revolution in naval armament.

There is not room here to speak of Sir Joseph Whitworth's eminent services to the cause of technical education. He has devoted a large part of the great fortune won by his inventive genius to the founding of schools and scholarships for the benefit of young men desiring to explore the wide field of mechanical industry.

Sidney Gilchrist Thomas.—It will be remembered that the Bessemer process failed after its first success, and that the reason of that failure was the presence of phosphorus in the pig iron. Such an insuperable obstacle did this present that Bessemer gave up the problem, and went to Sweden for his pig. To Mr. Sidney Gilchrist Thomas belongs the honor of discovering a means of getting rid of this obnoxious element. Acting upon his idea, he and his cousin Mr. Gilchrist, the first twenty-six, the latter twenty-five years old, conducted an exhaustive series of experiments to find a base with which phosphorus would unite. A base is the name given in chemistry to any element for which an acid has affinity. At last they made bricks of lime and magnesia, which they subjected to an intense white heat, when they became hard as flint. With these bricks, which were a base, they lined their converters, the melted pig iron was poured in, and the phosphorus at once left the metal and attached itself to the bricks. A quantity of lime is added to the run, and the result is a thoroughly dephosphorized iron.

The news of the new process spread through Europe, and to show how greatly the invention was appreciated, the following circumstance is detailed: A continental iron master called on Mr. Thomas at 7:30 one April morning to arrange for terms for the use of the patent. Just as they were concluded, a telegram was handed to Mr. Thomas, stating that another iron master from the same district was coming to arrange terms. The first visitor had secured a monopoly, and the second man was too late. Both of the iron men had come over on the same boat; one had driven straight to the patentee on landing, the other had gone to get his breakfast.

Before the process was three years old it was the means of producing half a million tons of steel per annum.

THE ANATOMY OF A STEEL RAIL[1]

BY HENRY COOK BOYNTON, S. D.
Metallurgist for J. A. Roebling's Sons Co.

Who would ever think, to look at a dull fragment of iron or steel, that such a piece of metal had an internal history! But if this same inert, apparently insensible, piece of metal be polished and suitably prepared for examination under a microscope, its internal structure is more clearly and surely shown than is the interior skeleton of a man by the X-ray.

However shapeless or structureless this piece of iron or steel seems to be, it is now perfectly easy to show by a proper treatment what the metal is composed of, how it was treated, and what makes it good or bad; in fact its entire "family skeleton" can be exposed with the greatest of ease. If it was created good, and has since degenerated through hard usage or abuse, or if it was predestined to be bad all its life, these properties and a great many more can be shown with an ordinary compound microscope.

It was only a few years ago that any intelligent engineer would have said, "If you will tell me the chemical composition of your metal, I will tell you whether it is of good or bad quality." This statement has been lately proved to be absurd. He might just as well have said, "If you will tell me how much carbon, oxygen, hydrogen, nitrogen, etc., there is in a certain man's body, I can tell you if he is a good healthy fellow."

Many times lately has the engineer's statement been disproved. A boiler explodes and scalds many men; an apparently sound rail breaks under the load of the "Light-

---

[1] Published in *Harper's Monthly Magazine* for March, 1906. Copyright, 1906, by Harper and Brothers.

ning Express'' and people are hurled to destruction; yet chemical analysis alone of the defective metals used showed them to have been apparently reputable; they had the requisite amounts of carbon, manganese, and silicon, and not too much sulphur or phosphorus, but just like many a person who mingles with his associates for years, and some day suddenly is found to be ''bad,'' so did these metals outwardly and inwardly, as far as the chemist was concerned, appear to be fulfilling their duties as respectable adjuncts to our civilization.

But take the bad boiler-plate or the defective rail and prepare it for examination under the microscope, and the whole reason for its failure to do its duty becomes as clear to the trained metallurgist as that the arsenic which the chemist finds in the stomach of the lifeless patient was the cause of his death.

To elaborate a little farther, let us take a steel rail, a plain every-day steel rail such as is used on all our railroads to hold up the daily loads of human beings and freight transported from one place to another. This rail is the band which joins one state to another, the East with the West, and one country with its neighbor. This rail was shaped from a huge white-hot piece of steel by being passed successively through properly shaped rolls. Suppose we saw out of the center of this rail a small specimen, about a one-half inch cube, and explain how it may be treated to bring forth its internal skeleton.

After cutting out our specimen with a steel saw, the piece must be ground to a plane surface on an emery wheel, given a second and smoother finish on another wheel fed with flour-emery, lastly receiving its final polish on two wooden wheels covered with the finest and smoothest broadcloth and fed respectively with a paste of tripoli and rouge powder. This whole operation of polishing, when done by an expert, occupies only about fifteen minutes.

Emerging from the rouge treatment, the metal stands forth in its best clothes, with not a spot or scratch to mar its silvery-white and mirror-like face. Like the ordinary workingman with his overalls off, a clean shave, and his best clothes on, you would hardly recognize the plain ordinary workaday steel rail with its old coat of brown or black.

But some one may ask, "Why do we seldom see steel with this silver-white color?" We do occasionally, as in razors, knives, etc., but ordinarily the moisture in the air so quickly attacks such a polished surface that if unprotected it speedily gains a coat of iron oxide or rust. A metallurgist keeps all his polished specimens of iron or steel in a desiccator, a receptacle which is kept free from moisture by some chemical that absorbs water, and in this way the prepared faces keep bright and untarnished for months and sometimes years.

Before the highly polished steel is ready to be photographed, it must be treated so as to make visible under the microscope just what its interior architecture really is.

The treatment consists simply in subjecting our piece of rail to the action of some reagent, some chemical compound, or to any treatment which will attack the different components of our metal to a different degree, and which will make each one stand out plainly from his fellows. Such a treatment is generally an "etching," and in the case of our steel rail we immerse it for a few seconds in a solution of nitric acid and alcohol. The acid first attacks the junctions of the different grains in the metal, then the grains themselves, coloring some brown or black, but leaving others white. Then our rail stands out in its true colors; it has lost some of its previous polish, but its whole true framework, its structure, lies plainly before us. But to the ordinary observer the polished surface of the metal shows practically no change; its polish is a little less brilliant, and only a slight grayish appearance is visible to the unaided eye.

"How then," says the layman, "can you tell if that was a good or a bad rail?" Then comes the microscope, that simple instrument which has revealed so many wonders. It enables the expert physician to tell the difference between the blood of a human being and that of other animals; the mineralogist, to discriminate between very minute particles of quartz or diamond; the zoölogist, to watch the embryonic development of the starfish; and it now permits the metallurgist to study the anatomy of so apparently lifeless a thing as a piece of steel.

With a vertical illuminator, or kind of reflector which takes the light rays from any source and bends them through a right angle, and then permits the observer to look through it down on to the polished surface of metal—equipped with such a reflector attached to an ordinary microscope, and with a number of different lenses called objectives and eyepieces, the metallurgist can look at his piece of rail under a linear magnification of forty to a thousand diameters. This means that if a spot measuring one hundredth of an inch across be magnified one hundred diameters, the original spot would appear to the eye of the observer one inch in diameter.

Can you conceive of anything in that rail that could escape the trained eye when under a magnification of one thousand diameters? It would have to be more elusive than the tiny germs which medical men look for as the cause of most of our contagious diseases, than the 500,000 bacteria in a cubic centimeter of the ordinary milk we drink.

By throwing the structure which we see under the microscope upon a ground glass in a special camera, and then substituting a photographic plate for the ground glass, a picture can be obtained in the usual way of photography. Such a portrait of our rail may be seen in Fig. 1, which is a fair average sample of a good steel rail.

By examining this picture a little more closely, we notice light and dark areas; the former are the pure iron grains, or ferrite, as the metallurgist calls them, and the latter "pearlite," because it looked like mother-of-pearl to the person who first discovered it. The ferrite makes the rail tough to resist fracture, and the pearlite is the part of the metal which contains the carbon and which makes the rail hard and stronger than iron and enables it to wear well under the friction of the car wheels. The metallurgist at a glance knows this to be the normal structure of a *good* steel rail such as daily and hourly fulfils its duty all over the world.

But let us return to the rail which broke, which could not stand the speed of the express train. This rail outwardly had the appearance of respectability; the section boss had tested it with his sledge many times; it had held up bravely under many a train; but suddenly it "went bad."

A good steel rail on the open road will stand at least ten years of active service, years during which the swiftest passenger trains with the heaviest of all cars, the "Pullmans," go pounding across the joints. The freight trains with their more ponderous engines and more heavily loaded cars seldom break a rail, on account of their much slower rate of speed; for the ordinary steel rail, good or bad, will sustain ten times the load put upon it if this be applied slowly; but the high speed of the heavy passenger train is apt to make the bad rail succumb to the sudden shock of the gigantic monster which hammers down upon it.

The rail which is put in a critical place, as for example on a very sharp curve, is seldom found wanting, for the very reason that only the best selected stock is used for such a locality, and a dangerous curve is always assiduously watched by the section man and the division superintendent.

The faulty rail, however, on the straight track, which got slipped in with the good ones, is the one to be dreaded, for after leaving the mill there is no possible way to distinguish this physically incompetent piece of steel from its good neighbors.

For a better understanding of some of the imperfections

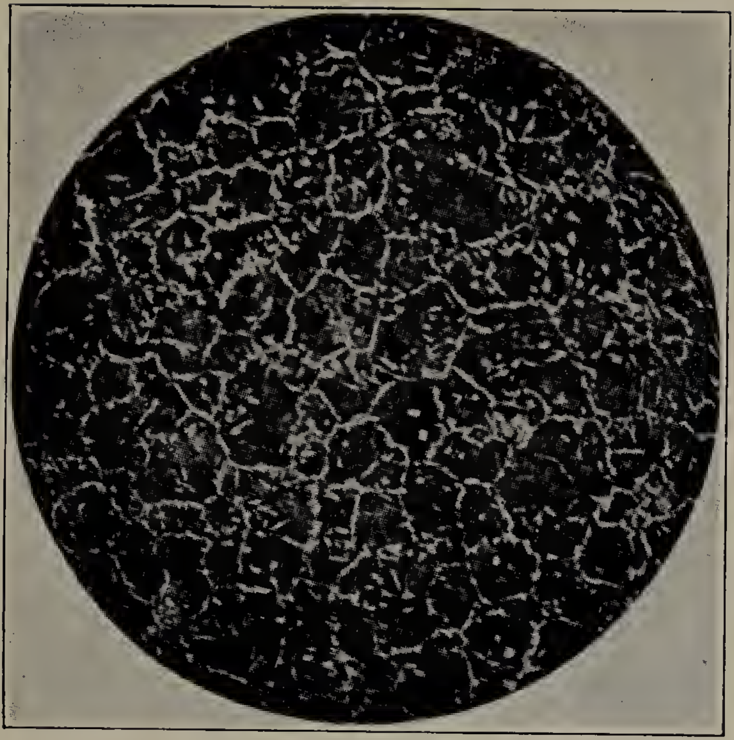


FIG. 1.—STEEL RAIL OF GOOD QUALITY, MAGNIFIED 100 DIAMETERS. ROLLING FINISHED AT THE RIGHT TEMPERATURE

FIG. 3.—LONGITUDINAL SECTION OF STEEL INGOT, SHOWING A "PIPE" AT C, AND BLOW-HOLES AT A AND B

of rails let us digress a little to explain the birth of the rail. The steel for a rail is made from a molten mass of cast iron, or pig iron, which is iron containing a large amount of impurities, the most notable of which is carbon. This cast iron is run, white-hot and liquid, from a blast furnace into a Bessemer converter, through the bottom of which air under pressure is blown in large quantities. The impurities in the pig iron are burned by the oxygen in the air blast, and pass off as gases or rise to the top of the refined metal as slag, essentially a silicate of iron. Fig. 2 is an illustration of a Bessemer converter in full blast.

The whole operation of converting ten tons of cast iron into steel takes only about ten minutes, and when complete the molten mass is made to absorb the required amount of carbon to give the necessary strength to the rail by adding spiegeleisen or ferro-manganese, both alloys of iron and manganese containing carbon.

We now have a molten mass of steel, which is poured into iron molds to solidify. When cool the molds are stripped off and we have left large masses or ingots of steel, and this steel is only an alloy of iron and carbon with a few impurities present in very small quantities. From one of these ingots several rails may be made by reheating and passing it through suitably shaped rolls.

I have shown here in Fig. 3 a diagram of a longitudinal section of one of these ingots. It is not at all homogeneous, as can readily be seen, and has a cavity or "pipe," above C, which is caused by the unequal cooling of the sides and the top. The black spots near the edge, A and B, are called blow holes and are caused by imprisoned gas; they are subsequently closed by the rolling, so that they are not detrimental to the quality of the steel rail.

Now this "pipe" cavity should be all cut off, as a rail which is rolled from the end of the ingot containing this pipe is sure to be faulty, for it will always contain this cavity, which will be but imperfectly closed by the rolling and only elongated. To be absolutely sure that all the pipe is removed, about twenty per cent. should be cut from the top end of each ingot. Let us suppose, for sake of illustration, that only ten per cent. is cut from the top of each ingot, which is often the case; a "pipe" rail then goes out to the stock pile with the good ones.

But now suppose we have before us a fractured rail broken by the impact of a heavy train going at a high rate of speed? Suppose we polish it and examine it in just the same way that we did our good rail? What shall we find?

We may find a partially welded pipe, which, it goes without saying, is a source of weakness. This cavity, which originated in our ingot when rolled, will look like the diagram in Fig. 4. It can be readily seen that the long bloom, as it is called, should be cut at C, and the butt sent to be remelted; but if cut at A, the end of one rail, just where great soundness is desired (near the joint), will be weak.

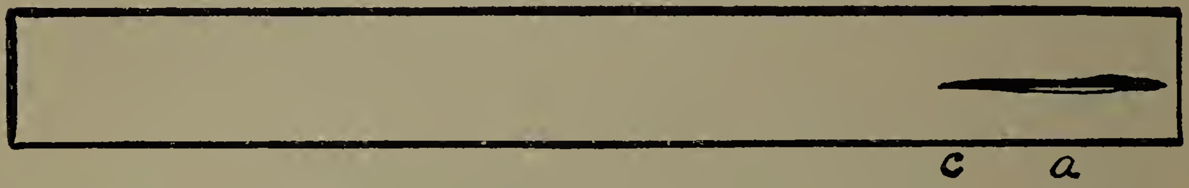


Fig. 4.—Diagram of the Pipe in a "Bloom," a Partially Rolled Steel Ingot

Such a pipe will be revealed almost instantly by etching a cross section of the rail and examining it under the microscope; in fact in some cases the microscope is wholly superfluous, for the defect and the reason for the disaster will be visible to the naked eye. See Fig. 5.

Let us go back to our ingot once more; at the foot of the pipe—the part which solidifies last, since top and sides cool first—will be found most of the impurities in the steel, the most deleterious of which are phosphorus and sulphur. Now a few tenths of a per cent. too much phosphorus or sulphur in a steel rail will make it "bad." These seemingly infinitestimal amounts of sulphur make a rail snap suddenly if worked hot; and worse yet, phosphorus will

FIG. 2.—TEN-TON BESSEMER CONVERTER IN FULL BLAST, MAKING TEN TONS OF RAIL STEEL IN TEN MINUTES

cause a fracture from a sudden shock when the metal is cold. Therefore phosphorus and sulphur are the evil associates which a steel rail must be as free from as possible to be classed as good.

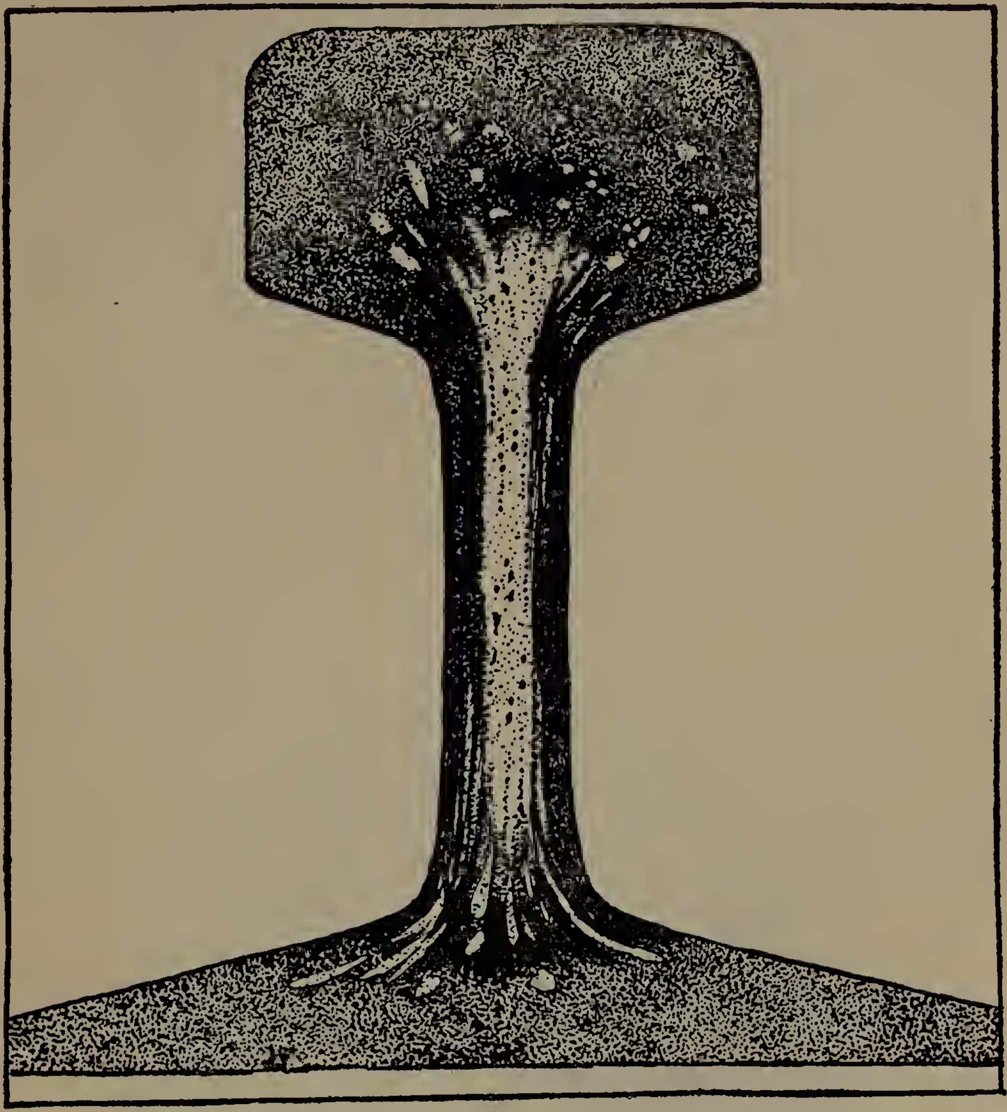


Fig. 5.—Etched Section of a Bad Rail, Showing the "Pipe." (The Light Area is the Revealed "Pipe")

So, you see, if no more than the "pipe" be removed, the segregation of impurities at the bottom of this cavity might cause the rail to snap as instantly if the load of the train above hammered down too suddenly as if it contained the pipe. Such a rail can generally be detected only by the etching method and the microscope. Fig. 6 shows a rail with a great many sulphur flaws present, the dark areas representing the flaws.

Moreover, a rail low in phosphorus or sulphur, which contains no traces of a pipe or segregation, may prove defective. The composition of the rail is normal. What then is the matter? On polishing and etching and examining it under the microscope the structure seen in Fig. 7 is brought to light. To the inexperienced it looks all right, but to the steel man it shows that the rolling of the rail was finished at too high a temperature, that the grains of the steel are too large, and long experience has shown that these large grains produce brittleness, and when the greatest toughness combined with strength is required, the finest possible grains should be sought for. This may be accomplished by continuing the rolling down to a certain ''critical temperature,'' below which no crystallization takes place when the rails cool after rolling. Such a structure is seen in Fig. 1 and such a rail will be strong, yet tough, and will resist sudden shocks.

I do not intend to convey the meaning that the microscope is the telescope by which all the ills prevalent in metals can be viewed face to face; but as used by the scientific man, together with his indispensable etching compounds, the microscope is able in many cases to give a clear clue to the sins of our metals and their makers.

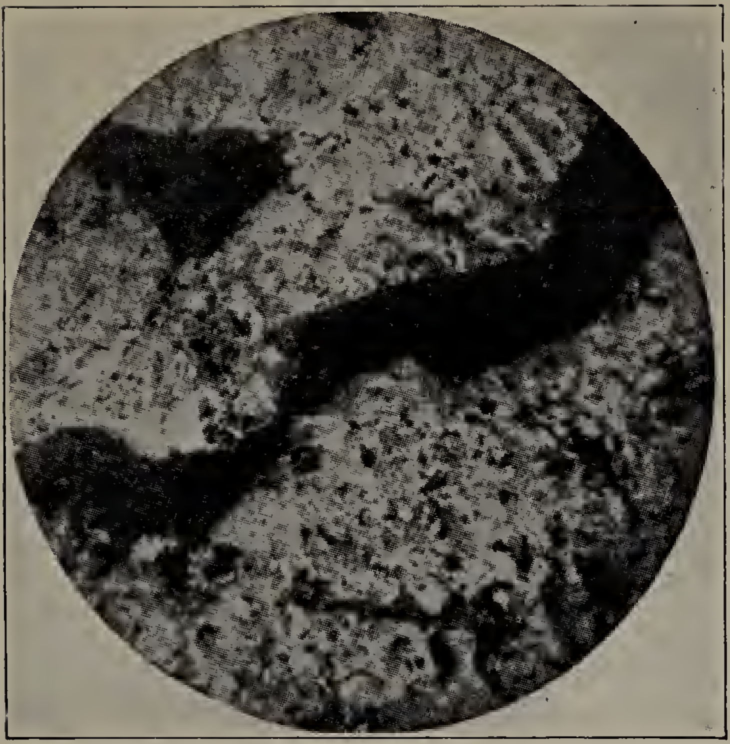


FIG. 6.—SECTION OF A STEEL RAIL CONTAINING TOO MUCH SULPHUR. THE DARK AREAS ARE THE SULPHUR FLAWS. MAGNIFIED 100 DIAMETERS

FIG. 7.—STEEL RAIL, MAGNIFIED 100 DIAMETERS. MADE OF GOOD STEEL, BUT ROLLING FINISHED AT TOO HIGH A TEMPERATURE

THE NATURE AND TREATMENT OF ALLOY STEEL[1]

BY JOHN A. MATHEWS, PH. D.

Operating Manager, Halcomb Steel Company

PARAPHRASING the remark that has been made about books we may well say, of making many alloys there is no end and much study of them is a weariness to the flesh and small profit to the maker. It is hardly necessary at this late day that an article upon this subject should consist of long tables of remarkable physical tests—elastic limits above 100 tons, coupled with the elongation of molasses taffy or illustrated with photographs of steel tied into bowknots and large forgings distorted in shapes that would make the "human snake" turn green with envy. Too often in the past such data have raised bright hopes in the mind of a steel consuming public, and too often results in practice have fallen short of published data.

A few generalizations in connection with these recent fascinating developments in the steel industry may serve a more useful purpose and help the user to obtain in practice results equal to those claimed by the maker. Let us then begin with the definition that "steel is a malleable alloy of iron and carbon which has been produced by casting from a fluid mass." Since by this definition all steel is an alloy, what is meant by "alloy" or "special" steels? While these terms are in general well understood, they are difficult to define, though they may be described.

Two elements, iron and carbon, are all that are necessary to produce steel. Four other elements are always present —silicon and manganese, which are useful and essential, and sulphur and phosphorus, impurities whose effects even

---

[1] Abstracted from a paper published in *Iron Age*, 1908.

in homeopathic doses are by no means negligible. Copper and arsenic, aluminium, oxygen, nitrogen, and cyanides are usually present in minute and negligible quantities. Ordinary steel, by whatever process made, is therefore a wonderfully complex alloy, though often spoken of as though it were an elemental substance. It may contain carbon and manganese from 0.10 to 1.50 per cent.; silicon from 0.02 to 0.25 per cent., and sulphur and phosphorus from 0.01 to 0.10 per cent., and the other elements named above which are rarely determined. Its complexity is further increased by the fact that iron and carbon may exist in several different physical conditions or combinations, while the intramolecular possibilities of the other elements are legion.

When to this very complex base material other elements such as nickel, chromium, tungsten, and vanadium are added, we begin to look wise and talk about alloy steels. Steels within the limits of analysis just mentioned serve an enormous number of purposes, and steel of a particular analysis adapted for rails, springs, knives, or gun barrels may in a limited sense be called a "special" steel, but such is not the commonly accepted use of the term.

When we materially exceed the limits just given or add elements not normally contained, such as nickel, vanadium, chromium, tungsten, molybdenum, etc., the product is called an alloy or special steel. Silico-manganese gear steel is an instance of an alloy steel containing no unusual elements but containing some of the ordinary elements in unusual amounts. Its analysis is about as follows: Carbon, 0.50 per cent.; silicon, 2.00 per cent.; manganese, 0.60 per cent.

In such a case it becomes difficult to decide arbitrarily the percentage at which we pass from a regular to a special steel. Abnormally increasing the ordinary constituents or adding other constituents so changes the properties that new qualities appear and new purposes are served. The effects of such additions are made manifest in various ways which may be summarized as follows: 1. By changing the critical ranges and recalescent temperatures. 2. By modifying the condition in which the carbon exists. 3. By removing harmful occluded gaseous impurities. 4. By combining chemically with iron or carbon or both. 5. Either combined or free, forming isomorphous solutions with iron or separating into distinct microscopic particles. By these means steel is improved or injured, hardened or strengthened, toughened, or made more brittle.

Notwithstanding its complexity, it is reasonable to expect, and much evidence has been brought forward to show that steel and its alloys obey the laws of physical chemistry which hold good for simpler and purer alloys, namely, the laws of solution. The problems presented by steel alloys have engaged the attention of the world's leading chemists and physicists, and they have made rapid strides within a generation in elucidating the molecular relations of the elements of steel. They have isolated by ingenious methods many well defined chemical compounds, such as the carbides, phosphides, and sulphides of iron and manganese.

The complexity of steel from a chemical standpoint is further increased by the allotropic character of iron, and by the fact that carbon and probably sulphur and phosphorus may exist in several conditions or combinations. As iron is cooled from a molten condition, it has been discovered that at from one to three temperatures below its freezing point cooling momentarily stops. For carbonless iron these temperatures are designated as Ar_3 and Ar_2 and occur at about 895° C. and 765° C. When carbon is also present a third well marked arrest in cooling is noted at about 690° C., known as Ar_1—the ordinary "recalescent" point. It is believed by many that the Ar_3 and Ar_2 temperatures indicate transition or critical changes in the nature of iron itself. In other words, that just as phosphorus may exist in two distinct forms, one yellow and one red, so the element iron is supposed to be capable of existing in different physical conditions at different temperatures. At temperatures above Ar_3 we have the "gamma" iron of Osmond, non-magnetic and a solvent for both elemental carbon and iron carbide. Between the Ar_3 and Ar_2 temperatures we have iron existing in its "beta" condition, non-magnetic but not a solvent for free or combined carbon. Below Ar_3 iron is in its "alpha" condition, magnetic but not a solvent for free carbon, but possibly a slight solvent for combined carbon. While some metallurgists do not accept this explanation of the significance of the critical temperatures and ranges, all concede that they do occur, and that other elements added to iron carbon alloys change, obliterate, or modify the temperature ranges, and it is just on account of this that different steels require different temperatures for forging, annealing and hardening.

So much for the nature of alloy steels, and now a few suggestions as to their treatment and a few words as to the various kinds of alloys. The constitution of these products, chemical and physical, for generations remained unknown and a matter of speculation. Tremendous progress has been made of late years in clearing up a few of the obscure points.

The first commercial alloy steel, at least the first to make a great name for itself, was Mushet's air hardening tool steel. The next alloys to attract attention were of the structural types, and may be said to have had a public introduction when Riley presented a paper to the Iron and Steel Institute of Great Britain upon iron and nickel. Shortly afterward Hadfield's famous manganese steel was proclaimed and later he has produced many valuable products, especially in the line of armor and projectile steels. Along with the making of the new products has proceeded the study of their properties and methods of heat treatment. To-day a host of devotees, skilled in the science of heat treatment, apply their knowledge to the manufacture of tools, automobile parts, and machinery to produce results never dreamed of a generation ago.

The principal types of alloy steels are those used (1) for materials of war, (2) for tools, and (3) for materials of construction. The first are mainly alloys of nickel, chromium, and tungsten or combinations of these elements. The makers of these alloys also conduct the heat treatments and guard their methods jealously. Alloy tool steels include air hardening and high speed steels together with a large number of steels of the "special" class containing relatively small amounts of alloying elements, giving them special characteristics and fitness for particular and severe requirements. One product of this class is remarkable in that it undergoes no change in form upon hardening; moreover, it hardens in oil sufficiently to make a remarkably good tap, cutter, or die.

The alloys receiving most attention to-day are those of the third class—namely, materials of construction, and particularly the automobile steels. These are in general of three kinds—nickel steels, chrome nickel steels, and chrome vanadium steels. Many different analyses are made under each class. The difficulty of producing sound nickel steel, free from pipes and seams, has injured the reputation of this most useful alloy with many users. This difficulty has been greater than need be because certain steel companies have mistaken a quality proposition for a tonnage proposition, and have offered nickel steel at absurdly low prices, wholly inconsistent with uniformity of analysis, careful workmanship and inspection. Discriminating users recognize this fact and are willing to pay a premium for the product of certain mills, because their steels are made in smaller tonnages and units, are more carefully handled from start to finish, are worked under hammers rather than in blooming mills, are made from purer materials and carefully inspected when done. The best is none too good for constructing the vital parts of an automobile, and when a concern has secured the best that the market affords, it has but taken the first step in producing good parts. Next come the forging and machining and the heat treatment, for better or worse. It is money wasted to buy good alloys unless one is willing to study them sufficiently to know how to treat them and then to supply adequate facilities for so doing.

It is not to be expected that small users will install complete testing laboratories, but a few dollars invested in having occasional tests made will be well spent. There are, however, many large concerns that could and should spend, say, $5,000, for which it is believed the whole or a large part of the following equipment could be obtained: The ordinary tensile machine, a microscope, electrical or gas furnaces, capable of fine regulation, a good pyrometer, preferably recording. The tensile machine can also be used for making Binnell hardness tests, spring deflection tests, etc. In addition to these some form of drop testing machine, such as the Fremont, will be found valuable; a vibratory or repetitive impact test is nowadays considered a necessity, while cold bending and torsion apparatus is useful. This equipment will be of small use, unless a thoroughly good man is put in charge—a careful, conscientious man of sound judgment. This man should direct the heating operations in the factory; he should construct furnaces which heat uniformly, and he should exercise eternal vigilance in keeping the pyrometric installations up to par.

The best pyrometer of the thermo-couple type[1] should be looked over and calibrated at stated intervals, especially if in constant use. Protecting tubes should be frequently examined and renewed, and electrical contacts looked over. Occasionally check up the millivoltmeter. Unfortunately there are many pyrometers of the thermo-couple type on the market which cannot be watched too closely. Quite recently I visited two concerns where they were hardening the same grade of steel and doing it well. I asked each concern what temperature it was using. One said 1,300° F. and the other 1,700° F. The actual temperature in both cases was probably 1,500° F. Another

[1] Compare Fig. 2 in "Why a Flame Emits Light."

so-called cheap pyrometer that I tested departed from the truth over 100° in a month, and another was 50° off when installed. In a lot of six couples tested after being in use some time, three were all right and three all wrong and by varying amounts. If you are going to use pyrometers by all means see that you have good ones and then see that they are systematically tested. Many people buy high priced alloy steels and get no better results from them than could be had from a carbon steel properly handled. If you cannot afford a good pyrometer stick to the trained eye of a skilled man; and if you have a good pyrometer employ a skilled man, anyway, and consider the pyrometer as an aid. With it you can at least give orders in temperatures rather than in heat colors, and the laboratory and works can meet on an intelligent basis. Pyrometers, like "smoke consumers," are all right if carefully watched and intelligently used. Too often both fail after about thirty days' use.

Heat treatment operations depend upon a solid scientific basis. And by this is not meant that steel essentially of inferior quality can be made to pass muster by heat treatment.

On the other hand, however, it might be said that alloy steel in its so-called natural state, as it comes from the rolls, hammer or drop forge, is almost unfit for automobile construction. Steel which depends upon alloys for a high elastic limit in its natural condition will have much less elongation than the same steel oil tempered and annealed. For example, a chrome steel gave in its rolled condition 158,000 pounds elastic limit and 5 per cent. elongation, with 9.4 per cent. reduction of area. The same steel oil tempered and annealed gave 153,000 pounds elastic limit, 14 per cent. elongation and 52 per cent. reduction of area. In other words, the material was transformed from brittle to tough, from treacherous to safe, without materially affecting its elastic limit. A nickel steel similarly treated had its elastic limit raised 20 per cent., with the reduction in area improved and its elongation unchanged.

OXYHYDRIC PROCESS OF CUTTING METALS[1]

TORCHES AND MACHINES THAT CUT STEEL

BY E. F. LAKE

It is seldom that the *American Machinist* has the privilege of publishing such a striking addition to machine-shop methods as the one which supplies the subject of this article. When we say that Fig. 1 represents a piece of 9-inch chrome-nickel steel armor plate which has been cut to a circular outline by the removal of the waste piece shown in the left foreground, and that this has been done at the rate of a linear foot of cut in 2¼ minutes, we think we are saying enough to indicate that here is something new in the machine shop.

Fig. 2 shows the work in progress with the pyrotechnic display that accompanies it. Further on in this article additional examples of the work done will be shown which are less striking than the one which forms the subject of the first two pictures only because of the smaller sizes of material acted upon. In some respects—notably the form of the cut made in some of the examples—these latter cases are, indeed, more striking than the ones shown in Figs. 1 and 2.

The remarkable results are obtained by an apparatus which is a development from one patented in 1901 by the Cologne-Meusen Mining Company for opening plugged blast furnace tap holes and now in considerable use in this country, where it has cut tap holes through 4 feet or more of solid metal, and with a reduction of time from days to as many hours. That apparatus, like this, makes use of

---

[1] Abstract of an article published in the *American Machinist,* 1909.

FIG. 1.—A 9-INCH NICKEL CHROME-STEEL ARMOR PLATE AFTER ONE-HALF THE CIRCLE HAS BEEN CUT AT THE COCKERILL WORKS, SERAING, BELGIUM

two nozzles through one of which a mixture of oxygen and hydrogen is supplied, while the other delivers pure oxygen only.[1] The action of the older apparatus is, however, to actually melt the metal, and while very effective for its purpose, it is impossible by it to produce a smooth and exact cut of any desired length.

With the present apparatus a preheating nozzle, delivering mixed oxygen and hydrogen, is used to continuously heat the metal, while immediately following it, and set at an angle such that both streams of gas strike the metal at the same place, is a second nozzle delivering pure oxygen only. This cuts the metal by oxidizing it without melting and blows away the oxides by the force of the blast. The result is a cut which may be fairly compared with that made by a cutting tool, while the heating is so local that the properties of the material cut are not affected beyond about 1/64-inch of the cut surface and the width of the kerf is surprisingly small.

The oxyhydric process is based on the well-known fact that iron burns easily and rapidly in an atmosphere of oxygen gas, as much heat is thus set free. If we throw a jet of oxygen upon iron that has been heated to red, the oxygen oxidizes the metal, which is to say, burns it. Thus the steel is heated only to from 1,300° to 1,500° F., as at this temperature iron has a great affinity for oxygen, and the combination produces different forms of oxides.

The double-nozzle torch may be manipulated by hand, or it may be guided by any sort of mechanical arrangement; and thin sheets or thick plates, steel tubes, structural shapes, castings, or any odd pieces of steel may be easily cut.

The cut can be made to follow any sort of a line whatever, as all forms of curves and odd shapes are cut as easily as the straight line. The cut is not necessarily square to the surface, as a beveling cut can be easily made,

---

[1] Acetylene is being used in this country in place of hydrogen, with some makes of torches.

and it is practically no wider at the bottom than at the top even when cutting very thick metal. The speed of travel of the torch can be made about 8 inches per minute on fairly thick metal, and this makes it compare very favorably with hot sawing.

The composition of the steel or its mechanical treatment does not affect the speed with which the metal is cut, or the amount of gas which is used in the cutting. In fact, there is no variation between the rolled, forged, or cast steels and the soft, hardened, tempered, carbonized or Harveyized steel; and a nickel chrome, high manganese or high carbon steel cuts as easily as the low carbon steels.

The complete apparatus for cutting, with one of the mechanical appliances for guiding the torch, is shown in Fig. 3. The two steel bottles at the right of the picture contain the oxygen and hydrogen which is stored under a pressure of from 1,500 to 2,000 pounds per square inch.

Each bottle is provided with a needle valve to which is attached a pressure regulator governing the flow, so that the gas will be delivered to the mixer and from thence to the torch at a constant pressure. A high-pressure gage is located between the needle valve and pressure regulator in order to show at all times the contents of the tank and to determine the amount of gas consumed in any cutting operation. A low-pressure gage is also attached to the regulator showing the pressure of gas as used for cutting. The cutting pressure can thus be varied to suit the character of the work by turning a thumb screw on the regulator. From the regulator the gas is conducted by heavily armored tubing to the mixer.

The mixer is shown on the floor beside the bottles and the gases are conducted through it by a conical worm-shaped pipe made of thin metal, this pipe being surrounded by cool water as a safety provision against explosion of the mixed gases.

In Fig. 3 the torch rides on a frame that is provided with two ways for guiding it in a straight line.

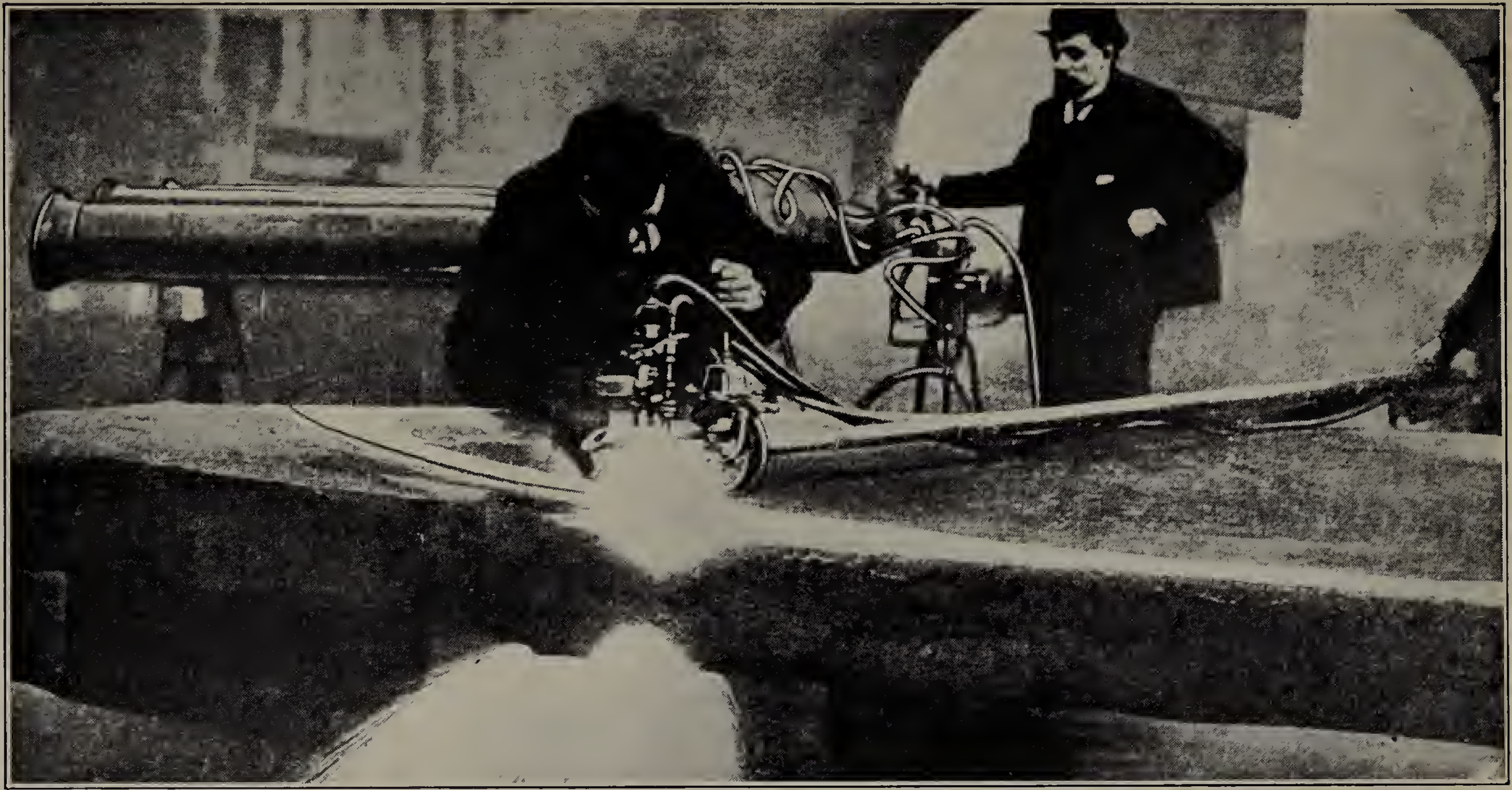


Fig. 2.—Cutting the 9-inch Nickel Chrome Plate at Rate of 2¼ Minutes per Lineal Foot

On steel four inches thick, the width of the cut is only one eighth of an inch, while on thin metal it is but five sixty-fourths inch, and the metal is practically as smooth as that coming from a saw.

The principal item in the cost of cutting metal with this process is the gases used, as the apparatus is much simpler than that used for cutting metals by any other means, and requires no power, and the time of cutting is as quick if not quicker. The consumption of gas naturally depends upon the thickness of the piece to be cut.

From the large amount of work which has been done and the numerous thicknesses of metal which have been cut, the amount of gases which should be used are pretty well known. In table II[1] is given the amount of the two gases which should be used for all thicknesses of metal from one tenth of an inch to five inches, as well as the size of nozzle which should be used for each gas.

In a machine which is designed for accurate straight cuts either parallel with or at right angles to the bed of the frame, the torch is mounted on a carriage which is moved longitudinally by hand wheels and a lead screw. Another hand wheel on the side of the carriage moves the torch away from or toward the machine, and as the oxygen nozzle should always follow the preheating nozzle, the torch may be turned around by a small lever. This torch, as are all the torches, is provided with a valve for shutting off the gas. At the bottom of the machine is located a straight edge on which the nozzle slides. By means of an additional attachment the torch can be made to cut in a vertical direction.

In Fig. 4 are shown some samples of the work done with the above machine. The slabs themselves were first cut off with the oxyhydric torch, and afterward the irregular cuts were made in the slabs. The narrowness of the cut, the square corners that it is possible to turn, and the fact

---

[1] See original article for these figures.

that the metal is not burned on the sides of the cut are plainly seen.

The closeness with which the metal can be cut to a line is best illustrated by the small slab in the upper right hand corner. In the center of the slab it will be noticed that there has been left a thin strip of metal. This is but one eighth of an inch thick, while the cut is one and one-fourth inches deep, and is practically no wider at the bottom than at the top.

Another appliance can be used in an ordinary brace for cutting circles from two to twelve inches in diameter, and yet another can be attached to a beam located in a trammel point for cutting larger circles. The torch is fastened by thumb screws to two U-shaped rods that are mounted on wheels. Either of these rods, or both together, can be raised or lowered so as to accommodate the torch to any inequalities in the surface of the metal, or to locate it the proper height above the metal for successful cutting.

One of the most useful applications of this process is in the cutting of steel tubes or pipe. A special attachment has been made for this purpose. It is made in several sizes to accommodate the different sizes of pipe.

The pipe is inserted in the center of a ring and is clamped there by three set screws. The torch is then revolved around the pipe and cuts it with a good clean cut and hardly any waste of metal. A small wheel, that runs around the pipe back of the nozzles, locates their position, and adjustment can be obtained by means of a spring inside of the apparatus. This apparatus is especially valuable in plants where power is not available.

Another style of pipe cutting machine is built, which can be used on pipe that has flanges on both ends, and it is made so it can be adjusted to fit different diameters of pipe. This machine can be used for cutting the openings for branch connections. Branch flanges can also be cut out.

A manhole cutting machine is also made which will cut oval, round, and square holes up to eight inches square.

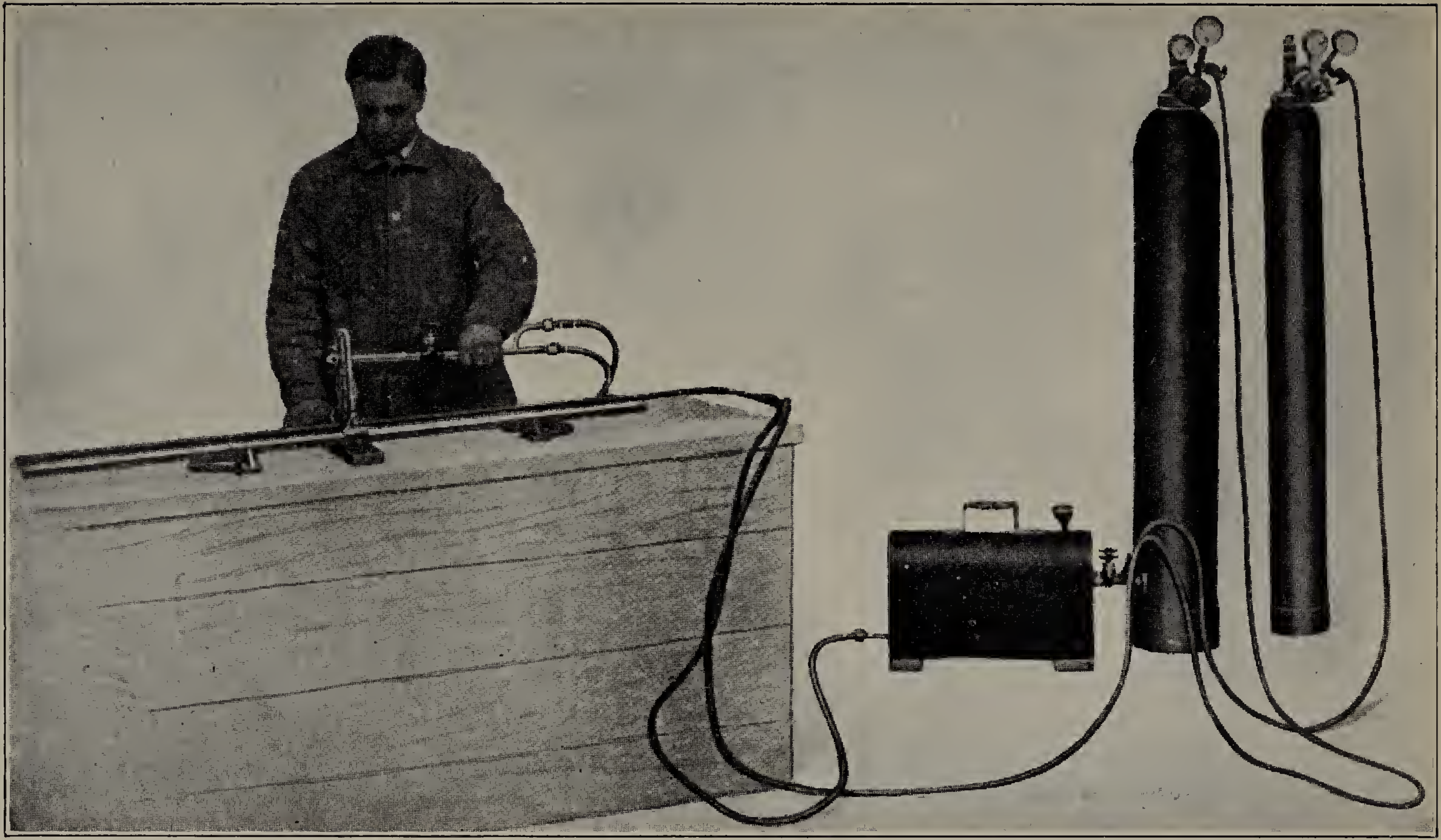


Fig. 3.—Oxyhydric Apparatus with Mechanical Appliance for Cutting in a Straight Line

One of the most interesting jobs which has been done with this process was the taking apart and cutting into scrap of an old English armored cruiser, which had been bought by a firm in Hamburg.

The method which had been employed formerly was to cut the rivets off, drive them out, remove the armor plate, notch it with compressed air tools and then break it up under a drop. To complete the work by this old method usually took one and one-half years. Now, with the oxyhydric process, the job was completed in two and one-half months.

The armor plate, as it was being cut up, is shown in Fig. 5. Some of this was fourteen inches thick and some of the heaviest guns which were cut up had an outside diameter of more than forty inches. All the metal in the boat was cut to sizes suitable for charging in the furnaces for remelting. See Fig. 6.

As a manufacturing proposition the oxyhydric process is equally as good as in the cutting up of scrap, and Fig. 7 shows a sample of work on which it is very useful. This is a face plate for the base frame of a locomotive. It was nine sixteenths of an inch thick, four feet wide by six feet long and about 264 lineal inches had to be cut in cutting out the opening. This work was done in exactly one hour, which is at a speed of three and three-fourths minutes for each running foot.

Many uses for this process will also be found in steel foundries. In Fig. 8 is shown a steel casting just as it comes from the mold, and Fig. 9 shows the same casting after the sprues, risers, etc., have been cut off with the oxyhydric process.

The oxyhydric process is also applicable for welding the various metals that can be fused together. The flame, however, must be the opposite of that used for cutting metals, as it must be one that freely reduces the oxide, rather than one causing oxidation, as is used in cutting, as oxides in the welds are inadvisable.

In the apparatus that is used for welding the same two oxygen and hydrogen bottles are used and the gas is piped from these to the same mixer that is used in cutting. Here, however, the similarity ceases as the extra nozzle for oxygen is not used. A torch with a single nozzle is substituted and the gas that enters the torch is piped through a single pipe from the mixer; thus only one line of armored hose, leading to the torch, is needed in place of the two.

The welding done by this method leaves the metal its ductility. If the welded joint is submitted to a slight hammering, while it is cooling down to a dull red, or even to a heat treatment after it has cooled, the steel in most cases can be brought back to its original structure and the joints can be made nearly as strong as the original metal.

In welding thick plates, say from three eighths of an inch upward, by any of the fusion methods, it is usual to bevel or chamfer the two edges of the joints and fill the V thus formed by melting metal from a rod, with the torch. If the metal is properly fused by this method a fairly good joint is obtained, but if the operator allows globules of metal to fall from the rod and drop on metal which has not been properly melted, the two do not fuse together and a poor joint is the result.

The German Oxyhydric Company adopted a different method of welding metals from three eighths to one inch thick, and have made many successful welds thereby. This method is to put the two ends of the metal together without overlapping, but in contact with each other. They are thus heated by two oxyhydric torches, one above and the other below the metal, and exactly opposite each other, and are given as extensive a heating zone as possible.

When the metal begins to show signs of melting on the outside, the interior of the sheets are doubtless at a white welding heat; the torches are then removed and an anvil and hammer brought into use for lightly hammering the joint. This causes a readjustment of the molecules, and they join together in the weld.

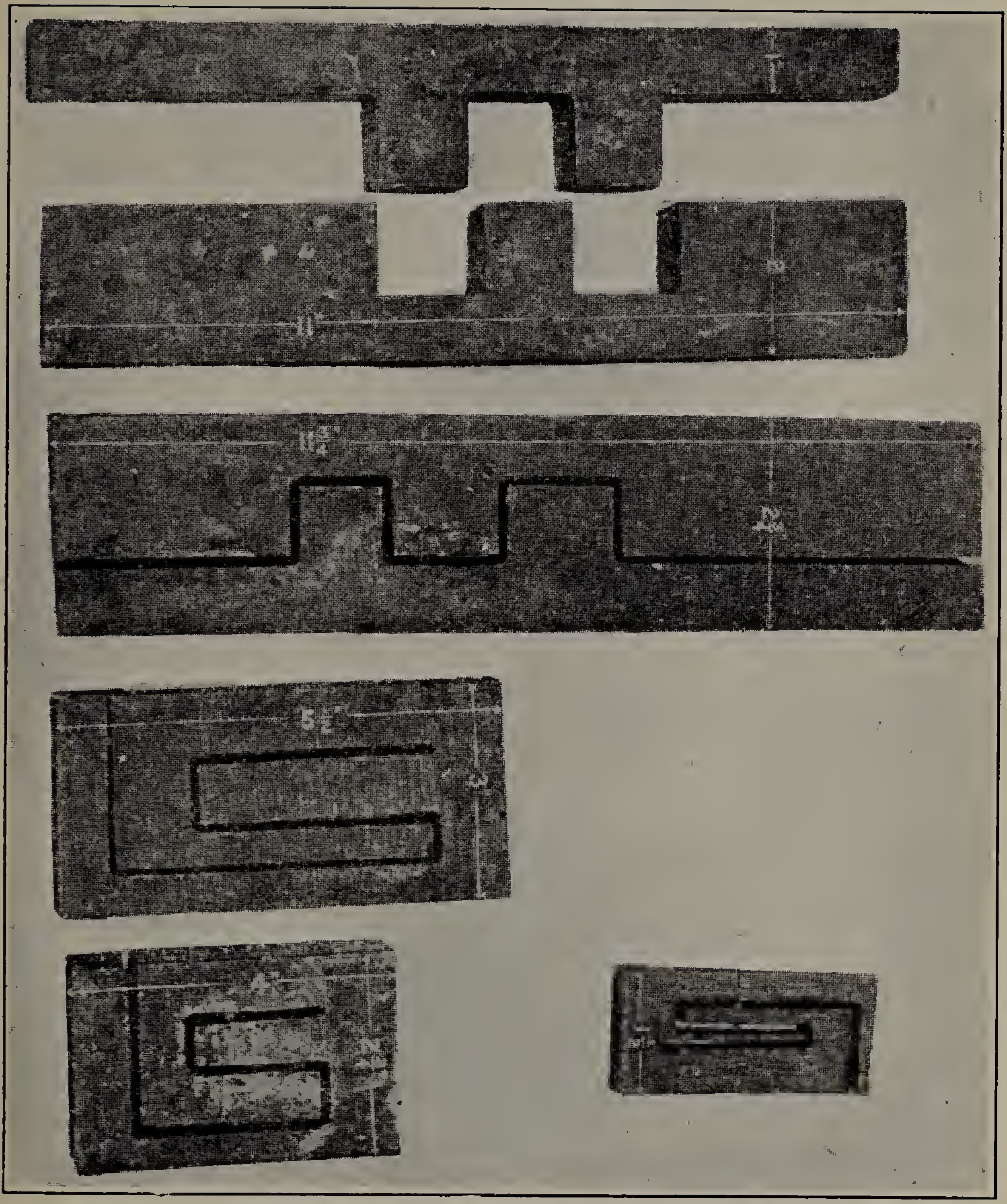


FIG. 4.—IRREGULAR SHAPED CUTS

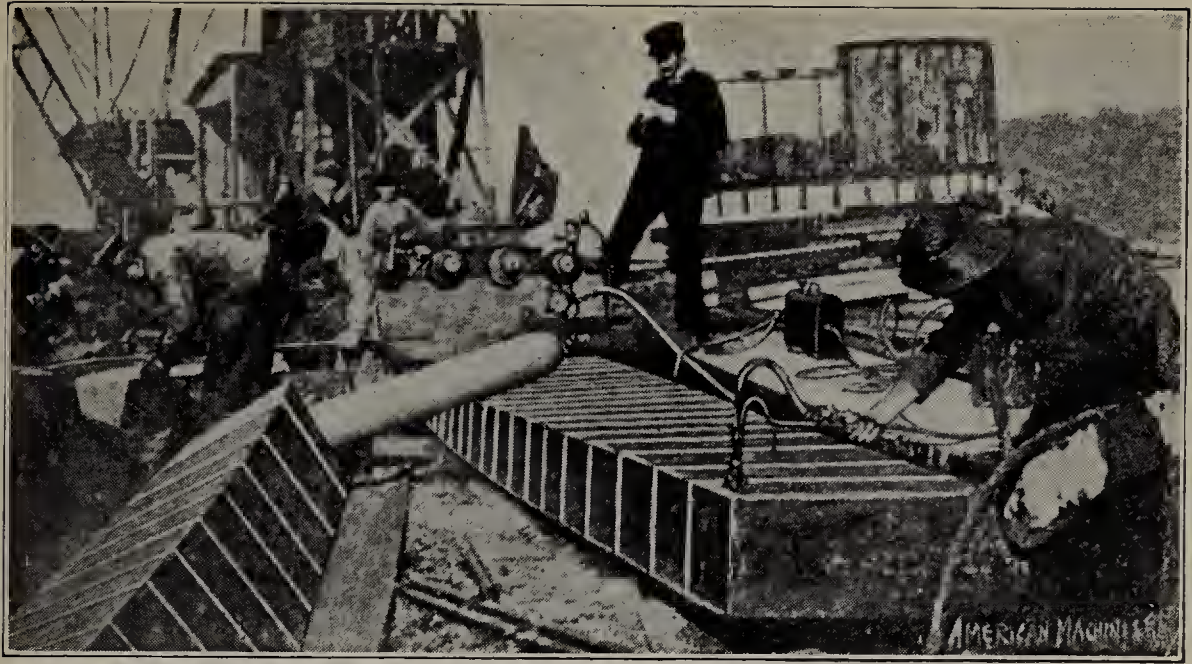


FIG. 5.—CUTTING UP THE ARMOR PLATE, SOME OF WHICH WAS 14 INCHES THICK

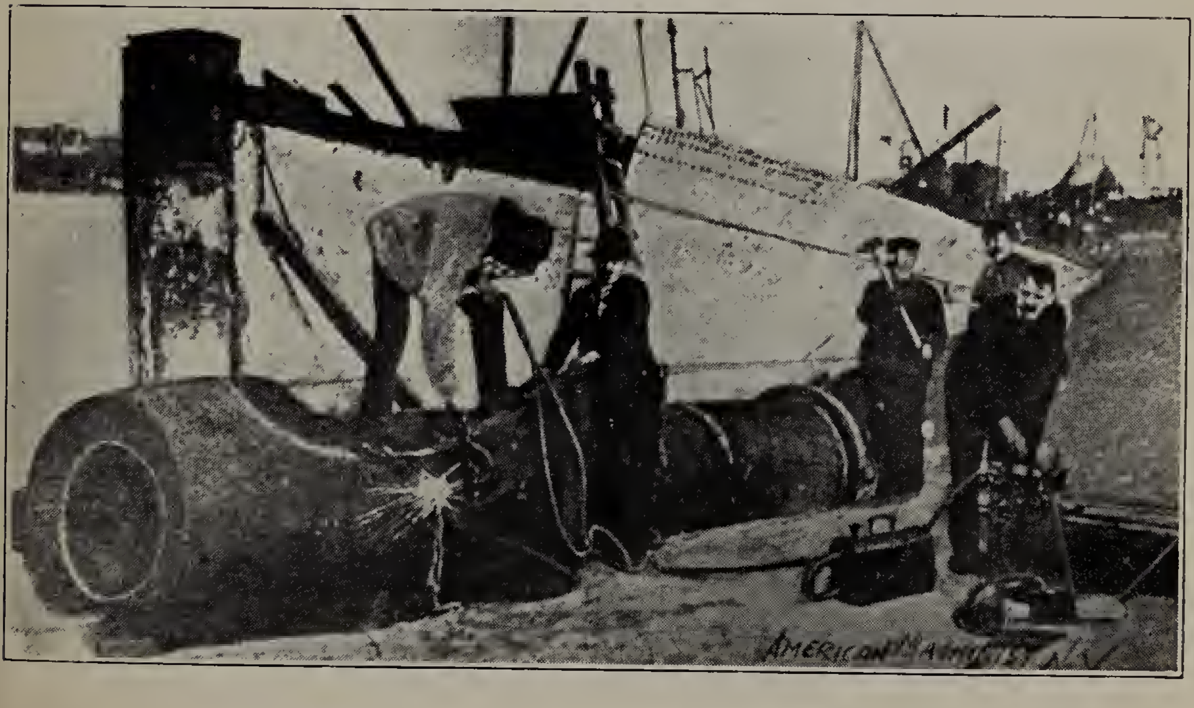


FIG. 6.—CUTTING CAST-STEEL FRAME FOR PROPELLER SHAFT

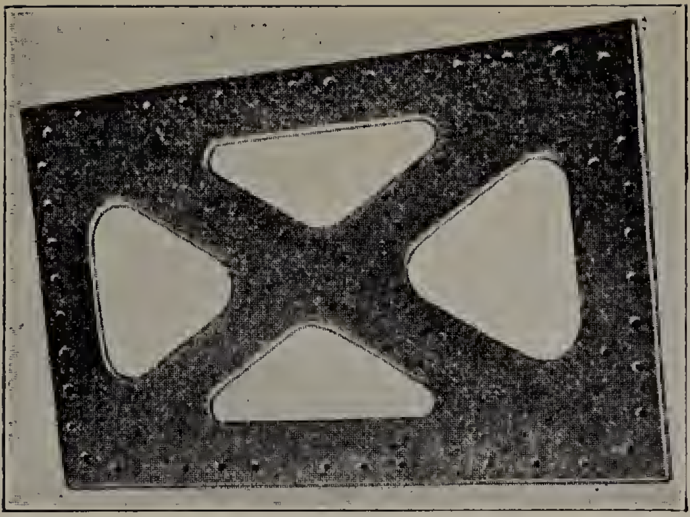


FIG. 7.—HOLES CUT IN PLATE 4 x 6 FEET, $\frac{9}{16}$ INCH THICK. CUT, 264 INCH. TIME, 1 HOUR

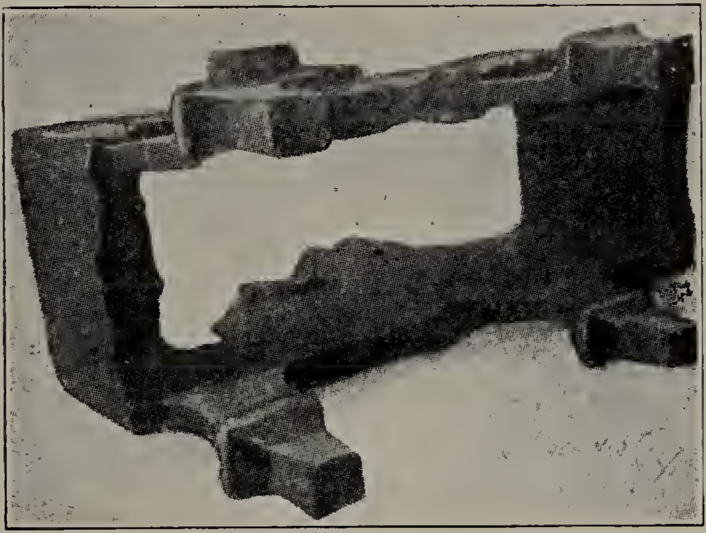


FIG. 8.—STEEL CASTING AS IT LEFT THE MOLD

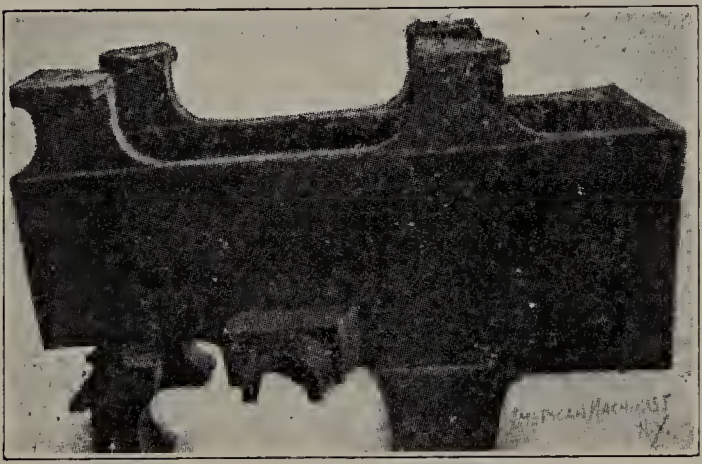


FIG. 9.—SAME CASTING AFTER CUTTING RISERS, SPRUES, ETC.

Fig. 10.—Welding Leaves and Petals on Blacksmith's Art Work

FIG. 11.—DAVIS-BOURNONVILLE PROCESS

A rush job. Corliss engine cylinder, weight, 3,800 lbs.; length, 5 ft.; height, 3 ft. 2 in., bore, 20 in. Breaks welded in one day. It would have taken three months to have obtained a new cylinder, and the expense of tying up the plant that long would have been great. Had been in use two months when the report was made on the job. (Davis-Bournonville Co.'s oxyacetylene process of cutting and welding.)

In welding, one part of oxygen to from four to six parts of hydrogen are used, and it is necessary to obtain a complete absorption of the oxygen, by the hydrogen in excess, in order to make a perfectly homogeneous flame. This was a difficult problem to solve as the fear of explosion long prevented the mixing of the two gases before their inflammation.

It was overcome by assuring to the mixture of the gases a velocity greater than the velocity of the propagation of the flame, as an explosive mixture contained in a tube does not ignite instantaneously in all of its mass when combustion is started at one end of the tube.

The ignition is propagated in the tube with a finite velocity which increases as the square of the section thereof. If, therefore, the gaseous mass moves toward the point of ignition with a speed greater than the speed of propagation, the flame will not reach the inside of the torch and much less that of the mixer.

Thus, having obtained a minimum for the speed to be given the gas, it is necessary not to exceed the maximum, and this is obtained by a practical consideration, namely, that the jet of gas leaving the torch must not be strong enough to set in motion the drops of the metal which are intended to constitute the weld.

In operation the two gases are carried from the steel bottles to the mixer where they are mixed as previously described from the cutting operation. From the mixer they are carried to the torch through a single tube and enter this where there is a sharp enlargement in its shape. This considerably diminishes the velocity of the gases, and from there they pass through a conical tube that is perfectly smooth on the inside. This tube gradually diminishes in size down to the nozzle, and the speed of the gases gradually increases again until the minimum speed required is obtained.

As a sample of some of the fine work which can be done by welding with the oxyhydric process, Fig. 10 shows an ar piece in which the leaves, petals, stems, and ribbon are worked out by a blacksmith with a hammer and anvil, and the whole was then welded together by welding the leaves and petals to the stem. Fig. 11 shows some difficult welding done in this country by the Davis-Bournonville oxy-acetylene process.

THE COMMERCIAL PRODUCTION OF OXYGEN[1]

BY ALFRED GRADENWITZ, Ph. D.

The European oxygen industry is passing through a period of most remarkable development. Oxygen factories are springing up everywhere to produce this valuable gas, which especially in metallurgy is now utilized for many purposes. This fact is due in a large part to the great improvements that have taken place during the last few years in the methods of liquefying air and separating it into its constituents, oxygen and nitrogen. The process due to Professor Linde, the celebrated scientist of Munich, Bavaria—which is based on the expansion of compressed air and the production of internal work during expansion through a constricted orifice—is fairly well known in this country. In order to obtain oxygen, Professor Linde liquefies completely some atmospheric air, so as to produce a liquid containing twenty-one per cent. of oxygen, which is then caused to flow down a rectifying column similar to those used in distilling alcohol or gasoline. In this column the liquid meets with oxygen vapors resulting from the liquid oxygen, which is vaporized by the latent heat of the air in course of liquefaction; in this way a pure commercial oxygen (ninety-six to ninety-eight per cent.) is eventually obtained, while the nitrogen produced at the same time still contains at least seven per cent. of oxygen, that is, one third of the oxygen of air.

Although giving better results, Claude's process is not perhaps so well known outside of the Continent because of its more recent origin. It is worked in France by L'Air

---

[1] Published in *Scientific American Supplement,* April 10, 1909.

Liquidé, Ltd., at Paris, Lyons, Marseilles, and in Belgium at Dugrée near Liège, while in October new works will be opened in Italy and Germany.

In the Claude process for the liquefaction of air, the expansion of compressed air with the production of recoverable external work is made use of, that is, expansion takes place on the piston of a reciprocating engine. Though this method, according to theory, gives far better yields than that of expansion through a valve, many scientists previous to Claude (such as Siemens, Solvay, Hampson) in vain endeavored to carry out the expansion of compressed air in an engine, and Linde even believed it to be utterly impossible.

There was, in fact, one great difficulty to be overcome in this connection, viz., the lubrication of an engine at such low temperatures that all lubricating substances would have become frozen. Claude succeeded in eliminating this difficulty by using light petroleum ethers, which at ordinary temperatures are not lubricants, but acquire lubricating properties as the temperature is getting very low. Claude's first successful experiments were officially announced to the French Academy in 1902 by the well-known physicist, Professor d'Arsonval.

In Claude's original machine (see Fig. 1) the compressed air was cooled in the inner tube of the exchanger *M*, in order then to be expanded in the engine, the liquefied portion being collected at the end of the expansion in the receptacle *R*, while the unliquefied portion was allowed to flow through the outer tube *B* of the exchanger *M*, thus cooling the incoming compressed air.

It is true that this original system failed to give really satisfactory results, because of the many difficulties arising from the liquefaction taking place in the cylinder itself; as moreover liquefaction is effected at —190° C. (—310° F.) at the end of expansion and under atmospheric pressure, the air in this condition, after traversing the exchanger, reaches the engine at about —135° C. (—211° F.),

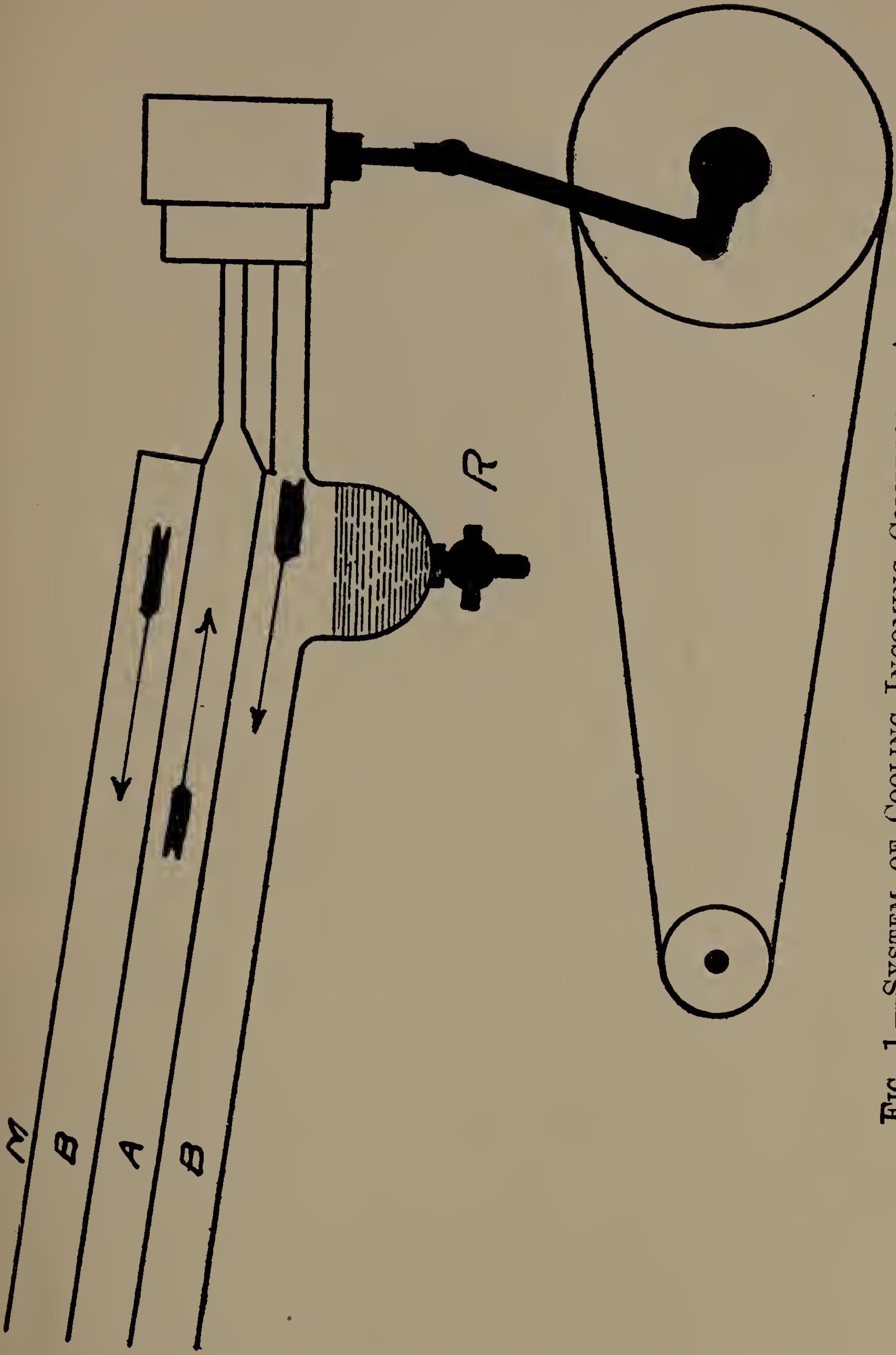


FIG. 1.—SYSTEM OF COOLING INCOMING COMPRESSED AIR

at which temperature it no longer obeys Boyle's law, but contracts much more than would correspond to the latter. A considerable excess of air should therefore be thrown into the engine, in order actually to produce an amount of cold as corresponding to theoretical calculation.

This drawback is greatly diminished by raising the initial temperature of expansion from —135° C. (—211° F.) to —100° C. (—148° F.); and in order to achieve this result, Claude interposes between the temperature exchanger and the expansion engine an apparatus *L*, called "liquefactor," (Fig 2), into which part of the compressed air is thrown after its passage through the exchanger.

The air in *L* being under a pressure of about 40 atmospheres will not liquefy as in Fig. 1 at —190° C. (—310° F.), but at —140° C. (—220° F.), which is the critical temperature of air. The air expanded in the engine accordingly is first heated in *L* up to —140° C. (—220° F.), before entering the exchanger *M*, instead of being at a temperature of —190° C. (—310° F.), as in the original apparatus. The air admitted into the engine thus is at a somewhat higher temperature. This liquefying process, which is called by the inventor "liquefaction under pressure," can yield one liter of liquid air for each horsepower hour.

This remarkable process seems to have been recently imitated by several constructors, such as, e. g., an engineer of the New England Refrigerating Company, of Norwich, Mr. Place, who in describing this process, states that:

"The cold exhaust air from the engine is carried over pipes containing air to be liquefied (in an opposite direction thereto) which is at a higher pressure of 600 pounds; this exhaust air is then carried back over the incoming compressed air being supplied to the engine, and cools that cold air. . . ." In fact, this process is identical with the one indicated by Claude in 1902.

In order then to separate the oxygen from the nitrogen, Claude uses a method based on the partial liquefaction of

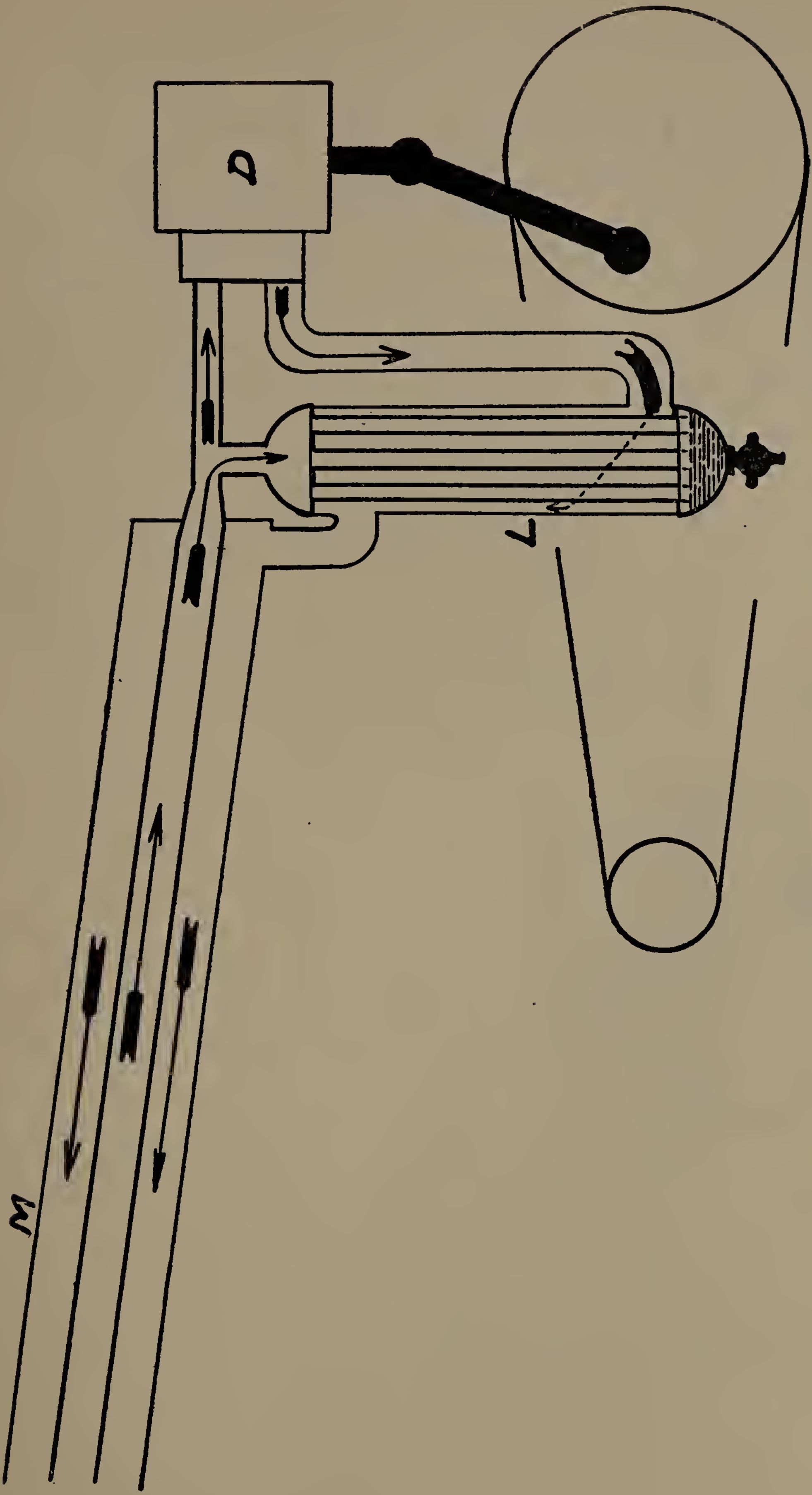


Fig. 2.—Process of Liquefaction Under Pressure

air. Although so competent an authority as Sir J. Dewar emphatically denied the possibility of partially liquefying air, maintaining that the oxygen would come down together with the whole of the nitrogen, Claude succeeded in experimentally demonstrating that his idea could very well be carried out in practice, a liquid rich in oxygen being at first given out from air. In Claude's process, this partial liquefaction is combined with what is called the "backward return" of the liquid portions, this additional factor being necessary to allow of a satisfactory separation of the air in course of liquefaction.

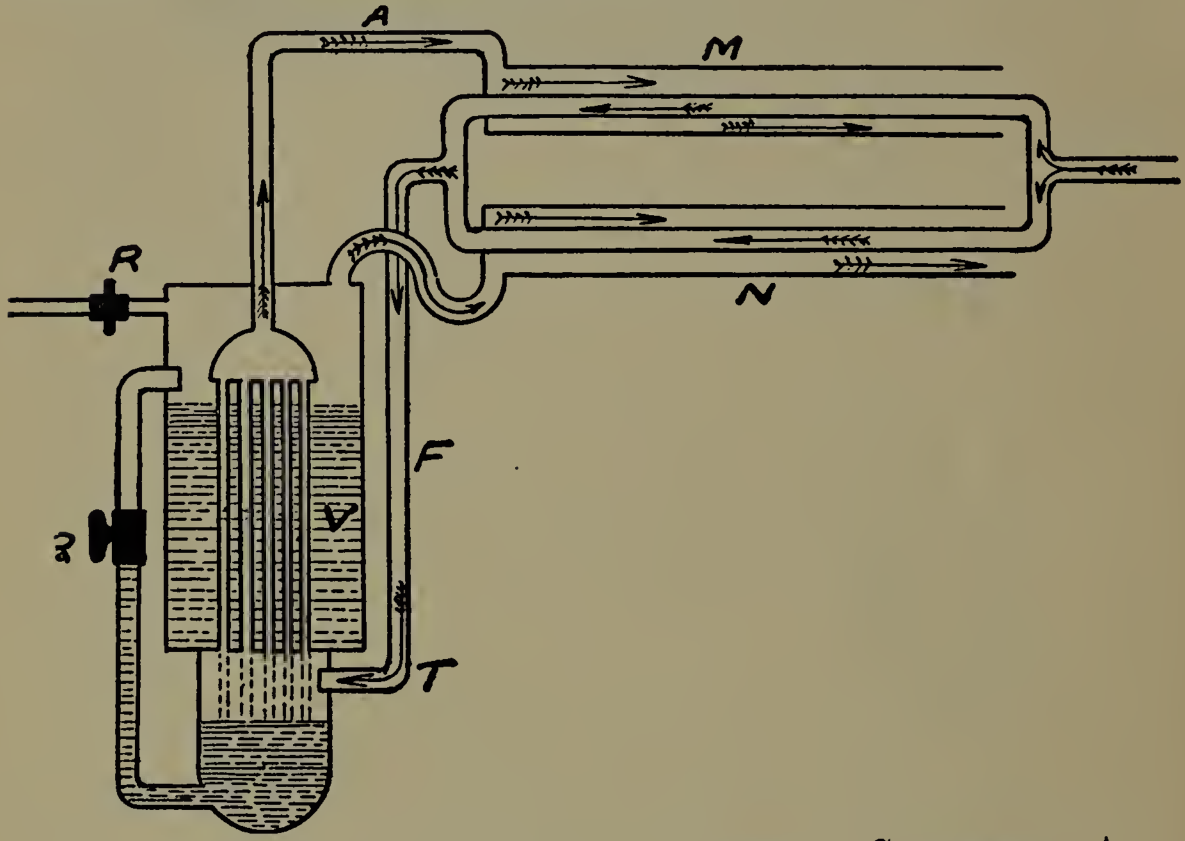


FIG. 3.—SYSTEM OF COOLING AND LIQUEFYING COMPRESSED AIR

In Fig. 3 the compressed air cooled in the exchangers *M* and *N*, after entering the apparatus in *T*, is liquefied gradually in the set of tubes *F* surrounded by liquid air, the first drops containing about 48 per cent. of oxygen.

While the remaining gas, which is a little poorer in oxygen than air, rises higher up in the tubes, a liquid comes off containing less than 48 per cent. of oxygen. However, as soon as some liquid is produced in the tubes, it, owing to its weight, returns backward in an opposite direction to the ascending gases and in contact with them, so that part of the oxygen of those gases is liquefied, replacing a corresponding amount of liquid nitrogen, which is vaporized.

The same process is repeated throughout the length of the tubes, and allows a liquid to be obtained holding forty-eight per cent. of oxygen and comprising the whole of the oxygen of the air, leaving on the other hand pure gaseous nitrogen.

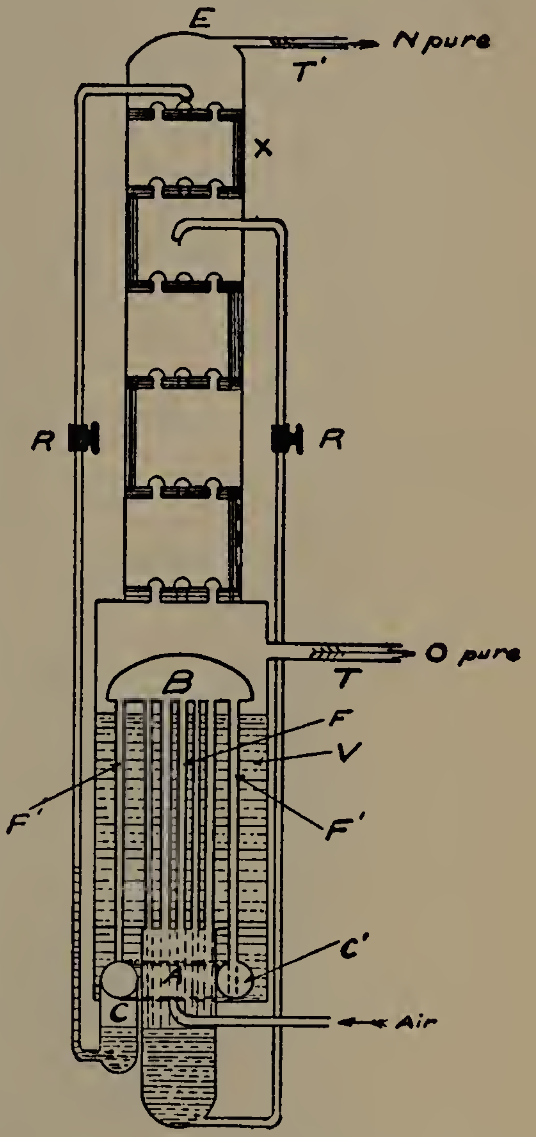


Fig. 4.—Apparatus for Separating Atmospheric Air into Pure Oxygen and Nitrogen

In spite of these remarkable results, the partial liquefaction conducted under the conditions described still proved inadequate for manufacturing pure oxygen. The latter was obtained only by combining the principle of liquefaction as above described with the rectifying process used for many years in the distilling industries.

Fig. 4 shows the apparatus constructed for this purpose. The cold compressed air at *A* enters the tubes *F*, and is partially liquefied in the latter. The liquid thus formed returns in an opposite direction to the ascending gases, and finally yields a liquid containing about forty-eight per cent. of oxygen, while pure gaseous nitrogen comes out at the top of the tubes *F*, in order then to be liquefied in the tubes *F'*. The liquid rich in oxygen collected at *C*, owing to its pressure, is poured out in the central part of the column, and rectifies the ascending gases up to a percentage of twenty-one per cent., while the liquid nitrogen collected at *C′* is poured out from the top of the column, and submits the gases at twenty-one per cent. to a further rectification.

After having been washed by pure liquid nitrogen, the gas finally becomes itself pure nitrogen gas, coming out of the apparatus at *E*.

The pure oxygen resulting from rectification at the bottom of the column is vaporized at *V*, the greater part of it entering the column of rectification, while the remainder comes out at *T* and is then collected.

By this means an integral separation of atmospheric air into its constituents, pure oxygen and pure nitrogen, is carried out.

Figure 5 illustrates a plant which is able to turn out each hour as much as 50 cubic meters (1,776 cubic feet) of oxygen.

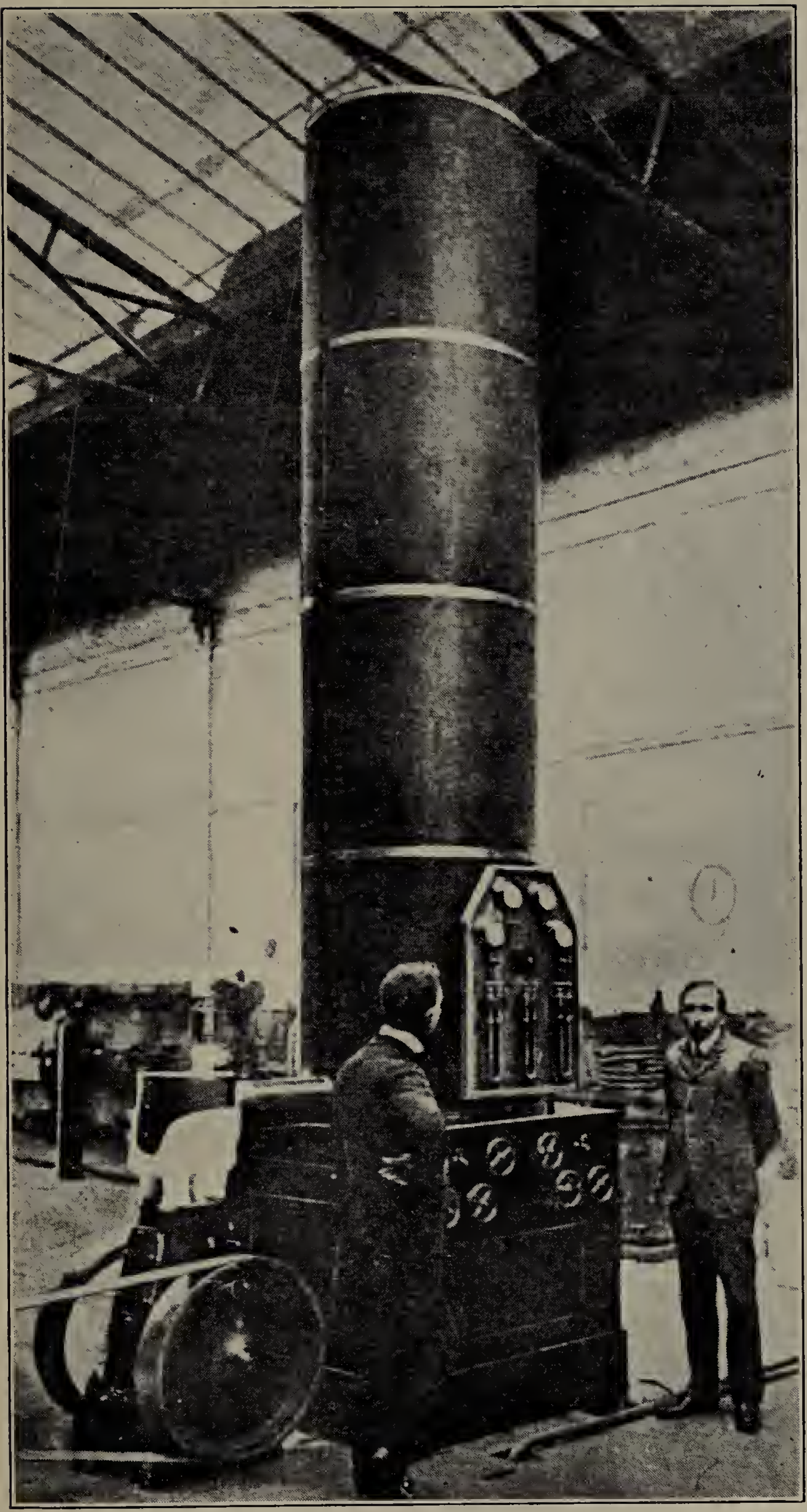


FIG. 5.—APPARATUS FOR THE PRODUCTION OF OXYGEN

WHY A FLAME EMITS LIGHT—THE DEVELOPMENT OF THE THEORY[1]

BY ROBERT MONTGOMERY BIRD, PH. D.

As one would naturally suppose, the theory now generally held regarding the nature of an ordinary flame and its power to emit light is not altogether the result of modern research, but one which has been evolved from very ancient and hazy notions. Naught else is to be expected when we consider the important place fire has held throughout the development of mankind. It is the first recorded object of his worship, and we have reason to believe that all architecture had its beginning in rude structures erected to protect the sacred fire. It is not the nature of man to see phenomena so striking as those which attend the consumption of matter by fire and not speculate upon them. But the centuries had multiplied and modern times had been reached before man's ideas regarding fire, flame and light became distinct, and the use of these terms differentiated. The best text-books and works on natural philosophy published near the end of the eighteenth century still used the terms with great looseness, and the conceptions of the material nature of flame and light were yet in their death struggles.

After the corpuscular theory of light had given place to the wave theory, conflicting ideas arose as to why and how a flame emits light waves. When it was agreed that the waves were sent out by solid particles of carbon heated to incandescence, the question of the origin of the carbon, or the chemical changes taking place in the flame, was discussed, and along with this the source of heat which renders it incandescent. The last and most generally accepted

---

[1] Published in *Popular Science Monthly*, 1903.

answer to these two questions—the origin of carbon particles and the source of heat—is given in the "acetylene theory," first advanced in 1892 by Professor Vivian B. Lewes, of England.

This theory expressed briefly is that a portion of the hydrocarbon gas, by the heat of combustion of another portion, is converted into acetylene, and that this on being decomposed by heat furnishes the carbon particles, which particles are rendered incandescent mainly by the heat liberated when the gas is decomposed; acetylene being a substance which absorbs heat during its formation and hence liberates heat when it breaks down. Whatever is burned, whether a solid candle or liquid oil, must pass through the gaseous state, and hence this applies to all flames used for lighting purposes.

But before explaining this theory more fully and seeing upon what experimental evidence it is based, it would be well to consider its genesis and briefly recall the ancient notions regarding "artificial" light.

Light was first confused with seeing, and it is said that up to the time of Aristotle men commonly thought they saw by reason of something shooting out from the eyes and coming in contact with objects; the converse of the Cartesian conception of many centuries later, that certain movements in bodies cause them to shoot out minute particles in all directions, which, striking the eye or causing "globules" of air to strike it, excite vision.

The fluid nature of fire and the corporeal nature of light, which were believed in throughout the early and middle ages, seem to have been first doubted by Sir Francis Bacon about the end of the sixteenth century, although he was by no means sure that these conceptions were wrong. Bacon classed together the light from flames, decayed wood, glowworms, silks, polished surfaces, etc., and said that inasmuch as some animals can see in the dark, air has some light of itself. Boerhaave, somewhat later, also expressed doubts as to the substantive nature of fire.

Among the first recorded experiments upon the nature and action of luminous flames are those which were carried out by Sir Robert Boyle between 1660 and 1670. He attempted to prove by experiment whether the light from a flame is like that from the sun, and whether it is corporeal or merely a quality. He allowed a flame to play on metals directly and also when in open and sealed vessels, and because the substance formed a calx and gained in weight, he thought that the light or flame (he uses the term indiscriminately) had combined with the metal, and hence it must be a fluid. Boyle also conducted a large number of experiments upon live or "quick" coals, phosphorescent bodies, animals and insects to see the effect of exhausting a receiver in which they were placed, and he seems to have concluded that the lights from live coals, rotten wood and putrefying fish differ not in kind but only in degree. He considered that the increase of light from coals, etc., and the reviving of certain insects when air was readmitted to the receiver indicated a relation between a visible flame and the so-called "vital flame." But he would not commit himself upon the question of the supposed kinship between the "flame" from live coals and rotten wood and the "vital flame" thought to be burning in the hearts of all living beings.

The interesting views of Sir Isaac Newton are set forth in a number of queries published in his work entitled *Optics*. As is well known, Newton believed in the material nature of light, and he asserted that the change of light into matter and of matter into light is an acknowledged possibility and of common occurrence. He attributed the light which appears when a body is rapidly and repeatedly struck or when heated beyond a certain point, as when flint and steel are struck together, etc., to vibrations of the parts of the body so rapid as to throw off the particles which, according to Newton's idea, occasion the sensation of light. With these he also classed electric sparks, saying that the "electric vapor" excited by rubbing glass dashes against a strip of paper or the end of the finger held to it, is thereby so agitated as to cause it to emit light. He thought the light from glowworms and putrefying matter was of the same kind as the above, and said that the light seen at night in the eyes of certain animals, cats for instance, is "due to vital motions."

Regarding true luminous flames Newton's ideas were nearer those of the present time. He wrote "Is not fire a body heated so hot as to emit light copiously? For what else is a red-hot iron than fire? And what else is a burning coal than red-hot wood?" "Is not flame a vapor, fume or exhalation heated red hot, that is, so hot as to shine? For bodies do not flame without emitting a copious fume, and this fume burns in the flame. Metals in fusion do not flame for want of a copious fume." "All fuming bodies, as oil, tallow, wax, wood, etc., by fuming waste and vanish into burning smoke." "Put out the flame and the smoke is visible, it often smells; and the nature of the smoke determines the color of the flame." "Smoke passing through flame cannot but grow red hot, and red-hot smoke can have no other appearance than that of flame."

During the hundred years, more or less, following the publication of Newton's views there was little change in the prevailing theories. Stahl said "flame is light" liberated from bodies in the act of combustion, and that light and heat are the constant attendants of fire; fire combined with combustible matter was "phlogiston." Scheele held, however, that light, heat and fire are combinations of air and "phlogiston." Lavoisier thought flame to be light disengaged from air, with which it had been in combination, and this idea seems to have been adopted by most of the French chemists.

There might be mentioned in this connection the queer ideas regarding our being able to see objects, and the emission of light by incombustible bodies, which were held during the latter half of the eighteenth century. As expressed by Macquer, and quoted by Fourcroy,[1] "The vibra-

[1] Fourcroy's *Chemistry*, press date 1796.

tions (under the impulse of more or less heat) dispose the particles (of bodies) in such a manner that their faces, acting like so many little mirrors, reflect upon our eyes the rays of light which are in the air by night as well as by day; for we are involved in darkness during the night for no other reason but because they are not then so directed as to face our organs of sight.''

At a single step we pass from the rather crude ideas of the older thinkers to those ideas which obtain at the present day, and the transition finds little expression in the literature.

About the year 1816 Sir Humphry Davy advanced what has been known ever since as the ''solid particle'' theory of luminosity; a theory which went unchallenged for forty-five years and was accepted by practically every one.

He was experimenting upon the combustion taking place in his famous safety lamp and said, ''I was led to imagine that the cause of the superiority of the light of a stream of coal gas might be owing to the decomposition of a part of the gas toward the interior of the flame, where the air is in smallest quantity, and the deposition of solid charcoal, which, first by its ignition and afterward by its combustion, increased to a high degree the intensity of the light; and a few experiments soon convinced me that this was the true solution of the problem.'' ''Whenever a flame is remarkably brilliant and dense, it may always be concluded that some solid matter is produced in it; on the contrary, whenever a flame is extremely feeble and transparent it may be inferred that no solid matter is formed.'' The idea that solid carbon in the flame is the source of its light was not original with Davy—he says it was suggested by a Mr. Hare—but it was Davy's investigations which put it on a firm basis and he formulated the theory.

Davy showed the relation between the heat and light of flames, the effects of rarefaction and compression of the surrounding air and the influence of cooling and heating. He pointed out also that a luminous flame will deposit carbon on a cold surface, and if rendered non-luminous no carbon can be obtained. These conclusions were immediately accepted and were not seriously disputed until the appearance in 1861 of a communication to the Royal Society from E. Frankland.

In this article Frankland advanced what has come to be known as the ''dense vapor'' theory. He and his adherents claimed that, although solid particles in a flame do cause it to emit light, the light from our ordinary illuminating flames is dependent to a great extent upon the presence of dense, transparent, hydrocarbon vapors from which it is radiated, and is not due to the presence of incandescent solid carbon particles. They further claimed that the soot deposited is not carbon, but a mixture of dense hydrocarbons of remarkably high boiling points.

Frankland was led to take up his investigations by seeing a report that candles burned at the same rate on the top of Mt. Blanc as in the valley at its foot, and a second report regarding the retardation of the bursting of shells with time fuses at high elevations in India.

Besides carrying on investigations in artificially rarefied air in his laboratory, he climbed to the top of Mt. Blanc with a goodly supply of standard candles and timed their slow wasting away; probably keeping warm in the meantime by the fire of his enthusiasm. Many interesting facts were brought to light by these investigations, but his use of them in interpreting the causes of luminosity in ordinary flames led him into error, and, although he found adherents at the time, his views have long since been replaced by those based upon more careful observation. The importance of the work of Frankland lay not so much in what he did as in what he led others to do; and since the publication of his views a great deal has been done by Heumann, Stein, Smithells, Burch, Lewes and others.

Stein disproved Frankland's assertion that soot is a mixture of dense hydrocarbons by showing that it cannot be volatilized even by great heat, and that it contains only about nine tenths of one per cent. of hydrogen, which can be separated from it only at high temperatures in an atmosphere of chlorine.

Nor did Frankland's view that glowing, dense vapors cause the light appeal to Heumann, who thought it unlikely that such dense vapors exist in a flame or that there is a sufficiently high temperature to cause them to glow. He knew, of course, that at a temperature like that of an electric arc many gases do glow and give continuous spectra, and that a highly heated gas under pressure acts likewise; but he argued that if carbon really does exist as such in a flame, it most probably is the source of luminosity. To prove its presence or absence he studied the effects upon a flame of heating and cooling it, of diluting and varying the temperature of the gases supplied to it, its transparency and the shadows cast by it, as well as other phenomena; and the results of his experiments led him to give unqualified support to the theory of Davy.

Some account of the salient features at least of Heumann's elaborate investigation must be given in order to convey any idea of his part in firmly fixing the "solid particle" theory. By allowing a luminous flame to play upon a surface which rapidly conducted heat away from it, like a platinum dish, its luminosity was destroyed. Heating the upper surface of the dish restored the luminosity, and hence Heumann concluded that cooling a flame diminishes its light-giving properties, while heating increases them. He varied the temperature of illuminating gas before it reached the burner and found that the same effects were produced. The heating in some cases increased the normal light-giving power as much as a hundred and twenty-five per cent. Further investigation showed that luminosity can also be diminished or destroyed by rapid oxidation of the hydrocarbons, as well as by diluting them with a neutral gas like nitrogen or carbon dioxide; the effect of dilution being to necessitate a higher temperature for luminosity. He next rendered a flame non-luminous by cooling, introduced chlorine into it to break down the hydrocarbons, and obtained a brilliant light. A porcelain rod introduced into the lower part of a flame cooled it and decreased its light, but collected no carbon, while, if introduced into the upper part, its *under side* became coated with soot. Heumann argued that if Frankland was right and the light is reflected from dense hydrocarbon vapors, these should be condensed on all sides of the rod at once in a quiet flame, while, as a matter of fact, soot was deposited only on the under side; and furthermore, soot can also be collected upon a surface too hot to condense hydrocarbons at all. He therefore concluded that the surface merely stops carbon which is formed lower down in the flame. If one luminous flame is allowed to play against another, the carbon is rolled up and can be seen as glowing particles in the outer non-luminous sheath.

Frankland had said that flames cannot contain solid particles because they are transparent. Heumann pointed out that thick flames are opaque and that thin ones are no more transparent than is an equal layer of soot rising from burning turpentine; the rapidity of the motion of the particles preventing any obstruction to the view, just as is the case with a rapidly revolving, spoked wheel.

Heumann next took up the phenomena of shadows and showed that the luminous portion casts a definite shadow when interposed between sunlight and a screen, and that the shadow is continuous for a luminous turpentine flame and the column of soot above it. And further, that a hydrogen flame which ordinarily casts no shadow and gives no light will cast a sharp shadow and emit a fairly bright light if passed through suspended lampblack or if it sweeps any solid matter into the flame. Luminous vapors do not cast shadows, absorption bands being very different from true shadows.

C. J. Burch found that when sunlight is reflected from a luminous flame it is polarized, while if reflected by glowing vapors, however dense, it does not exhibit this phenomenon. Sunlight which was reflected and refracted by luminous flames was found to exhibit phenomena identical with that reflected and refracted by non-luminous flames rendered luminous by the introduction of solid matter, and also with light reflected and refracted by very finely divided solid matter held in suspension in a liquid. The phenomena presented by like experiments with glowing vapors were totally different. All of Burch's work was confirmed by Stokes some years later.

There was now left no shadow of doubt about carbon being the source of the light rays, and the next question that concerned investigators was the chemical changes which give rise to carbon particles.

Sir Humphry Davy thought the separation of carbon to be due to a decomposition of the hydrocarbon compounds (of which all illuminants are composed) within the flame where the air is in smallest quantity, and no other cause was assigned by other investigators. Prior to 1861 the view, it seems, was that carbon is liberated because of a supposed greater affinity of oxygen for the hydrogen of the hydrocarbon than for the carbon, there not being enough for both. But these points had to be tested.

In the study of the chemical changes that take place, a flame burning at a circular orifice offered the best conditions. As explained in text-books of chemistry, such a flame may be thought of as being made up of an inner, faintly luminous cone fitting into an outer, brightly luminous one—as a finger fits into a glove finger—this latter being surrounded by a non-luminous sheath of water vapor and carbon dioxide. It was desirable to separate these two cones, in order to study the gas after it had left the inner cone and before any change had been brought about by the conditions existing in the outer cone. This separation was first accomplished by Techlu, in France, and Arthur Smithells, in England, working independently, with a piece of apparatus, the essential features of which are pictured in cross section in Fig. 1. By a proper control of the relative proportions of gas and air the inner cone was made to burn at the orifice *i*, while the outer cone burned at the orifice *o*. The outer cone got its oxygen from the surrounding air, while that for the lower flame was supplied along with the gas. The temperature of each cone was measured and the gases entering and leaving each were analyzed. It was found that as the proportion of gas to air was increased, the tip of the inner or lower cone became *brightly* luminous and a column of soot passed upward through the tube, becoming *faintly* luminous in the outer edge of the upper flame. As soon as the inner cone becomes luminous the unsaturated[1] hydrocarbon compound known as acetylene begins to appear among the gases passing to the outer cone.

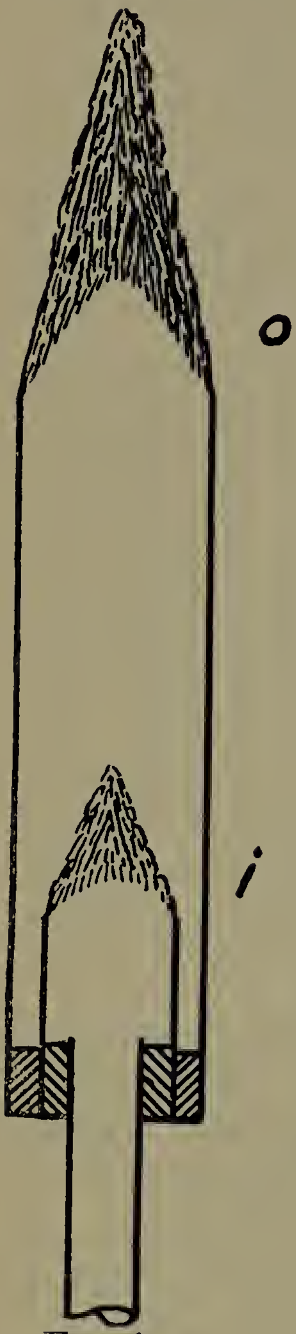


FIG. 1

Vivian B. Lewes now attacked the problem as to how carbon comes to be in the flame in the free state. He analyzed gas drawn from different parts of a coal gas flame, measured the temperature of its different parts, etc., publishing his results between 1892 and 1895. These results may be stated as follows: Coal gas consists mainly of a mixture of hydrogen and hydrocarbons, both saturated and unsaturated. In an ordinary "fishtail" burner flame all hydrogen is consumed before the middle of the luminous portion is reached. Of the *saturated* hydrocarbons about seventy-five per cent. disappears as such in the dark portion and about twenty-four per

---

[1] The terms "saturated" and "unsaturated" have reference, among other things, to the relative quantity of hydrogen to carbon in the molecule, an unsaturated compound having relatively less hydrogen than a saturated one.

cent. is lost in the lower half of the luminous part. In the dark part there occurs a transformation of saturated into unsaturated hydrocarbons, along with a general breaking down of all to yield products less rich in hydrogen and the oxides of carbon. At the point where luminosity just begins, seventy to eighty per cent. of the unsaturated compounds is acetylene, although less than one per cent. was originally present. No acetylene could be found in the flame when it was made non-luminous.

By causing pure gases to pass through tubes heated to known temperatures and analyzing the products formed, Lewes studied the effects of heat upon both saturated and unsaturated hydrocarbons. At 800° C. an unsaturated compound, like ethylene, C_2H_4, breaks down into hydrogen and the still more unsaturated acetylene, C_2H_2. At 1200° C. the very stable saturated hydrocarbons decompose into acetylene and hydrogen, and the acetylene in turn decomposes into carbon and hydrogen. Even very dense hydrocarbons decompose at 1200° C. These results strengthened Lewes' conviction that under the baking action of the flame walls in the lower portions acetylene is produced in relatively large quantities and that this is the source of the carbon.

The question which immediately presented itself was, Does there exist in an ordinary flame such conditions of temperature as may bring about the formation of acetylene from the very stable constituents of the illuminants? On measuring the temperatures at various places the necessary temperatures were found to exist.

The work was complete and conclusive and forced a general acceptance of the theory that acetylene is the immediate source of the carbon.

But a yet harder problem presented itself, What gives rise to heat sufficient to make the carbon become incandescent?—a burning question certainly and one not easy to answer.

From the time of Davy to the year 1892 the only opinion was that the burning hydrogen, carbon monoxide and hydrocarbons furnished the heat necessary to raise carbon to incandescence. In that year Lewes advanced his ''latent heat'' theory. This theory declared that the latent heat set free when acetylene is decomposed instantly heats the carbon particles thus set free to incandescence.

After showing that the heat of combustion of a flame is only sufficient to render carbon faintly luminous, Lewes compared the temperatures of flames burning coal gas, the unsaturated hydrocarbon gas, ethylene, and the still less saturated acetylene, and also the amount of light given by each when burning equal volumes of gas per hour from burners best suited to each. He likewise studied the temperatures developed when acetylene is exploded and the localization of the heat set free by its decomposition. His experiments were ingenious and convincing. By comparing ethylene, C_2H_4, with acetylene, C_2H_2 (where for equal consumption the same number of carbon atoms were present), and also with coal gas, it was seen that the luminous portion of the acetylene flame is not as hot as that of either ethylene or coal gas, while the illuminating powers of the flames were: acetylene, 240.0 candle power, ethylene, 65.5 c.p. and coal gas, 16.8 c.p. Evidently the heat of combustion does not account for the incandescence of the carbon; for if it did the cooler acetylene flame would give less light, while, as a matter of fact, it gives twice as much as the ethylene and about fourteen times as much light as the very much hotter coal gas flame. It was evident that our temperature measuring instruments do not detect the heat of the carbon particles themselves.

To see if luminosity be even partly due to the latent heat of acetylene, Lewes exploded that gas in a closed tube. This was done by wrapping a bit of fulminate of mercury in tissue paper and suspending it by copper wires joined by platinum in contact with the fulminate, and passing an electric current. There followed a brilliant flash of light and a complete decomposition of the gas, and of the eudiometer as well. Pieces of glass were coated with carbon, and the tissue paper was not scorched except in a small hole where the explosion of the fulminate had burst through. This experiment showed the formation of carbon, the emission of a brilliant light and the localization of the heat liberated. But as the decomposition in a flame can hardly be as rapid as in this experiment, and as hydrogen and oxygen also give a feeble light when exploded, he sought to detect the rise in temperature at the moment of decomposition when this is caused by heat. He arranged a thermo-couple in a small tube so that only the turn of wires was exposed, and after sweeping out the air passed a slow current of acetylene through the tube, the arrangement being as shown in Fig. 2. The heat was raised throughout the tube at a rate of about 10° C. per minute, and almost as soon as the temperature of area *a* passed 800° C. it took a sudden leap to 1000° C., the gas burst into a lurid flame and streams of carbon passed on through the tube. Although the temperature of area *b* was made considerably higher than *a* the carbon passing through it was not luminous. This experiment would seem to leave no doubt that the incandescence is caused by latent heat, yet further evidence was produced. In another experiment in which diluted acetylene was used it required a higher heat to cause the decomposition and luminosity. This latter is the condition existing in a flame, and the temperature there found is above that required. In other experi-

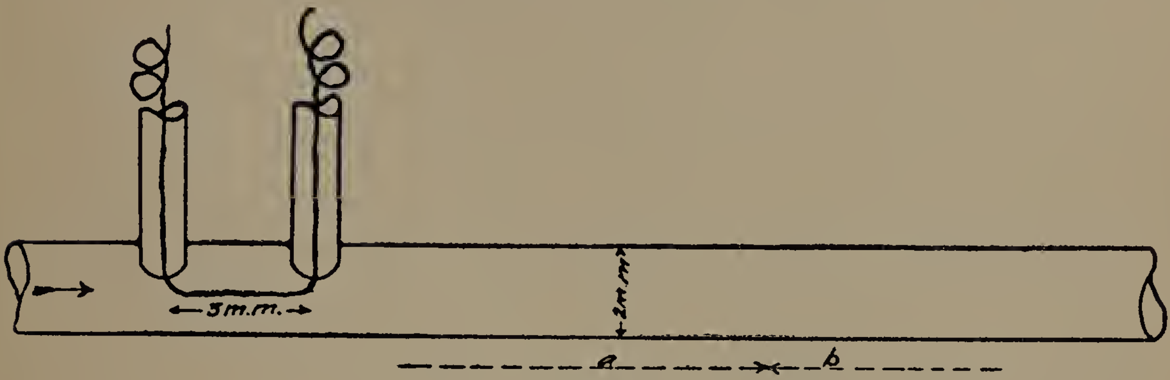


Fig. II

ments it was found that if the flame temperature were high enough the luminosity was directly proportional to the amount of acetylene in the flame *at the point where luminosity generally begins.* Acetylene was introduced at the corresponding place in a non-luminous flame through very fine holes in a small capillary platinum tube, and the rate of its flow, as well as that of the illuminating gas, was measured and controlled so as to have present the amount of acetylene, which analysis showed to exist in a similar luminous flame. At the holes there was an intense light, and dull red streams of carbon passed upward in the flame.

Lewes sums up his conclusions, drawn from all his work, about as follows: When the hydrocarbon gas leaves the jet at which it is burned, those portions which come in contact with the air are consumed and form a wall of flame, which surrounds the issuing gases. The unburnt gas in its passage through the lower heated area undergoes a number of chemical changes, brought about by the heat radiated from the flame walls; the principal change being the conversion of hydrocarbons into acetylene, hydrogen and methane. The temperature of the flame rapidly increases with the distance from the jet and reaches a point at which it is high enough to decompose acetylene into carbon and hydrogen with a rapidity almost that of an explosion. The latent heat so suddenly set free is localized by the proximity of carbon particles, which by absorbing it become incandescent and emit the larger part of the light given out by the flame; although the heat of combustion causes them to glow somewhat until they come into contact with oxygen and are consumed. This external heating gives rise to little of the light.

There have been opponents to this theory of the cause of luminosity—as there are, fortunately, of all theories—but the evidence is so strong and covers so many points, and so many investigators have confirmed one part or another of the work, that it has been generally accepted as a true statement of the facts with which it deals.

MARVELS OF A PLANT'S GROWTH, AND THE CHEMISTRY OF DECAY[1]

BY PROFESSOR VIVIAN B. LEWES

In the whole of Nature's wonder book there is nothing that appeals more to our sense of the marvelous than the way in which all the waste of animal and vegetable life is converted by decay into those simple compounds, carbon dioxide and water vapor, which are again used in the wonderful processes by which all forms of life are synthetically recreated.

It is the sun's rays which are the mainspring of this regeneration, and the growth of vegetation is the means by which it is brought about. All the ordinary forms of plant in which the green pigment known as "chlorophyl" is present, owe their growth to energy derived from the sun, under which the chlorophyl contained in the small glands of the plant absorbs carbon dioxide and water vapor from the atmosphere, while more moisture and traces of mineral salts are drawn in by the roots. Once absorbed the carbon dioxide and water vapor under the influence of the chlorophyl commence a marvelous series of changes, which result in the formation of the first visible product, the starch granules and also sugars, which afterward become practically the food of the plant, and are incorporated as the cellulose or woody fiber, of which the solid portion chiefly consists, the completed reaction being of some such nature as that expressed by the equation—

$$\left.\underset{6\,CO_2}{\text{Carbon dioxide}}+\underset{5\,H_2O}{\text{Water vapor}}\right\}+\text{Sun's energy}=\left\{\begin{array}{ll}\text{Cellu-} & \text{Oxy-}\\ \text{lose} & \text{gen}\\ C_6H_{10}\,O_5+ & 6O_2\end{array}\right.$$

And it is this oxygen so liberated in the early days of the

---

[1] *Journal of the Society of Arts,* abstracted in *Scientific American Supplement.*

world's creation which according to some theorists formed the atmosphere, and has since kept the oxygen present in it a practically constant quantity.

It must be borne in mind, however, that, although such an equation is capable of representing the sum of the actions taking place, yet it only in reality represents the first and final stages of a series of most wonderful and beautiful reactions, the exact course of which is but little understood. The fact that the sun's energy is necessary to bring about this reaction is made manifest by the growth of vegetation when kept from the light, when it merely gives rise to a few sickly and colorless shoots formed by the plant food already stored in the plant or seed, while on the other hand recent experiments have shown that ordinary vegetation can be accelerated in its growth by the illumination from certain forms of artificial light during the hours of darkness.

Probably the first attempt to use artificial light for hastening the growth of plants was made in 1861 by Hervé-Magnon, while twenty years later Siemens, by experimenting with an arc lamp of 1,400 candle power, placed ten feet from the plants, with a glass screen interposed, came to the conclusion that this illumination was capable of producing an effect equal to about half that of the sun. In more recent years various artificial lights have been employed for accelerating growth, and it has been found that nearly all plants, aided in their development by artificial light to which they are exposed during the usual hours of darkness, reached the flower and fruit bearing stage much earlier than with sunlight alone, some few, however, like the onion, declining to be hurried. That this growth and progress is not at the expense of root formation is abundantly proved in the case of such plants as radishes, in which not only was the top growth three times that of a similar plant growth in sunlight alone, but the root growth also amounted to two and a half times the normal in a given time.

From the exhaustive researches which have been made upon plant life, it seems fairly clear that the function of the chlorophyl in the growing plant is practically threefold. It has been shown that it is those rays in the immediate neighborhood of the red and orange in the spectrum which most keenly excite the assimilation of carbon dioxide and water vapor, and that the chloropyhl absorbs those rays which hinder the formation of carbohydrates, transforming rays of short wave lengths into those rays which most favorably effect the production of the sugars and starch, which are the food of the plant structure, and that it also acts by the conversion of light into heat.

The usual statement that the solid matter of the plant consists of cellulose is, of course, only an approximation to the truth, as cellulose is only one of several modifications produced by the actions taking place in the growth of the plant; but as from a calorific point of view the other organic bodies present have practically the same thermal value, it is a convenient simplification to take wood as being composed of cellulose, water, and the constituents of the sap, mineral salts and extractive matters, which may be resinous (as in coniferous woods), extractive (as in beech or birch) or tannin (as in oak).

The chemical actions which have resulted in the formation of the cellulose have required an expenditure of energy which, in the primary decomposition of the carbon dioxide and water vapor, can be expressed in terms of the heat necessary to raise a unit weight of water one degree.

As in the growth of the plant this energy has been derived from the sun, and has been partially rendered latent in the cellulose, when we burn that compound in the form of wood so as again to convert the carbon and hydrogen to carbon dioxide and water vapor, we once more set free the stored energy in the form of heat and can render it available for heating purposes or for doing work.

The variations in the physical properties of wood are dependent upon the constituents of the sap and the density with which the solid matter is packed away in the structure, and when the wood comes to be burnt its calorific value is found to vary slightly owing to these factors, and also to the amount of moisture which it contains; as upon the constituents of the sap will largely depend the amount of ash which is formed, and upon the moisture the amount of heat which will be rendered latent in the conversion of the water into steam. Moreover, in the formation of the cellulose oxygen equivalent in quantity to that which was originally in combination with the hydrogen will have been again taken into combination in the formation of the plant's structure, with the result that air-dried wood, when tested for its calorific value, is but a poor fuel.

The moisture present in a sample of wood will vary enormously with the time of year at which the tree has been cut down, and also with the nature of the tree, so that while as little as eighteen per cent. of moisture has been found in one kind of wood, it may exceed fifty per cent. in another, while, under the most favorable conditions, air drying will only reduce the moisture in wood to form eighteen to twenty per cent. It may, therefore, be roughly stated that at the best, wood will only contain eighty per cent. of combustible matter, while the large amount of heat absorbed in heating and evaporating the water present is a serious drawback to it as a fuel.

The combined oxygen also present in the cellulose, as has been before indicated, seriously detracts from its value, and where wood is the only fuel that can be employed, and great local heat is required, a fuel of practically double the value of wood can be obtained by its conversion into charcoal before use. Under the influence of destructive distillation the contained moisture and combined oxygen are driven forth as water vapor; and although four fifths of the weight of the wood is lost in the liquid and gaseous products escaping, yet the twenty per cent. of carbon that remains on burning is free from the drawback of having the intensity of the heat of combustion lowered by the rendering latent of heat, which, in the case of wood, was lost in vaporizing the water and bringing about the decomposition.

In the same way that human beings and animals of the present day are of a very different and higher type to those which first appeared on the earth's surface, so our plant life has undergone a great alteration in character, and as we trace by the light of geology the birth and growth of vegetation, we are led to the conclusion that as the earth cooled down, soil was first formed upon its rock surface by the disintegrating action of water containing carbon dioxide and by those processes to which we usually give the name of "weathering." Spores of the lower forms of plants, like lichens and mosses, then appeared, and in their growth fixed the carbon and hydrogen from the carbon dioxide and water vapor to the atmosphere. By their decomposition they supplied the soil, which up to that time had been of a purely mineral character, with the organic constituents necessary for the growth of vegetation of a higher order.

This next form of vegetation, urged on in its growth by the heat permeating from the cooling mass of the earth, and fed by the excess of carbon dioxide and moisture in the air and the virgin soil in which it grew, attained a rapidity and luxuriance of growth which probably has never been equaled. In type it consists chiefly of cryptogamic plants, such as club mosses, sedges, and other forms of marsh vegetation, which, however, instead of growing to a height of a few inches, attained enormous dimensions. Dying down year by year they formed a densely packed mass of vegetable matter, which undergoing the process of checked decomposition of the same character as can be recognized in the peat deposits of the present day, gradually built up those masses of semi-decomposed vegetable matter which were afterward converted by time, heat, and pressure into the coal seams.

The formation of peat is apparently due partly to fermentation when exposed in its wet state to air, and partly to checked decay when covered with water, and it is the latter process which is the most valuable in converting it into a form which is available for fuel.

When decomposing matter is freely exposed to moist air, processes of fermentation and still further oxidation convert it ultimately into carbon dioxide and water vapor, leaving as a residue only the mineral matters and more resistant hydrocarbons, the latter in turn also disappearing, and it is by such processes of decay that Nature cleanses the surface of the earth from all waste vegetable matter. When, however, the dead vegetation has its decay checked by immersion in water or the deposition over it of silt or soil of such a character as to cut off from it the supply of atmospheric oxygen, the processes of decay continue, but instead of exterior oxygen acting on the decomposing molecules, the changes that take place are restricted to those set up between the constituents of the molecule itself, and result in the elimination of carbon dioxide, water, and methane, with consequent lowering of the proportion of hydrogen and oxygen left in the residue.

Enormous areas of peat exist at the present day not only in the British Isles, but in even greater quantities in Russia, Sweden, Norway, Germany, and Finland, while in Canada and America the peat bogs are still more vast, and in the future this material will probably play an important part in the supply of fuel when the depletion of our coal supplies drives us to utilize these natural stores.

The great interest, however, attaching to peat at the present moment is that the same action which converts cellulose into peat will, if continued under conditions of considerable pressure and higher temperatures than ordinarily exist at the present day, convert the peat deposits into a coal seam.

Taking the luxuriant vegetation of the carboniferous era, it is easy to imagine the way in which the huge peat bogs were formed in the low-lying watersheds, and in which the agglomeration of vegetable matter swept down by the hurrying streams accumulated in the deltas of the prehistoric rivers, while the volcanic actions which marked this period would often cause so great an alteration in the earth level that the decomposing vegetable matter became subject to the inrush of water bearing with it huge quantities of mud and silt, which, depositing above the collected vegetation, gradually hardened there and formed the strata which we find above the coal.

Nor were these actions confined to that particular period to which we look back as the carboniferous age. We find that whenever the conditions were favorable for the deposition of great beds of vegetable matter, actions of a similar nature have led to its conversion into coal in strata of a more modern character, and the formation of coal appears to have been going on ever since the inception of vegetable life on the earth's surface, and there is no reason to doubt that the swamps and bogs of the sub-tropical forests of the present day are to a minor extent carrying on the early stages of the same action.

The chemical actions that took place during the period when the peat deposits, heated from below by the earth's temperature and pressed on by the superincumbent deposits above them, underwent those changes in composition which we now recognize in our coal, can be traced by analysis, and the following table indicates the way in which the gradual

THE CONVERSION OF WOODY FIBER TO COAL
(Butterfield)

	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Cellulose	44.4	6.2	49.4	....	....	....
Dry wood (average)	4.85	6.0	43.5	0.5	....	1.5
Dry peat	58.0	6.3	30.8	0.9	trace	4.0
Lignite	67.0	5.1	19.5	1.1	1.0	6.3
Coal	77.0	5.0	7.0	1.5	1.5	8.0
Anthracite	9.00	2.5	0.25	0.5	0.5	4.0

elimination of the hydrogen and oxygen altered the cellulose of the growing plant to the product of our coal seams.

This action is made even more manifest by calculating the analyses so that the carbon is kept as a fixed quantity, which brings into bold relief the gradual elimination of the other constituents of the cellulose.

THE CONVERSION OF WOODY FIBER TO COAL

(Percy)

	Carbon	Hydrogen	Oxygen
Wood	100	12.18	88.07
Peat	100	9.85	55.67
Lignite	100	8.37	42.42
Bituminous coal	100	6.12	21.23
Anthracite (Wales)	100	4.75	5.28
Anthracite (Penna.)	100	2.84	1.74
Graphite	100	0.00	0.00

These changes in composition may also be traced in the calorific value, and show the thermal advantages gained by the elimination of the oxygen during these processes of natural distillation.

	Calories	British Thermal Units
Wood	4,771	8,588
Peat (dry)	5,600	10,080
Lignite	7,000	12,600
Bituminous coal	8,446	15,203
Anthracite	8,677	15,618

It is not, however, time alone which causes alteration in the character of coal. The factors of temperature and pressure also play so important a part in its composition that it is unsafe to base any far-reaching ideas as to the age of a coal upon the amount of natural carbonization which it has undergone. One may look upon coal as consisting of a basis of carbon together with the mineral matters that were mostly present in the sap of the plant, and on the combustion of the coal will remain behind as ash, these forming the solid residue which is left on heating the coal out of contact with air. The portion which under these conditions escapes, and may therefore be termed the volatile matter, consists of various compounds of carbon and hydrogen and other more complex bodies containing not only these elements, but also the oxygen and nitrogen present in the coal.

The proportion of volatile matter present, consisting as it does largely of hydrocarbons, makes a wonderful difference in the way in which a coal burns, the presence of hydrogen and lower members of the hydrocarbon series giving the coal ease of ignition and the property of burning with flame, while the more complex hydrocarbons and organic bodies render the flame so produced heavy and smoky in its character. If a coal which contains a very small percentage of volatile matter, such as anthracite, be taken, it is found difficult to ignite and almost impossible to burn without specially arranged conditions of draft, while the more bituminous coals, such as cannel, can be ignited by the flame of a match, and will burn with the greatest ease.

With the increase in bituminous matter in the coal, the fixed carbon or coke left on distillation naturally decreases in quantity, and coals are generally classified on the basis of the amount of fixed carbon they contain, into lignites, cannels, bituminous coal, steam coal or semi-bituminous coal, and anthracite, the percentage of carbon varying from sixty-five per cent. in some lignites up to over ninety per cent. in the anthracites. The relation existing between the composition of the coal and its powers of smoke production is one that will have to be discussed again in considering the fitness of fuels for the class of work they have to perform.

Any form of bituminous coal when subjected to a raised temperature begins to yield products of a liquid and gaseous character; and if the temperature be kept at the lowest point at which any action can take place, the liquid distillates formed are of an oily character and not greatly dissimilar to some crude mineral oils. Indeed, it seems highly probable that when the coal has been formed under conditions where no escape of gaseous matter could take place owing to the impermeability of the low-lying strata, a natural distillation at very low temperature has gone on over long ages and some of the bituminous products of the decomposition distilling into the earthy strata next to the coal have formed with it the shales which differ from coal in that the fixed residue left on their distillation consists of earthy matter instead of coke. It is also perfectly well known that in some of the more extensive peat bogs a trickle of oil is occasionally found escaping from the decomposing mass, showing that even in the early stages of the action, oils are produced, while it was from a spring of oil in the shale measures of the Alfreton Colliery that Young first got the idea of utilizing shale for distillation as a source of mineral oil.

It has been known for centuries that in certain districts of America and Eastern Europe a scum of oil would frequently gather on the surface of the pools and streams, and these districts have since become famous as the great sources of American and Russian oil supply. Although many observers cling to the belief that the oil fields have been formed by animal or mineral agency, there seems but little reason to doubt that our liquid fuels, like the solid, are of vegetable origin, and are indeed by-products of great subterranean distillations, in which at high pressures and comparatively low temperatures the accumulated vegetation of past ages has been partly liquefied or even gasified, as the same areas which yield our stores of mineral oil are also famed for the production of natural gas.

The Pennsylvania oil fields of America yield crude oil consisting largely of members of that group of hydrocarbons which we know as the "saturated series," the lower and more simple members of which are gases, and with the fifth member commence to give highly volatile liquids yielding the pentane which we use for our standard of light, and the hexane and heptane known as "petrol" in England and "gasoline" in America, while higher members of the series constitute the burning, lubricating, and fuel oils which have played so important a part in the technical world during the past fifty years.

The Russian oils, on the other hand, contain hydrocarbons of a slightly different character, having as chief constituents "naphthenes," a group which, although in many properties similar to the saturated hydrocarbons, yet in composition must be ranked with the unsaturated. So laborious, however, is the separation of the hydrocarbons present in these great natural distillates, that our knowledge of their constituents is still far from perfect, and recent researches upon the tars obtained at low temperatures from coal show that they are characterized also by the presence of the naphthene group.

The valleys of the Alleghany, which gave so abundant a supply of oil to Drake and the pioneers of the oil industry in the early sixties, also yielded that great output of natural gas which concentrated the manufacturing activity of America to so large an extent in these districts. Although such gas is found in small quantities in many parts of the world, no output of the same magnitude has ever been discovered.

This gas, which is by far the most valuable of the gaseous fuels, is practically methane.

Weight for weight natural gas is the most valuable of all the fuels, having a calorific value of 12,008 calories (21,615 British thermal units), and its history affords a graphic object lesson of what within a hundred years will be our condition with regard to coal supply, the actions, however, having been concentrated into a period of not less than fifty years.

With the first discovery of natural gas waste of the grossest character took place, followed by a period in which, the value of the gas having been realized, it was consumed with the utmost prodigality, and no thought was ever given to the future. Then as reduced pressures in the supply began to give a warning note, economy at length began to be exercised, while now the rapidly decreasing supply threatens failure at an early period and has at length forced attention to every point at which economy can be obtained.

COAL: ITS COMPOSITION AND COMBUSTION[1]

GENERAL DISCUSSION OF THE ELEMENTS THAT PROMOTE COMBUSTION

BY WILLIAM H. BOOTH

It is usual to speak of heat under various names. It is thermometric, specific, or latent. By the first is meant that property of heat which sets up molecular vibrations in a substance, which are capable of transmission to surrounding bodies by radiation or by contact.

By specific heat we mean the amount of heat energy that is necessary to set up a certain degree of thermometric heat in a unit of mass of some body. The same addition of heat to a pound of lead that has made a pound of water comfortably warm would enable the lead to burn a hole through a man's hand.

By latent heat is understood heat that has become converted into energy of condition without thermometric manifestation, as when heat added to ice at thirty-two° F. enables that ice to exist as a free liquid and still only to affect the thermometer to thirty-two° F. Here, heat represents mobility of the molecules.

In a wide general sense every chemical reaction may be cited as a combustion. Certainly the converse is true—combustion is a chemical reaction. All substances are, in a broad sense, fuels. Many are difficult to ignite. Many have already entered into combustion or are results of chemical processes so energetic that it is difficult to establish any other reaction. Lime, for example, is the product

---

[1] Abstract of paper read before the Association of Engineers-in-Charge (England). From *Scientific American Supplement* No. 1729, February, 1909.

of a combination of the metal calcium with the gas oxygen, and the energy of union is so great that the metal calcium, though one of the most common of nature's so-called elements, is hardly known in nature except as an oxide or a carbonate.

Aluminium is a metal that unites so firmly with oxygen that it will usurp the place of iron in a mass of burned iron, and convert a mass of mill scale into pure iron by itself becoming an oxide. Hence the thermic process. The fuels that are commonly regarded as fuels are wood and coal and mineral oils. These are found free in nature, and are easily burned and give out considerable heat. Ages of experience have taught us that air is necessary to combustion. The fire of wood burns the better when the wind blows upon it. The wind we can feel, if we cannot see it. The effect is to blow away the CO_2 and leave the fuel freely exposed to fresh supplies of oxygen.

Carbon gas is ideal only. Carbon exists, as gas, in the electric arc at 3,600° C. When carbon is burned to monoxide, CO, there are set free 4,415 B.t.u. per pound. When this monoxide is burned to dioxide a further heat of 10,232 B.t.u. is set free. Why the difference? Physicists say that the first oxidation also generates at least 10,232 B.t.u. or 5,817 units more than is thermometrically discoverable. They say that the 5,817 units have become latent because the carbon which was solid is now gaseous in the CO. Therefore, the total heat of combustion of carbon gas, if carbon could be taken in its gaseous form, is $10,232 \times 2 = 20,464$ B.t.u. per pound.

Now, in CO_2 there are 12 parts of C. and 32 parts of O, or

$$C : O :: 3 : 8.$$

Then

$$20,464 \times 3/8 = 7,674$$

B.t.u. produced by the combustion of one pound of oxygen.

Now, for combustion with hydrogen: One pound of this gas gives 62,100 B.t.u. The ratio of the two elements H_2O is 1 : 8.

Now,

$$62,100 \times 1/8 = 7,763$$

B.t.u. This is almost exactly the heat developed when oxygen is destroyed by gaseous carbon.

In each case three volumes of gas become two volumes, so there is no difference due to a different degree of condensation. Let there be next taken the heat of combustion of a series of hydrocarbons: C_2H_2, C_2H_4, CH_4, C_2H_6 and C_6H_6. These are shown in the second column in B.t.u. per pound of the hydrocarbon.

$$\begin{array}{lllr}
 & \text{B.t.u.} & & \text{B.t.u.} \\
C_2H_2 = & 21{,}850 & \times\ 26/80 = & 7{,}003 \\
C_2H_4 = & 21{,}927 & \times\ 28/96 = & 6{,}395 \\
CH_4 = & 24{,}017 & \times\ 16/64 = & 6{,}003 \\
C_2H_6 = & 22{,}338 & \times\ 30/112 = & 5{,}983 \\
C_6H_6 = & 18{,}094 & \times\ 78/240 = & 5{,}880
\end{array}$$

for benzine vapor.

$$C_6H_6 = 17{,}930 \times 78/240 = 5{,}827$$

for benzine liquid.

In the third column is the ratio of the oxygen consumed, and in the fourth the heat units per pound of oxygen used. This table gives room for thought. It shows, in the first place, a gradually decreasing result in heat set free per pound of oxygen destroyed. Between C_2H_2 and C_6H_6 two hydrocarbons, with exactly the same proportions of carbon and hydrogen, using up exactly the same weight of oxygen per pound of each, there is a difference of heat set free of seventeen per cent. (nearly). Burned as vapor and burned as liquid, benzine, C_6H_6, gives a different amount of heat again. The figures become confusing when thus treated, and it is necessary to deal with them by the molecule, as they are treated by the chemist.

How coal is formed cannot be said with absolute certainty, but the probability is that the coal plants accumulated like the accumulation of the peat bogs and became buried in sand and gradually sank to a considerable depth in the earth. There under the influence of heat and pressure, the vegetable matter changed its nature. Its watery constituents were driven off and the remaining portions carbonized, and then were also set up those reactions that produced what we term the bituminous quality. There is no bitumen in coal, but what we mean by bituminous is known to all. Some coal was so much heated that its hydrocarbonaceous matter was driven off to be absorbed in other rocks, such as certain clay shales, or it escaped to the surface and was lost. Thus possibly the Welsh coal was formed with its short flaming qualities that earn for it the term "smokeless," because, though not smokeless in all circumstances, it can be burned without smoke if any simple precautions are taken. Exposed to still greater heat or pressure or both almost all the hydrogenous matter is driven off and the coal is converted into anthracite, a flinty hard variety of carbon.

If samples of coal be examined their composition cannot be regarded as so different as is their behavior. There is a substance found in parts of the West Indies which resembles anthracite in appearance, but it is plastic brittle. It is said not to contain more than one per cent. of hydrogen to ninety-nine of carbon. Yet this one per cent. entirely changes the nature of the carbon, producing a smoky fuel and the capacity of becoming soft with but a moderate heat. Ordinary bituminous coal contains very much more hydrogen but does not soften at the same low temperature, and when it is exposed to heat it softens in spots and gives off tar vapors. Nothing is known really of the chemical composition of coal. It can be found out easily and with close accuracy just how much hydrogen, how much carbon, oxygen or sulphur a piece of coal does contain, but how the atoms of these elements are joined together seems quite beyond finding out at the present time. Thus, if a piece of coal be exposed to distillation in a retort and the different things collected that are produced, there will be found tar, creosote, carbolic acid, cresylic acid, hydrogen, various light and heavy hydrocarbon gases, and so much water and ammonia. But it cannot be said these substances are present in the coal. They have simply been built up or broken down from the material of which coal is really formed, and, for anything known to the contrary, a piece of bituminous coal is homogeneous throughout in chemical composition and only splits up into many and various bodies when heated. It may be inferred that if the coal begins to split up as soon as heated so it will continue to split up as more heat is applied, the material splitting up more and more into lighter and heavier portions so that nothing but pitch remains in the still, and after a little further heating, even this is resolved into coke and vapor.

When coal is burned in a fire exposed to air, there is a perhaps more complicated set of reactions put into operation. These are operations both of distillation and combustion. An experiment first shown by Horace Allen was the sprinkling upon a red-hot plate of porcelain of some finely divided bituminous coal. At once vapor commences to be given off and a dark spot surrounds each bit of coal. The coal does not glow so long as the vapor is coming away from it. When the vapor ceases to escape the coal begins to get hot and the dark spots on the plate disappear. The coal now begins to glow, to sparkle; in fact, to oxidize and disappear.

Now, from this experiment much may be learned. First, that the primary effect of heating coal is to drive off its volatile portions. Actually, of course, heat renders the coal partly volatile and drives this part away. The vaporizing of this demands heat and the vapor renders so much heat latent that it dulls the surface of the plate. When this chilling effect is finished by the escape of all vapor, the remaining bit of coke gradually becomes hotter. But it does not oxidize brightly until it has attained a high temperature. These actions teach that coal upon a grate will be very seriously cooled if fresh coal is thrown upon it, and that the volatile matter must be thrown off any piece of coal before its carbon skeleton will begin to burn. In a thick bed of coked coal on a grate the chilling effect of fresh coal may not extend right down to the grate surface and the fuel next the grate will burn with the incoming air at the same time as the gas from the green coal burns on the surface. If the fuel bed is thin, the carbon dioxide first produced on the grate comes to the surface as dioxide, and hinders the combustion of the volatile matter. If the fuel be thick the dioxide may be converted into monoxide in its upward passage through the fuel, and this will again hinder the combustion of the volatiles. The final gaseous mixture above the fuel will be very complex, and usually it will be by no means very hot. Experience tells, as explained by Mr. Swinburne, that this mixed mass ought to be kept hot in a non-absorbent furnace until combustion is complete.

What now deserves attention is a simple means of examination of a fire with the object of ascertaining to what degree combustion has attained. This is blue glass of a deep tint. Blue glass will not permit the passage of light of a wave length greater than blue. It is because it will not permit this that it is blue. High-temperature radiation has the shortest wave length. Violet light has double the number of waves per inch that represent red light, and red light has millions of times the waves per inch as sound notes. Sound would become visible to a man moving fast enough toward its vibratory origin. Low-temperature flame is red, orange, yellow; blue is hot; violet is so potent that it brings about various chemical reactions, as in photography. A red-hot brick seen through blue glass becomes drab, and gives no illumination. A brilliantly incandescent brick lined furnace seen through blue glass appears of a light French gray, and is of illuminating quality.

Now, if a dull flaming fire be observed, such as is obtained if badly mixed gases rise directly upward from the fire to pass among cold tubes, there will be seen through blue glass no illumination above the fire beyond about six inches. The flames are resolved into dark streams of gas; no light comes from them. But if the interior of a furnace be observed when properly lined with brick, and with suitable direction of flow and air mixture, the whole will be illuminated. Streaks and splashes of dark gas will be seen coming forward over the fire, and these melt away as they travel, and burn and help to keep up the temperature. The dark streaks are simply gas not hot enough to give violet light. They are red or yellow flames of burning gas ready to produce smoke if sent upon cold surfaces. Kept off cold boiler plates, they complete their high temperature combinations, and may then be used for heating anything.

It is not that blue glass marks the state of combustion beyond which one must pass, but it seems certain that if a properly mixed gas attains this temperature before exposure to cold surfaces, it will be properly burned. It would be interesting to experiment with red, yellow, and green glass, so as to find how these help in analyzing the state of a fire. It is certain that if blue glass cuts the flame very short there is imperfect combustion.

Now I have not told you much about coal, for I know nothing myself of the way it is put together. All I can infer is that a very small amount of combined hydrogen will change the physical nature of much carbon. Analysis of coal seems to point to the presence of oxygen as the potent cause of so-called bituminosity. Knowledge of the phenomena of heat—such as latency—teaches that the fuel bed must be chilled when fresh coal is giving off vapor.

On the supposed atomic arrangement of hydrocarbon, speculation may be indulged in on the facts that hydrocarbon is first attacked by the oxygen, and that the carbon is set free by itself or in some different combination with hydrogen, and so readily condenses on the first cold surface. And so it is learned to mix atoms of oxygen in excess of what the hydrogen atoms will snatch up and to maintain everything hot until the carbon has had its chance to find its own atoms of oxygen. And as it may be inferred that a thick fuel bed implies shortness of oxygen above the fire—for the fire has perhaps been converted into a gas producer—so it may be learned not always to regulate combustion at the chimney damper, but to keep this open sufficiently to pull in all the air we need as a maximum above the fire, and to regulate the combustion by combined movements of the door grids and ashpit dampers.

Safety valves are locked up from tampering; why not also lock the chimney damper? It should be locked, for it is not fit to be used as a regulator of the combustion of bituminous coal, for this is a double process, the coal burning partially as solid fuel on the grate and partly as gas above the fire, and each operation requires separate and yet conjoint air regulation.

Ordinary coal has a calorific capacity of about 14,000 B.t.u. per pound. The volatile matters distilled from it have a capacity of 18,000 to 24,000 B.t.u. The extra 4,000 to 10,000 heat units they now possess are borrowed from the heat of combustion of the solid fuel on the grate, and when the green gas is wasted unburned it is carrying with it the latent heat of distillation. Assuming 20,000 as its average heat value and assuming one third of the coal to be volatile, the green gases carry off nearly half the heat value of the coal.

Though the molecular structure of coal may not be discoverable, there can be no doubt as to the results of the systems of combination ordinarily adopted. If fired on the coking system, the gas is driven off more or less steadily and continuously, and places less of a tax on the surface at any one moment in respect of maximum air supply above the fuel to burn the gas than is levied when fresh coal is spread heavily over a fire at more or less wide intervals of time.

In solid fuel the carbon has not changed its state, but any hydrogen has been somehow rendered solid by its combination with carbon.

The gaseous hydrocarbons become liquids when their molecular weight gets up to about seventy to eighty, and solids begin to appear when the molecular weight reaches 128 or 136.

The trouble with coal is that it is not simply a hydrocarbon of even unknown proportion, or a mixture of hydrocarbons. It contains oxygen built into its solid structure, and this oxygen is not necessarily there as water with some of the hydrogen as H_2O. But it is there, and it comes off in distillation, and forms that complex substance—tar. Tar contains phenols—carbolic acid, C_6H_5OH, is one of them—and there are phenols with eight and nine carbon atoms, and even ten.

It would fill this whole paper only to name the known carbon or organic compounds containing the three elements C, H and O variously hooked together. But with all the knowledge of the many substances given out from tar, it cannot be said they are present in coal in the form they take on. But the main facts of physics can be relied on. Heat is swallowed up when solids are liquefied or liquids gasified, and these are the things that happen to coal when burned. They retard its perfect combustion, and the engineer who can best fit practice to meet nature's laws on proper conditions will best utilize coal as regards economy and cleanliness. The knowledge of what happens thermochemically in the life history of the hydrocarbons furnishes ample explanation of the failure of ordinary methods of burning it without heat or temperature conservation. The behavior and properties of the gaseous hydrocarbons may be regarded as the gaps in the bounding walls of knowledge through which glimpses may be had sufficient to serve as the jumping-off points of the flying machines of speculative imagination; and after all it is imagination which differentiates the engineer from the mere mechanic. Armies are never likely to be conveyed by either balloon or flying machine, but both these frail craft may serve to point the way by which an army may best proceed. The mere speculative engineer will not perhaps carry out work so well as the constructional man who follows beaten paths, but his speculative habit of mind does enable him to point the way for others to follow.

THE COAL-TAR DYE INDUSTRY[1]

ITS WONDERFUL RISE AND ITS IMPORTANCE

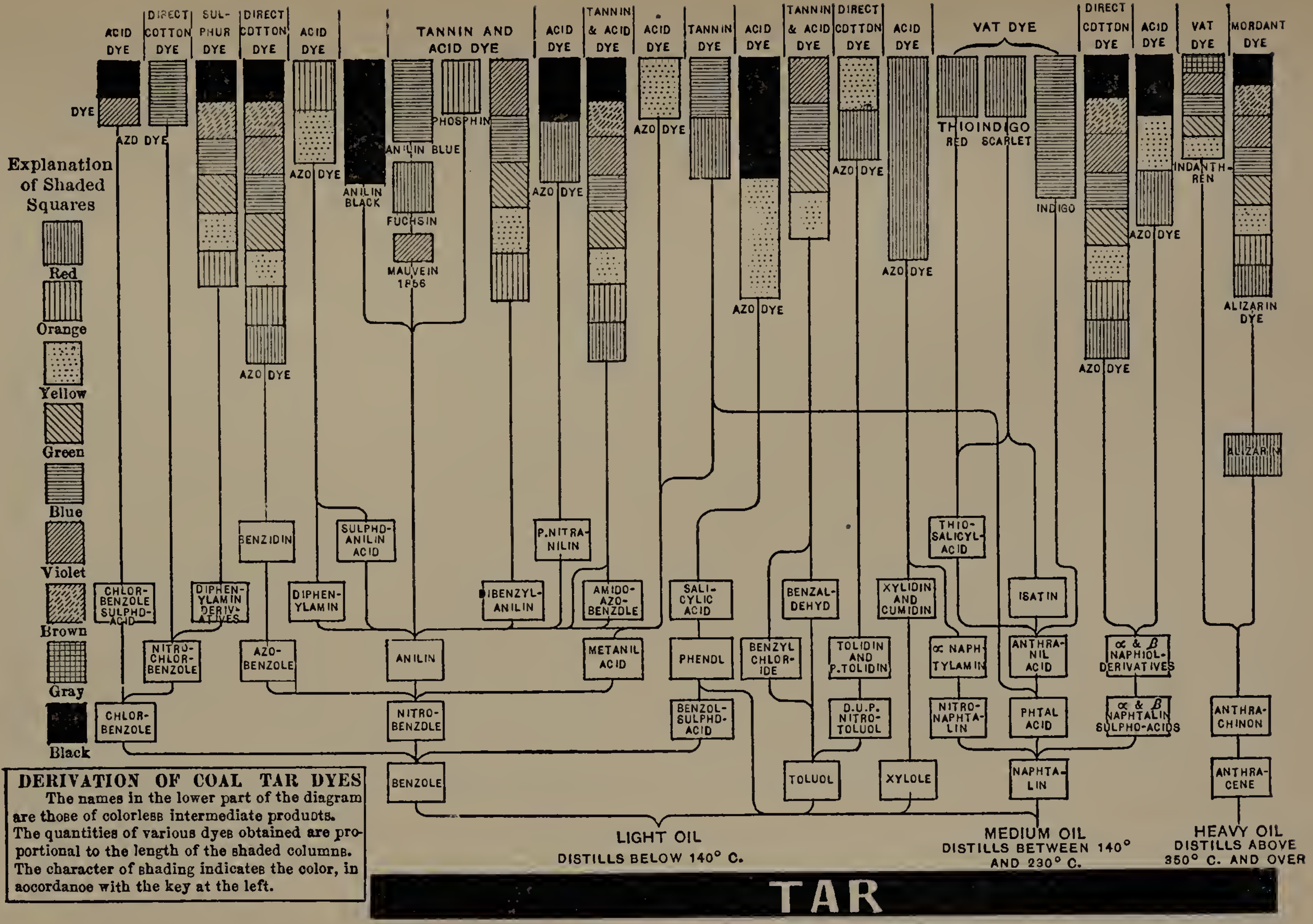
THE semi-centennial celebration, in 1906, of Perkin's discovery of the first of the aniline or coal-tar dyes passed almost unnoticed by the general public, and the term "coal-tar dyes" conveys very little meaning to the majority of people. Yet these dyes are applied to a great many objects that everybody sees and uses daily—fabrics and fibers of every kind used in the manufacture of clothing, ribbons, curtains, carpets, etc., matting, straw and felt hats, leather goods, and many other articles. Of all the great chemical establishments of Germany the largest are those which are devoted to the preparation of these dyes. One of these factories has a capital of $8,000,000 and a force of more than 6,000 workers, including 200 chemists.

The art of dyeing is 3,000 years old, but the ancient dyers had only a few colors: madder, saffron, and possibly orchil for red, indigo for blue, and saffron for yellow, in addition to the celebrated Tyrian purple. The last named was the secretion of a shell fish, the others were derived from plants, and all were furnished directly by nature.

The discovery of America brought new natural dyes—cochineal, logwood, Brazilwood, quercitron, and others—and the opening of the sea route to India made indigo less costly and also stimulated the cultivation of woad, a European plant furnishing a dye very like indigo. The dyes named above, with a few of mineral origin, constituted, down to the beginning of the nineteenth century, the entire resources of the dyer, with which he colored yarns by complicated processes and often with uncertain results.

---

[1] Published in *Kosmos;* translation published in *Scientific American Supplement,* June 12, 1909



DERIVATION OF COAL TAR DYES

The names in the lower part of the diagram are those of colorless intermediate products. The quantities of various dyes obtained are proportional to the length of the shaded columns. The character of shading indicates the color, in accordance with the key at the left.

DERIVATION OF COAL TAR DYES.

One of the first achievements of the nineteenth century, in the field of chemical technology, was the production of illuminating gas from coal. The dry distillation of bituminous coal yielded, in addition to gas, various tarry matters which were collectively named gas tar, or coal tar. This at first was a perfectly useless and annoying waste product.

In 1834 Runge obtained from coal tar, by distillation, a liquid of basic properties which he called cyanol. Before this, in 1826, Unverdorben had obtained by the dry distillation of indigo a basic liquid which he called crystallin, because it formed, with acids, crystallizable salts, and about the same time Zinin had obtained a basic liquid, which he called benzidam, by treating nitrobenzol with ammonium sulphate. Hofmann proved the identity of these three liquids. The substance is now called aniline, from *anil,* the Arabic name of indigo, and from it many of the coal-tar colors have been derived. The discoveries of Hofmann and Zinin made it possible to obtain aniline in large quantities. Coal tar contains aniline, but too little to pay for extracting. On the other hand, coal tar contains a large amount of benzol, which can easily be separated. By treatment with nitric acid, benzol can be converted into nitrobenzol, and from this aniline can be obtained by Zinin's process.

In 1856 William Henry Perkin, who was attending Hofmann's lectures at the Royal College of Chemistry in London, attempted to produce quinine by oxidizing aniline with potassium bichromate, and obtained a black precipitate. Others had done the same and gone no further, but Perkin found that the precipitate dissolved in alcohol, forming a violet solution, with which silk could be dyed. In the following year he started a factory for the production of the new dye, which was first called "Tyrian purple," and subsequently became known as mauve, aniline violet, or Perkin's violet. Aniline red, or fuchsine, was discovered also in 1856, by Nathanson, but its commercial production was first accomplished in France by Berguin.

The price of aniline, at first nearly three dollars per pound, was soon lowered by competition. It was treated with all sorts of reagents in the hope of producing new dyes. A mixture of aniline and fuchsine yielded aniline blue, and with the production of the first aniline yellow, called chrysaniline or phosphine, a feeble competition with vegetable dyes began.

Practice outran theory and produced dyes of which the chemical character and relations were little known. Again it was Hofmann who illuminated the darkness. He determined the chemical nature of fuchsine and discovered iodine violet and iodine green, which were at once manufactured and put on the market. They were made under pressure, often in old champagne bottles, which had a disagreeable habit of exploding, but possessed the advantage of cheapness.

These two new dyes were discovered, or rather invented, in accordance with scientific principles, and they proved that the chemistry of the coal-tar colors was being developed correctly. This development was further promoted by Kekulé's ingenious theory of the structure of the aromatic hydrocarbons which solved the intricate problems of isomerism.

Kekulé's pupil, Bayer, was one of the first to apply this theory to the coal-tar colors, and after seventeen years' labor he achieved one of the greatest triumphs of chemistry, the synthesis of indigo.

Meanwhile Graebe and Liebermann had taken up the study of anthracene, also a constituent of coal tar. After proving that anthracene can be obtained from alizarine, the red coloring matter of the madder root, they endeavored to reverse the process, and make alizarine from anthracene. They succeeded, and so did Perkin, in the same year, 1869. The German chemists applied for an English patent one day earlier than their English rival, and so the English market was secured for German artificial alizarine. Now began the first serious competition between a natural and an artificial dyestuff. The latter won, for a root yielding one or two per cent. impure coloring matter and requiring valuable land for its cultivation could not long compete with factories producing the pure dyestuff from coal tar.

In dyeing with most of the colors so far mentioned the yarn must first be impregnated with a substance, called a mordant, which has the power to fix the color. Different dyes require different mordants. Dyes which are fixed by compounds of alumina or chromium are called, simply, mordant dyes. Tannin dyes are those which require the application of tannin as a mordant. After a time the chemists succeeded in producing dyes which color wool and silk without the use of any mordant. As these dyes were obtained by treating tannin dyes with sulphuric acid, and are used in a slightly acid solution, they are called acid dyes. In this class belong the azo dyes, the manufacture of which, commenced about 1875, has developed amazingly. They are now the most important of all dyes and have been the most formidable competitors of cochineal and dyewoods.

In 1884 appeared the first direct cotton dye; that is, a dye which colors vegetable as well as animal fibers, without mordanting. Many such dyes were soon produced and were eagerly adopted by dyers, as they saved both time and money. They were not as fast as the mordant dyes, but this defect was remedied toward the end of the century by the production of the sulphur dyes, which also require no mordant on either vegetable or animal fibers and yet leave little to be desired in point of permanence.

Some of the direct cotton dyes can be changed in color, after application, by treating the dyed goods with certain reagents. Thus blue can be changed to black, and yellow to bright red, and the new colors are more permanent than the originals. This suggested the production of colors within the fibers, by the reaction of two colorless substances. Many shades are now produced in this way. They are called ice colors because the goods are usually cooled with ice during the operation. The process is cheap, as the expense of heating the vats with steam, which is necessary with most other dyes, is saved. It is also very rapid and the colors are very permanent.

Quite recently Professor Friedlander of Vienna has produced an indigo red, which contains sulphur and is therefore called thio-indigo. In its permanence, which greatly surpasses that of indigo blue, as well as in its shade, the new dye resembles the celebrated Tyrian purple of antiquity.

Now let us glance at the magnitude and importance of the coal-tar dye industry. The first benefit it brought was the utilization of coal tar, which cheapened the production of gas and made it possible to establish gas works in small towns. The second benefit was the scientific development of the arts of dyeing and calico printing which had previously been conducted empirically and handed down from father to son. The chemists who produced the new dyes also extended their field of application and invented new methods of treating cotton, linen, silk, wool, felt, jute, furs, leather, paper, feathers, straw, tinsel, wood, and other materials. The consequence was a greatly improved market for dyed and printed goods of all sorts, and for textile fabrics in general. Improved printing machinery, capable of printing from six to twelve colors, instead of two or three, was invented. The production of the new dyes in very large quantities involved the treatment of immense amounts of raw material and necessitated the invention of machinery for crushing, disintegrating, mixing, and heating. Some of the materials are heated in iron or steel shells, called digesters or autoclaves, strong enough to withstand a pressure of fifty or one hundred atmospheres. Centrifugal machines and huge filter presses are employed to separate the dyes in solid form. In the manufacture of the azo dyes large quantities of ice are used, and ice-making machinery is included in the plant. All these things benefit the steel producer, the machine builder, and the mechanical engineer, while the manufacturing chemist derives benefit from the demand for nitric, sulphuric, and hydrochloric acids, soda, dextrine, and other substances consumed in vast quantities in the manufacture and application of dyes.

In Germany the development of the coal-tar dye industry has brought another and more general benefit, for it was the principal cause of the establishment of the imperial patent office, in 1877.

Allied to the production of dyes is that of remedies, germicides, explosives, perfumes, photographic developers, and many other valuable substances from coal tar. This industry has attained gigantic proportions. A few of its most valuable and extensively used products are carbolic and salicylic acids, saccharin, antipyrine, and other febrifuges, artificial vanilla and artificial musk.

The coal-tar dye industry has conferred a benefit of incalculable value upon bacteriology and upon all mankind by furnishing dyes which, when applied to microscopic preparations, make it possible to distinguish and recognize the germs of typhoid, cholera, tuberculosis, and other diseases.

The first aniline dye was produced in England, but the manufacture of the coal-tar colors has been developed chiefly in Germany, where it may be regarded as a national industry.

NATURAL AND ARTIFICIAL PERFUMES[1]

BY DR. MAX HEIM

Scarcely any natural sensation strikes deeper into man's elemental being than the perception of the fragrance of flowers, and from primeval times and in all lands he has cherished the art of conserving their too fleeting perfume and adding its grace to his environment. Starting in Egypt this art spread to the sunny land of Greece, and from there reached Italy, where, at the time of the first emperors, it was practised to such an immoderate extent that Vespasian, that wise observer of men, found occasion for the saying: *"Mulieres bene olent, si nihil olent"*—"Women smell good when they smell of nothing."

But, like many other wise men before and after him, Vespasian was not in accordance with general opinion; and from the Middle Ages until the present time perfumes have enjoyed constant favor with the fair sex. Although they are no longer employed upon the individual person in such extravagant quantities as in earlier times, their use has become more general, and their manufacture has become an important industry of to-day.

If we inquire into the principles of the production of these perfumes, we find that we have to-day, in many respects, the same path to follow which was trodden ages ago. Aside from the use of fragrant flowers, leaves, and especially balsams and resins, simply dried, as perfuming agents—as in the case of incense—the process was soon reached of impregnating with the fresh flowers of fragrant plants some liquid which absorbed and kept the perfume.

---

[1] Published in *Prometheus,* translation in *Scientific American Supplement,* September 17, 1904.

Certain fats and oils were soon recognized as the best mediums for this, and such were specially prepared—we might almost say made aseptic—by the Greek physician Dioscorides, under Nero, through boiling with water, salt and wine. If freshly-dried flowers are immersed in a fat or oil thus purified, and slightly warm, and if they are replaced after a few hours by new ones, and this process repeated several times, there is obtained in the first case a product resembling a salve or a pomade, and in the second an oil, which retains the perfume of the flowers in greater or less degree, according to the quantity employed, but always in perfect naturalness and purity.

This old method, with some improvements, is employed at the present time to a very large extent, especially in the south of France, in the neighborhood of Cannes, Grasse and Nice. The most delicate perfumes, such as those of the jasmine, the violet, the tube rose and the orange blossom, are thus fixed, and sent in enormous quantities to all parts of the world in the form of pomades or oils. In the latter case the ancient method of production is indicated by the designation *huiles antiques.*

Although the natural fragrance is most perfectly reproduced in these products, their form is not suitable for all purposes. The favorite form of flower odors is that of the volatile "perfumery," so called, with which garments, handkerchiefs, gloves, etc., can be moistened, which would of course be impossible with the oils and pomades. This perfumery, technically called "extracts" or "spirits," results from a simple process of shaking the pomades and *huiles antiques* with pure alcohol, which does not dissolve fats or fixed oils, but upon continued and intimate contact absorbs the incorporated fragrance and becomes entirely saturated with it. The alcohol is mechanically separated from the oil by filtration, and a double product is obtained—an alcoholic, perfectly volatile and pure "extract" and a residue of weak but pleasantly fragrant and utilizable fat or oil.

The above described method of immersing flowers in fatty substances is called ‘‘maceration’’; it is the most primitive and without doubt the most ancient process, but it has many disadvantages, among which may be reckoned first of all the loss of the oil adhering to the flowers. Efforts have constantly been made, therefore, to replace this method by a more perfect one. In the so-called ‘‘enfleurage’’ the flowers do not come into direct contact with the liquid or solid fat; frames covered with gauze are placed above one another in cupboards which admit of being closed, and upon these frames are placed alternately a stratum of purified and pulverized fat and a layer of flowers. By means of a current of air, the perfume of the flowers is conveyed to the fat, and after repeated renewals there is obtained a pomade of a strong and natural flower odor, which can be treated with alcohol to make extracts.

This method not only has many technical advantages, but it permits first of all a more complete utilization of the odorous plants. Since the flowers do not come into contact with the fat, they exhale their fragrance as long as they have any vitality, that is, the fragrant secretions are continued for a time after separation from the stem, and by the ‘‘enfleurage’’ process can be brought into effect. Accurate analytical tests have of late led to the belief that seven times as much of the odorous substance of jasmine can be obtained in this way as by direct extraction with liquid fat which quickly destroys the vital functions of the plant.

In spite of this, the extraction of the odorous elements is still an important process, especially in cases where they exist in tangible quantities, and also where they are to be obtained from dried portions of plants, from seeds or roots, instead of from the plant in bloom. The best of results have been reached here by the use of volatile extracting agents, such as petroleum ether and benzin. With suitable extracting apparatus, the solutions, through evaporation of the dissolving agent, yield the less volatile odorous substances in the form of a thin or thick liquid, sometimes even of the consistency of a salve, mostly colorless or pale in color. These substances are generally called essential or volatile oils. They all have the property of being entirely volatile with steam, and for this reason they are easily separated from other substances. The plants are put into stills filled with water, and steam is forced through in such a way that, after it has heated plants and liquid to the boiling point, it can escape into a cooled receiver, where it is condensed. It has by degrees taken from the plants all their essential oil, and carries it with itself into the receiver, where it collects in drops upon the surface of the condensed liquid. From large quantities of the distillate these drops can be gathered together and separated from the liquid by pouring off or skimming.

This method has likewise been long in use in various parts of the world; it is practised in some places in a very primitive form, and has made possible the production of a great number of fragrant volatile oils.

The very costly oil, or attar, of roses, is manufactured in Persia, and now especially in Bulgaria. On the island of Luzon, in the Philippines, and in Java is produced from the blossoms of a tree belonging to the family of Anonaceae—*Cananga odorata*—the no less exquisitely fragrant oil of ylang-ylang, called in Java, oil of cananga. In France neroli oil, an important constituent of eau-de-cologne, is obtained from orange blossoms—to say nothing of the numerous oils, less costly, but still valuable, employed in the greatest quantities in the manufacture of perfumery, soaps and cordials, as, for example, rose-geranium, peppermint, lavender, etc.

The volatile oils produced by either method are characterized, as has already been remarked, by fixed properties, especially by their individual and very strong odor, which to a certain degree can at once be distinguished from any other.

In spite of this they are very far from representing uniform chemical substances; each, rather, is a mixture of several different substances, some one of which, for the most part, is the real odorous principle, and therefore the only valuable one.

The technical production of volatile oils having become a great industry of modern times—pursued with especial zeal in Germany—the chemists are making more and more strenuous efforts to reach an understanding of the intimate composition of these substances and of odorous substances in general; and chemical science has attained in this field the most notable and brilliant results. In this matter technics and science have been obliged, as so often before, to go hand in hand. The great firm of Schimmel & Co., for example, of Leipsic, manufacturers of volatile oils, have had most of their products subjected to the most exact scientific investigations, and in many cases light has been thrown thereby upon obscure and complex points of composition.

Not a few chemists of repute have devoted all their energies to this interesting field; a prominent pathfinder, whose efforts were attended by unusual results, was the late Professor Ferdinand Tiemann, of the University of Berlin, who had most admirable and astonishing success with syntheses of two of the most valuable perfumes, vanilla and violet.

Looking at the results of these investigations, as far as it is possible to do so within the limits of our article, we shall see that in the examination of single natural perfumes they were quite simple and comprehensible. Liebig and Wohler, in their fundamental labors, had already recognized the oil of bitter almonds as the aldehyde of benzoic acid, and this was not only confirmed later by synthetic methods, but the *benzaldehyde* soon became a subject of technical synthesis. The aldehyde of cinnamic acid was found to be the principal constituent of the spicy Ceylon cinnamon and cassia oil; and the methyl-ester of salicylic acid almost the sole constituent of the fragrant oil of the American wintergreen (*Gaultheria procumbens*).

The artificial production of such substances was early undertaken, and has tended to increase their use by making prices lower. A number of perfumes which very perfectly reproduce the odors of various fruits are called fruit-ethers, and their composition has been known for a considerable length of time. They are compounds—esters, so called—of alcohols, such as ethyl-alcohol, butyl-alcohol and amyl-alcohol, with acetic, butyric and valerianic acids; and they are extensively used in the manufacture of fruit beverages and confectionery for the imitation of all possible fruit aromas.

Researches into the nature of these few comparatively simple substances comprised at first the whole of our chemical knowledge of the subject, and it was a long time before further information was gained in regard to the complex odorous elements. It seemed at first as if a hydrocarbon, $C_{10} H_{16}$, were a common and characteristic constituent of a large proportion of the essential oils; but it was soon discovered that this substance, isolated from the different oils, showed, with the same composition in point of percentage, entirely different physical properties, and above all things did not determine their odor. The essential and very important practical question of the characteristic odorous principle of each volatile oil was thus little advanced and was the chief point of interest in all researches. The investigators were led in the main to observe the oils of similar odor in groups, and to look for them according to their common constituents. For example, the costly oil of roses, valued sometimes at one thousand marks and more per kilo, is unmistakably similar in odor to a very inexpensive oil obtained from a species of East Indian grass, *Andropogon schoenanthus,* and also to geranium oils distilled from different species of Pelargonium, in Spain and North Africa, particularly at Reunion. This resemblance was well enough known to the old

Oriental producers of oil of roses, and was probably of less interest to them from a scientific standpoint than on account of the opportunity thus offered of adulterating the costly liquid, a practice always willingly and extensively followed.

As a matter of fact, there has been very recently produced from all these oils a common, nearly if not quite identical, substance, called by different investigators geraniol, rhodinol, or reuniol; and chemists are inclined to regard it as the essential odorous principle of oil of roses. It is not yet equal in abundance and character to the oil of roses, but it is believed that only a few trifling additions are needed to make it so. The very latest researches claim the discovery of the required substances in the so-called phenyl-ethyl-alcohol, and in the aldehyde of nonylic and decylic acids, and there is already upon the market an artificial oil of roses, prepared according to these formulae.

Similar perhaps, even finer, results, had before been reached in the production—or, more correctly speaking, imitation—of another costly perfume, the oil of jasmine. It was proved that this oil, obtainable from the blossoms in very small quantities, consists essentially of the familiar benzyl-alcohol and an acetate of benzyl, which, in an undiluted state, has a very strong flower fragrance; together with two or three per cent. of a substance, discovered indeed some time ago, but not sufficiently regarded in point of odorous properties. The latter, which can be produced in beautiful white crystals by the combination of methyl-alcohol (wood spirits) with anthranilic or ortho-amido-benzoic acid, has so distinct and intense a fragrance of orange blossoms that with its aid an artificial orange blossom oil has been manufactured which is almost equal to the very valuable natural product, and seems qualified to enter into strong competition with it.

With the above-described substances it was evidently a matter of copying, so to speak, a complex perfume by a compound of already known odorous substances; and although this was in a certain degree successful in the case of jasmine oil, neroli oil, and even oil of roses, yet in none of these cases was the real odor-bearer detected and named with certainty. There was only a combination of several substances, which, with manifold variations of their compound perfume, imitated more or less perfectly the fragrance of the orange blossom, the rose and the jasmine. But Ferdinand Tiemann had already succeeded in producing, by pure scientific synthesis, the first characteristic precious perfume, the substance whose delicate lustrous crystal needles cover the pods of the vanilla bean, and give it the delicious fragrance especially esteemed by northern nations. This was recognized as the methyl-ether of the aldehyde of protocatechu, and Tiemann produced it (an enigma to the unscientific mind) from the sap or pitch of our native pine. It was very soon employed technically. In regard to the value of such substances, it is interesting to know that this, on its appearance in commerce, was sold for not less than six thousand marks per kilo. The price long remained quite high, but advancing technics soon learned to replace the first method of its production by a cheaper one, which is always the case when the composition and decompositions of a chemical substance have once been accurately learned and studied in all their bearings. To-day vanillin is exclusively manufactured from eugenol, abundantly present in the inexpensive oil of cloves and chemically related to it. To the sorrow of all manufacturers and patentees, the price has gone down from six thousand marks per kilo to sixty in a few years. A hundred times as much can thus be had for the same money as in the first years of its production, and the use of vanilla for perfumes, foods and beverages is practicable to a degree formerly impossible. Similar changes have taken place in the prices of other perfumes which science has made accessible, as, for example, piperonal, or heliotropin, the odorous principle of heliotrope, which resembles vanilla, and is related to it in chemical composition. Other examples of such technical achievements are coumarin, which perfectly reproduces the odor of the fragrant herb called woodruff (Waldmeister) and lends its characteristic aroma to many a spicy brew, and terpineol, obtained from ordinary turpentine oil, which has an extremely strong odor of lilacs, and is an indispensable adjunct to all modern lilac perfumes; to say nothing of the cheaper and more ordinary perfumes, such as safrol, nitrobenzol, etc.

To name all would lead us too far; but we must not leave unmentioned one discovery, that of the artificial violet perfume, the last important work of Tiemann. Starting from the analyses of orris-root, the rhizoma of a species of lily, *Iris florentina,* in which he suspected the existence of the genuine aroma of violets, he succeeded through his wonderful gift of combination in condensing with acetone the so-called citral contained in lemon-rind and some other volatile oils, and obtained a substance which he called pseudo-ionon. Under the action of dilute sulphuric acid this is changed to the real ionon, which, in a thousand-fold dilution with pure alcohol, exhales a delicious and natural fragrance of violets, and is the foundation of the favorite violet perfumes, whose use has been so widely extended since the discovery.

Our subject would now be nearly exhausted but for one remarkable substance, which must not be forgotten, artificial musk. Baur, its fortunate discoverer, found, about fifteen years ago, that if toluol and butylic chloride are combined according to the well-known chemical method of Friedel and Craffts, and the resulting oil treated with highly-concentrated nitric acid, the so-called "trinitro-butyl-toluol" is obtained in pretty crystals, which have an odor of musk wonderful in quantity and intensity. When we remember that the natural musk—a secretion of an animal of the deer family, native to the interior of Asia—is a very costly and extensively used substance, sold for more than three thousand marks per kilo, we shall become conscious of the economic bearings of this and analogous discoveries. Scientifically considered, the manufacture of artificial musk does not stand upon the same plane as the synthetic construction of vanillin, coumarin, or ionon. With these substances the chemist has succeeded in discovering, by dint of laborious researches, their correct composition, and has then reproduced the natural product in a more advantageous way. Perfumes, on the other hand, like mirbane oil or artificial musk are simply imitations of the corresponding natural substances, and chemically unrelated to them.

SCIENTIFIC DEVELOPMENTS IN THE GLASS INDUSTRY[1]

BY DR. R. SCHALLER

THE manufacture of glass involves first the chemical process of producing glass from the proper raw materials, and secondly the mechanical art of fashioning the molten glass into the multitude of articles for which the market calls. The mechanical aspect of the industry was early developed to a high state of perfection. It is only within comparatively recent times, on the other hand, that the chemistry of glass making has been worked out with scientific method. The need for such a development first made itself felt with special force in connection with the manufacture of optical instruments, and it is largely this circumstance which caused the famous Jena Glass Works to undertake the systematic study of the physical and chemical properties of glass.

The influence of the composition of glass on its properties is best brought out by a graphic representation. Thus in Fig. 1, distances measured off to the right, along the axis of the abscissae, represent the composition of a soda glass, while the corresponding ordinates represent temperatures. The curve drawn out in a full line shows the upper limiting temperature of devitrification. This means that a soda glass of a given composition remains glassy provided it is not cooled below that point on the curve, which corresponds to the particular composition of the glass. Thus for example a glass containing about 75 per cent. of silica (SiO_2) and 25 per cent. of soda (Na_2O) can be cooled to

---

[1] Abstracted from a paper read before the Verein deutscher Chemiker at Frankfort, a. M. From *Scientific American Supplement* No. 1797, June, 1910.

nearly 700° C. without devitrifying. The significance of this curve is obvious when we consider that in working the glass it must be brought down to a temperature at which it possesses a sufficient degree of tenacity. The dotted line on Fig. 1 indicates points of equal tenacity. It will be seen that at temperatures corresponding to this particular tenacity, glasses of certain compositions are below the temperature required to keep them from devitrifying. They cannot therefore safely be cooled down to this degree of tenacity. Others, in a small region extending about from seventy-one to seventy-six per cent. SiO_2, are above that temperature, and will therefore remain glassy if cooled till they have the tenacity corresponding to the dotted line.

The pure soda glasses cannot be used for the general purposes to which "glass" is put, as they are water-soluble. The second diagram shows some of the properties of a lime-soda glass, such as we have for example in window glass. In this diagram the ordinates represent the proportion of soda (Na_2O), and the abscissae proportion of lime (CaO). It is understood throughout that the proportion of silica (SiO_2) is 100. The lines drawn out in full are lines of equal stability, the numerals 2, 3, 5 representing increasing degrees of instability. The dotted lines correspond to equal temperatures of devitrification. The compositions suitable for window glass are those comprised within the field bounded below by one of these dotted lines, and above by one of the full lines. For if we step outside this region, either the temperature of devitrification is too high, so that the glass cannot be cooled down to a working temperature, or else the glass is too unstable.

In addition to lime and soda, many glasses contain also alumina or boron trioxide. The effect of these constituents is to increase the stability of the glass. In the case of alumina this is probably due to the formation of double silicates of the type of feldspar. The beneficial influence of the boric oxide is probably due to another cause: this body functions as an acid, setting free silica.

As has already been pointed out, the physical and chemical investigations at the Jena Glass Works were in the first place aimed chiefly for the production of new optical glasses. All the glasses known in the earlier days were

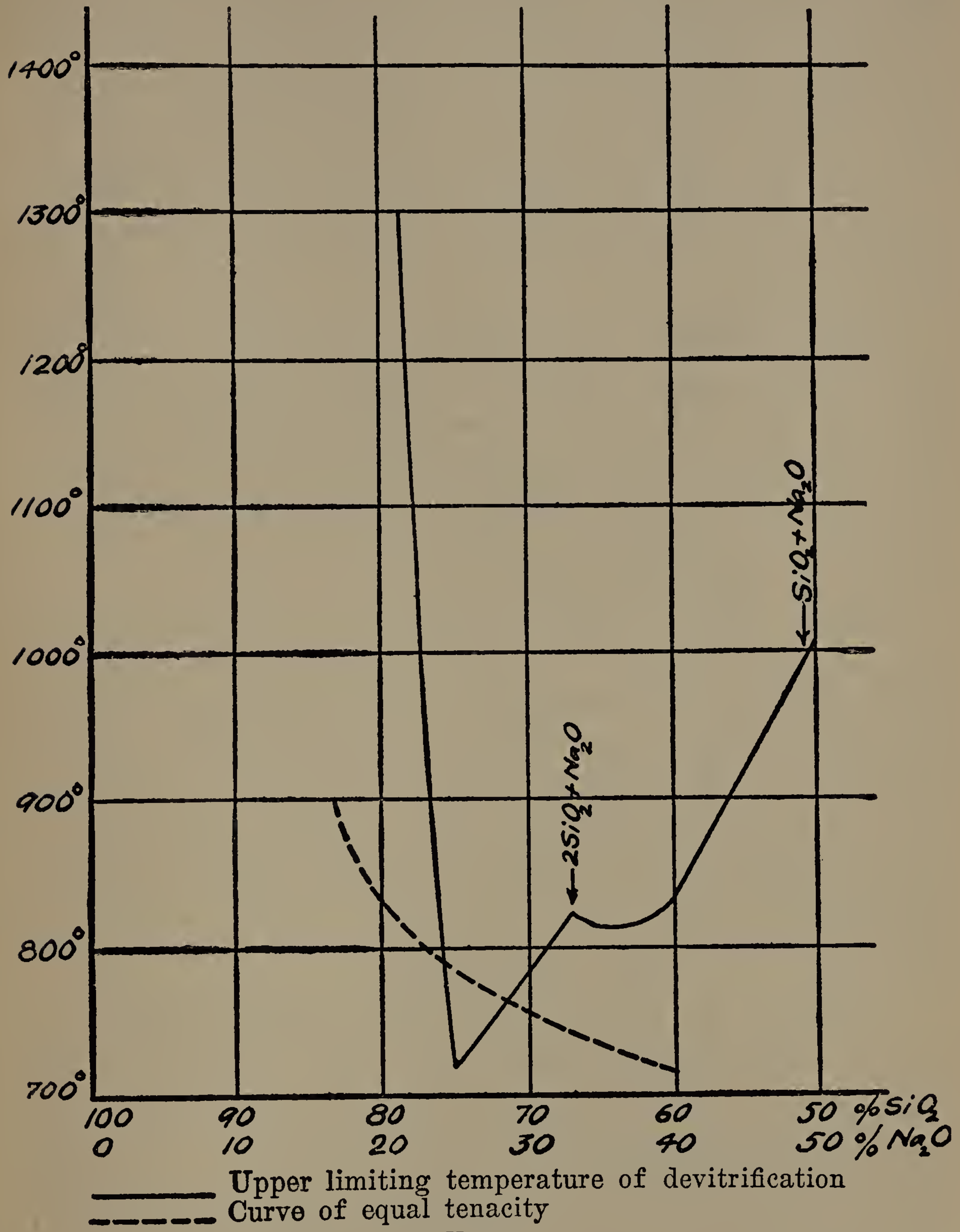


FIG. 1

somewhat similar in their optical properties. That is to say, while their refractive index and dispersive power varied within certain limits, they ran parallel throughout, so that if the known glasses were arranged in order of increasing refractive index, this would at the same time place them in the order of their dispersive powers. Glasses were needed which should not conform to this order, and it was found that especially barium and zinc possessed in a high degree the property of imparting to glass a high refractive index, accompanied by a comparatively low dispersive power.

Another problem was to prepare crown and flint glass which would give as nearly as possible similarly proportioned spectra. The flint glasses then known gave a spectrum which was much more drawn out in the blue than that produced by crown glass. The remedy was found in the addition of boric oxide, which foreshortens the blue end of the flint-glass spectrum.

Another class of optical glasses are the colored glasses. The principal problem in the preparation of these is to produce as nearly as possible ideal color filters. Such a glass must absorb as completely as possible some particular portion of the spectrum, while transmitting the remainder. The materials added to give the requisite color are the oxides, sulphides and selenides of certain metals, or in certain cases the metal itself in a highly divided state. The color imparted by such additions depends in part on the composition of the glass in which they are dissolved.

A problem of the same character is the preparation of glasses which transmit very short wave lengths of light. It is well known that quartz and boric acid have the property of being transparent to ultra-violet rays. The presence of metallic oxides more or less completely destroys this property, the extent to which this takes place depending on the nature of the metal, thus sodium has a stronger effect than potassium, while lead glasses are particularly opaque to short wave lengths. However, by carefully observing certain precautions, it is possible to prepare silicate glasses of much greater transparency to ultra-violet light than common glass. A special product of this character made by the Jena works and marketed under the name of "uviol glass" has found application especially in astro-photography and in the manufacture of the uviol mercury lamp. This latter, as our readers may remember, is used for medical purposes in the treatment of skin diseases, and in certain chemical industries, especially in the production of linseed oil products.

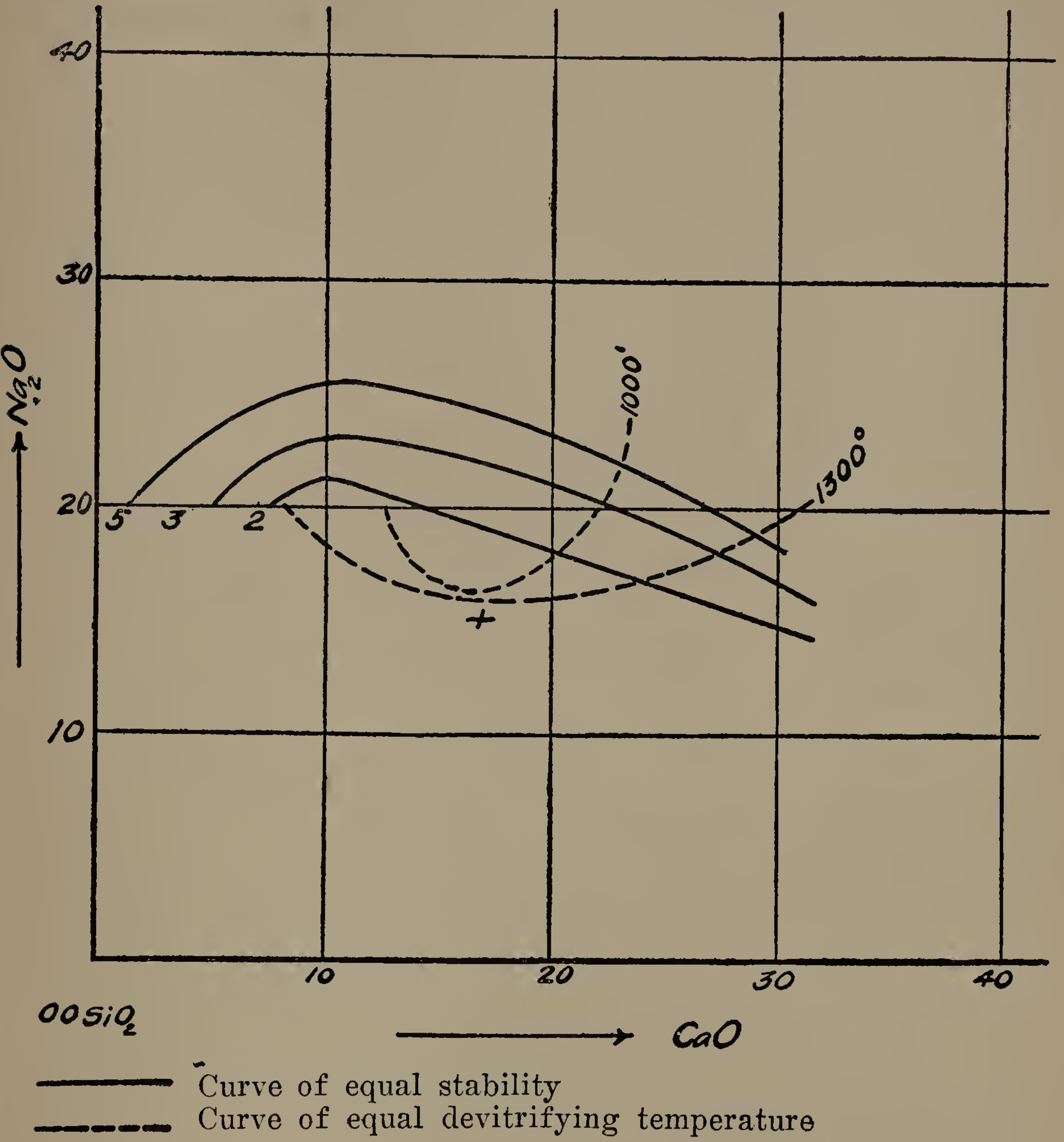


FIG. 2

Another property of glass which is of great importance in connection with certain of its applications is its behavior toward changes of temperature. If a hot glass article, while still soft, is allowed to cool quickly, inequalities in density are produced within the mass of glass, giving rise to internal strains. A glass tube, for this reason, is always under a peripheral compressing strain, while the inside is under tension. The consequence of this is a high resistance to mechanical injury on the outside, while any scratch on the inside, especially in the case of thick walled tubes, almost inevitably leads to the cracking of the tube. Such tubes in which the outer wall is under a compressing strain and the inner wall under tension nevertheless possess certain advantages over tubes free from strain. For if such a tube is heated from within to a temperature considerably exceeding that of its surroundings, the thermal expansion of the inner layers must first neutralize the existing tension before the tube can acquire any tangential expansion strain tending to burst the tube. Such a tube can therefore withstand considerably higher differences of temperature between its inner and outer surface than a tube initially free from strain. The same advantage is gained where the tube is to be subjected to pressure from within, as in water gages for boilers. For this purpose tubes free from strain cannot be used at all. The sensitiveness of the inner wall may be prevented by making the tube of two layers having a different coefficient of expansion with temperature. Tubes of this kind are largely employed for boiler gages.

A glass having a very low coefficient of expansion will cool without acquiring any appreciable strain. Such a glass is particularly well adapted to resist sudden temperature changes and is used for example in making chimneys for incandescent gaslight. Another purpose for which glass possessing special properties is required is the construction of thermometers. One of the errors to which thermometers are subject is the apparent lowering of the freezing point if the latter is observed soon after the thermometer has been used to measure a high temperature. Experiments showed that the simultaneous presence of potash and soda is particularly responsible for a large error of this character. Finally, the brand known as Jena normal thermometer glass 16 III was evolved, and this is now regularly manufactured in uniform quality. It is commonly formed with a red streak to render it readily distinguishable. Its coefficient of expansion is so nearly alike to that of platinum that the metal can be fused into it, making a gas-tight joint. Another special thermometer glass is the boron glass 59 III, which is particularly well adapted for high temperature thermometers ranging up to 500° C. This glass is even superior to the first mentioned, having a lower coefficient of expansion. This, however, brings with it the disadvantage that a gas-tight joint with platinum cannot be made through it by fusion.

In conclusion it may be said that the principal characteristic of the advances made at the Jena works during the last twenty-five years consist in the production of special glass adapted for definite purposes. This was rendered possible only by greatly increasing the variety of types of glass prepared and by the utilization of elements which previously had not been employed in glass making. Nevertheless, had the demand been exclusively for glasses for scientific purposes, this would never have been sufficient to enable the manufacturer to meet the requirements and at the same time secure a margin of profit. The commercial possibility of the developments which have taken place necessarily rested on their exploitation for general technical purposes, as for example in the manufacture of the Jena incandescent gas-light chimneys.

WHAT ELECTROCHEMISTRY IS ACCOMPLISHING[1]

BY PROFESSOR JOSEPH W. RICHARDS

My theme is to depict for you, as clearly as I may be able, the part which electrochemistry is playing in modern industrial processes. I have no exhaustive catalog of electrochemical processes to present, nor columns of statistics of these industries; but my object will be to classify the various activities of electrochemists and to analyze the scope of the electrochemical industries.

Electrochemistry is the art of applying electrical energy to facilitating the work of the chemist. It is chemistry helped by electricity. It is the use of a new agency in accomplishing chemical operations, and it has not only succeeded in facilitating many of the most difficult and costly of chemical reactions, but it has in many cases supplanted them by quick, simple and direct methods; it has even, in many cases, developed new reactions and produced new materials which are not otherwise capable of being made. A few examples will illustrate these points: Caustic soda and bleaching powder are made from common salt by a series of operations, but the electrical method does this neatly and cheaply in practically one operation; lime and carbon do not react by ordinary chemical processes, but in the electric furnace they react at once to form the valuable and familiar calcium carbid; carbon stays carbon except when the intense heat of the electric furnace converts it into artificial graphite. The list of such operations is a long one, and it may be said that the chemist has become a

---

[1] An address before the American Electrochemical Society, in Pittsburg. Published in vol. xvii (1910) of the *Transactions* of that society.

much more highly efficient and accomplished chemist since he became an electrochemist, and he is becoming more of an electrochemist daily.

Electrometallurgy applies electric energy to facilitating the solution of the problems confronting the metallurgist. Its birth is but recent, yet it has rendered invaluable service; it has made easy some of the most difficult extractions, has produced several of the metals at a small fraction of their former cost, and has put at our disposal in commercial quantities and at practicable prices metals which were formerly unknown or else mere chemical curiosities. It has, further, refined many metals to a degree of purity not previously known. The metallurgist is rapidly appreciating the possibilities of electrometallurgical methods, and they already form a considerable proportion of present metallurgical practice.

Applied electrochemistry, covering in general all of the field just described, is therefore an important part of chemistry and metallurgy, and is rapidly increasing in importance. It is a new art, people are really only beginning to understand its principles and to appreciate its possibilities; it is an art pursued by the most energetic and enterprising chemists, with the assistance of the most skilled electricians. Some of its most prominent exponents are electrical engineers who have been attracted by the vast possibilities opened up by these applications of electricity. The chemists have worked with electricity like children with a new toy, or a boy with a new machine; they have had the novel experience of seeing what wonders their newly applied agency could accomplish, and it is no exaggeration to say that they have astonished the world —and themselves.

THE AGENTS OF ELECTROCHEMISTRY

The operating agent in electrochemistry is, of course, electric energy, which may be used in three classes of apparatus, viz.:

(I) Electrolytic Apparatus.
(II) Electric Arcs and Discharges in Gases.
(III) Electric Furnaces.

I. Electrolytic Apparatus

Electrolytic apparatus and processes use or utilize the separating or decomposing power of the electric current. Whenever an electric current is sent through a liquid material which is compound in its nature, i. e., a chemical compound, the current tends to decompose the compound into two constituents, appearing respectively at the two points of contact of the electric conducting circuit with the liquid in question, i. e., at the surface or face of contact of the undecomposable conducting part of the circuit with the decomposable part. If the current has a definite direction the constituents appear at definite electrodes. The action is simply the result of the current extracting (or tending to extract) from the electrolyte one of its constituents at each of the two electrode surfaces. All subsequent changes following upon this primary tendency of the current are called secondary reactions, and are practically simultaneous with the primary. These may even be regarded as truly primary reactions also, the primitive decomposing or separating power of the current passing being regarded only as a *tendency* or a *determining* cause which practically results in the reactions actually taking place.

This agency is an extremely vigorous and potent force for producing chemical transformations. It enables us, for instance, to split up some of the strongest chemical compounds into their elementary constituents, to convert cheap materials, in short, to perform easily some very difficult chemical operations, and in some cases to perform chemical operations otherwise impossible. A description of all these various processes would take a volume, but a short explanation of a few of them will make the principles clear and suffice for my present purpose.

Electrolysis of Water: As a raw material, water may be said to cost nothing. Apply an electric current to it in the proper way, and it is resolved into its constituent gases, hydrogen and oxygen, as cleanly and perfectly as any one could desire. These gases have many and various uses, and are valued each at several cents per pound. A whole industry has thus grown up, based on the simple electrolysis of water, to supply these two gases for various industrial uses. Europe possesses many of these plants; there are a few in the United States. The speaker has translated from the German a small treatise on this industry.

Electrolysis of Salt: Common salt, sodium chloride, is one of the cheapest of natural chemicals. It has some uses of its own, but centuries ago chemists and even alchemists devised chemical processes for transforming it into other sodium salts, caustic soda or soda lye, for use in soap, soda ash or carbonate, for washing or glassmaking, and into chlorine bleaching materials. Chemical works operating these rather complicated chemical processes exist on an immense scale in all civilized countries; it is estimated that $50,000,000 is thus invested in Great Britain alone. The electrolytic alkali industry is barely twenty years old, yet it is already more than holding its own with the older chemical process, and advancing rapidly; twenty years more will probably see the older processes entirely superseded—they are at present fighting for their existence. As for the electrolytic process, the salt is simply dissolved in water and by the action of the current converted into caustic soda at one electrode and chlorine gas at the other. By some special devices these are kept separate and collected by themselves, and the work is done. The principles involved are simplicity itself as compared with the older chemical processes, the only agent consumed is electric energy, and the products are clean and pure.

Chlorates: These are salts used on matches and in gunpowder. Chlorate of potassium is a valuable salt with important uses. It is made from common cheap potassium chloride, in solution in water, by simply electrolyzing the solution without trying to separate the products forming at the electrodes. It is a simpler operation than the production of electrolytic alkali. Chlorate thus forms in the warm solution, and is obtained by letting the solution cool and the chlorate crystallize out. The ordinary chemical manufacture of this salt was tedious and dangerous; the electrolytic method has practically entirely superseded it.

Perchlorates: These salts have more limited uses, but are made by expensive chemical methods. The electrolysis of a chlorate solution at a low temperature, without separating the products formed at the two electrodes, results in the direct and easy production of perchlorates. I cite this more to illustrate what I might call the versatility of electrochemical methods, rather than because of its commercial importance.

Metallic Sodium: The caustic soda produced from salt can itself be electrolytically decomposed; this is the easiest way of producing metallic sodium. Sir Humphry Davy discovered sodium by electrolyzing melted caustic soda and at this moment several large works are working this method on an immense scale. The caustic contains sodium, hydrogen, and oxygen, and the current simply liberates the sodium as a molten metal and frees the other two as gases, which escape into the air. The process is simplicity itself —when the exact conditions are known and rigidly adhered to. Metallic sodium is a very useful material to the chemist, and the electrolytic method produces it at probably one fourth the cost of making it in any purely chemical way.

Magnesium: This is a wonderfully light metal, whose chief use is in flash-light powders. Its compounds are abundant in nature, but its manufacture by any other than the electrolytic method is almost impracticable. The operation consists in simply passing the decomposing current through a fused magnesium salt—a chloride of magnesium and potassium found in abundance in Germany.

Aluminium: The most useful of the light metals; an element more abundant in nature than iron, yet which costs by chemical methods at least $1.00 per pound to produce; electrochemistry enables the makers to sell it at a profit at $0.25 per pound. This is probably the most useful metal given to the world by electrochemistry. Although the French chemist Deville obtained it by an electrolytic method in 1855, yet he had only the battery as a source of electric current, and the process was too costly. This very city of Pittsburg was the real cradle of the electrolytic manufacture of aluminium, when, in 1889, Mr. Chas. M. Hall, with the financial assistance of the Mellons and the business assistance of Capt. A. E. Hunt, commenced to work his process up at Thirty-third Street on the "West Side." The principle of the process is here again one of beautiful simplicity—when it is once made known. Aluminium oxide, abundant in nature, is infusible in ordinary furnaces, but easily melts and dissolves, like sugar in water, in certain very stable and liquid fused salts—double fluorides of aluminium and the alkali metals. On passing the electric current through this bath, the dissolved aluminium oxide is decomposed, appearing at the two electrodes as aluminium and oxygen respectively. When all the oxide is thus broken up, more is added, and the operation continues. One of the most difficult problems of ordinary chemistry is thus simply, neatly and effectively solved by electrochemistry. The lower cost of power at Niagara Falls drew the industry away from Pittsburg, in 1893, and it is now run on an immense scale at several places where water-power is cheap and abundant. Mechanical power is, however, being produced cheaper every year; gas engines have halved the cost of such power, steam turbines on exhaust steam may even do better; there is no inherent impossibility in the return of the aluminium industry to the Pittsburg district. Many other factors besides cost of power bear on the question; cost of labor, abundance of labor, cost of carbon, coal for heating, various supplies, railroad freights, nearness to the consumers, and many other considerations must be taken into account. Aluminium is certainly destined to become the most important metal next to iron and steel, and, as far as one can now foresee, will always be produced electrochemically. To have accomplished the establishment of this one single industry, would itself have proved the usefulness of electrical methods and their importance to chemistry and metallurgy.

Refining of Metals: Unless metals are of high purity they are usually of very little usefulness. Electrolytic methods enable almost perfect purity to be easily attained, and in addition permit the separation at the same time of the valuable gold and silver contained in small amount in the baser metals. Over $100,000,000 worth of copper is electrically refined every year in the United States; the metal produced is purer than can be otherwise obtained, giving the electrical engineer the highest grade of conducting metal, while several million dollars' worth of gold and silver are recovered which would otherwise have to be allowed to remain in the copper. Again, the method is so simple that but a few words are necessary to set it forth in principle. The impure copper is used as one electrode —the anode—in a solution of copper sulphate containing some sulphuric acid; the receiving electrode—the cathode —is a thin sheet of pure copper, or of lead, greased. The electric action causes pure copper only to deposit upon the cathode, if a properly regulated current is used, while a corresponding amount of metal is dissolved from the anode. Silver, gold, and platinum are undissolved, and remain as mud or sediment in the bottom of the bath; other impurities may go into the solution, but are not deposited on the cathode if the current is kept low. The cost of this operation is small, and the results are so highly satisfactory that 90 per cent. of all the copper produced is thus refined. Similar methods are in use for refining other metals; silver, gold, and lead are thus refined on a large scale; antimony, bismuth, tin, platinum, zinc, and even iron can be thus refined; the field is very inviting to the experimenter and to the technologist, and is rapidly increasing in industrial importance.

Metal Plating: All electro-plating is done by the use of electrolytic methods similar to those just described. If we imagine the impure metal anode replaced by pure metal, and the receiving cathode to be the object to be electroplated, we have before us the electro-plating bath ready for action. Everybody knows the value and use of gold, silver, and nickel plating; less well known are platinum, cadmium, chromium, zinc, brass, and bronze plating. These are among the oldest of the electrochemical industries. Electrotyping is only a variation of this work; also the electrolytic reproduction of medals, engravings, cuts, etc., and even the production of metallic articles of various and complicated forms, such as tubes, needles, mirrors, vases, statues, etc. There is opportunity here to hardly more than catalog these various branches of electrometallurgical activity. Pittsburg people will be interested, however, in knowing that many of the newer buildings in this city contain thousands of feet of electrical conduits zinc plated in splendid fashion by electrolysis, at a works within a few miles of this city. At McKeesport, tubes are coated by dipping into melted zinc, on an immense scale, but the electrolytic method is gaining a foothold, and we may live to see all galvanizing in reality practised as it is spelled. The removing of metallic tin from waste tin scrap is also accomplished on a large scale by the application of similar principles. It is being operated at a distance from Pittsburg, but your open-hearth furnaces use up annually thousands of tons of the scrap steel thus cleaned and saved for remanufacture into useful shape.

Without having mentioned or described more than a fraction of the electrolytic methods in actual industrial use, I hope that I have made clear the importance and extent of this kind of electrochemical processes. Assuming this, we will pass to the consideration of another, entirely different and yet important, class of apparatus and processes.

II. Electric Arcs and Discharges in Gases

Electric arcs and high-tension discharges through gases are capable of producing some chemical compositions and decompositions which are very useful, and profitable to operate. This is a branch of electrochemistry which has not been as thoroughly studied as some others, its phenomena are not as thoroughly under control as electrolysis and electro-thermal reactions, and its possibilities are not as thoroughly understood or utilized.

Ozone is being made from air by the silent discharge of high-tension electric current. The apparatus is so far simplified as to be made in small units suitable for household use, ready to attach to a low-tension alternating current supply. The uses for the ozone thus produced are particularly for purifying water and air; it makes very impure water perfectly safe to drink, and purifies the air of assembly halls and sick-rooms, acting as an antiseptic. According to all appearances, this electrochemical doubling up of oxygen into a more efficient oxidizing form is developing into a simple and highly efficient aid to healthy living.

Nitric Acid is an expensive acid made from the natural alkaline nitrate salts, such as Chili saltpeter. These nitrates are the salvation of the agriculturist, for they furnish the ground with the necessary nitrogen which plants can assimilate. The Chili ''nitrate kings'' have gained many millions of dollars, even hundreds of millions, in thus supplying the world's demand for fertilizer. But, electrochemistry has another solution to this problem, which is rapidly rendering every country which adopts it independent of the foreign fertilizer. The air we breathe contains uncombined nitrogen and oxygen gases, which if combined and brought into contact with water furnish the exact constituents of nitric acid. The way to do this has been laboriously worked out, and the electric arc is the agent which does it. Air is simply blown into the electric arc, where it for an instant partakes of the enormous temperature, and on leaving the arc is cooled as quickly as possible. In the arc, the combination of nitrogen and oxygen is effected to a certain extent, and the mixture is cooled so suddenly that it does not find time to disunite. The nitrogen oxides thus obtained are drawn through water, and this solution of nitric acid is run upon soda, to produce sodium nitrate, or on lime to produce calcium nitrate, the latter called nitro-lime or "Norwegian saltpeter." These salts entirely replace the South American natural salt.

The materials used in this industry are air and lime, and to these is added electrical energy. Air is universal, lime cheap almost everywhere, and electrical energy is cheapest where water powers are most abundant. In Norway, water-power can be developed and electrical energy supplied from it at a total cost of $4.00 to $8.00 per horse-power-year. Some other countries can do nearly as well. Under these conditions, almost every country can afford to make its own nitrates, and so be independent of other countries for the fertilizer needed in peace and the gunpowder used in war. Norway felicitates itself already on being thus independent; nearly 200,000 horse-power is being utilized there by a $15,000,000 syndicate, and the industry is spreading rapidly over Europe. The study of this problem, its solution, and the rapid development of this vigorous industry, is one of the most remarkable chapters in the history of recent industrial development. In this accomplishment, electrochemistry has signally aided the agriculturist, and demonstrably multiplied the food-supply resources of all civilized and highly-populated countries.

Boron is an element which has until recently defied the best efforts of chemists to isolate in a pure state. It is an element which may have important application in the manufacture of a high-class special steel—boron steel. Dr. Weintraub, one of our fellow members, has recently solved the problem of its production by an adaptation of the "oxygen-nitrogen" arc apparatus, and utilizing the same principle of introducing the material into the arc and very rapidly cooling the products obtained. We mention this not because of its great commercial importance at present, but because it shows how the "arc method" may be of wide application in solving other difficult chemical problems; it has opened before us a new method in chemical science, and may give birth to many and various new chemical industries.

III. Electric Furnaces

Electric furnaces are furnaces in which the necessary heat or degree of temperature is produced or attained by means of electrical energy. The electric current is used in these furnaces solely for its heating or thermal effect, and either alternating or direct current may be used, but alternating is preferred because of its easier generation and management, capability of being procured from transformers, and absence of electrolytic effects.

Electric furnaces render remarkable and highly valuable service to the chemist and metallurgist, for two distinct and unique capabilities; they can generate heat within themselves without the use of combustion and the consequent products of combustion to complicate the working of the furnace, and they can besides, if desirable, produce temperatures absolutely unapproachable in furnaces using fuel, and thereby enable the carrying out of operations only possible at these extremely high temperatures. The upper limit of electric furnace temperature is simply the volatilizing point of carbon, the temperature at which the material of which the lining of the furnace is made is boiled away. This is about 3,700° C. or 6,692° F. The simple statement that this is three times as high as the melting point of cast iron may give some notion of the enormous temperature here at one's command. Besides high temperature, the efficiency of application of electrical heat to the useful purpose is usually high; in many cases 50 to 75 per cent. of all the heat developed can be usefully applied, as against 5 to 50 per cent. utilized in fuel-fired furnaces. The heating value or thermal equivalent of the electric current is perfectly definitely known; one kilowatt-hour will furnish 860 calories (3,400 B.t.u.), which if applied usefully at 100 per cent. efficiency would bring to boiling and convert into steam 1.35 kilograms (3 pounds) of water, or bring to melting and melt about 3 kilograms (6.6 pounds) of cast iron, or 2.5 kilograms (5.5 pounds) of steel.

Artificial graphite is a product particularly electrochemical in its manufacture. Your fellow-townsman, Dr. E. G. Acheson, has practically created this industry and his name sticks to the product—Acheson graphite. No temperature but that of the electric furnace can convert the ordinary amorphous carbon, containing small amounts of foreign substances, into pure, soft, homogeneous, unctuous graphite. The purity of the product and its quality has even surpassed the artifice of Mother Nature herself. Whereas before graphite in small scales was laboriously gathered from Ceylon and Siberia, and with great pains worked up into graphite articles, now the articles are simply molded in ordinary impure amorphous carbon, and converted through and through, retaining their shape, into finished and complete graphite articles. What this highly pure product is going to do for lubrication, for annihilating the friction of the world's machinery, perhaps only a few suspect and only Mr. Acheson knows. You will all know more about this soon, and every one of you who uses machinery will profit by it. Meanwhile, in another direction, probably half the electrochemical industries now operating are beneficiaries of this invention, using artificial graphite anodes in electrolytic operations or as electrodes in electric furnaces. The electrochemical industry in general has been most wonderfully helped by this one electrochemical process.

Carborundum stands for a large industry, centered at Niagara Falls, and founded also by Mr. Acheson. Twenty years ago the name was not in the dictionary; now it is known all over the world as the most efficient abrasive material in use. First produced just across the Monongahela, in a little furnace as large as a cigar box, and sold for polishing diamonds at many dollars per ounce, it is now made by tons in electric furnaces of 2,000 horse-power capacity, and competes successfully with such common natural abrasives as emery and common sand. And in fact, common silica sand, the most abundant material on earth, with common carbon, like coke, furnish all the ingredients necessary for the furnace to work upon to produce SiC, silicon carbide. Mr. Acheson not merely founded another new industry, but he discovered a new chemical compound; he has enriched science, promoted industry, and created new instruments of service; no wonder that his scientific friends have showered on him honors—the Rumford Medal, the Perkin Medal, and two years ago the presidency of this Electrochemical Society.

Silicon is the metal whose oxide is silica or sand and is by far the most abundant metallic element on earth. Up until very recently it was to be seen only in chemical museums, costly and useless—a chemical curiosity. Now Mr. F. J. Tone, one of Mr. Acheson's former lieutenants, is producing it by the ton and selling it by the carload, at a few cents per pound. The chemical world has found uses for it, large uses, such as in solidifying steel, making good copper castings, reducing other metals from their oxides, chemical "pots and pans," etc. This illustrates again the variety of the achievements of electrochemistry. Here is a new material furnished the world at a low price and all sorts of workers are finding all sorts of advantageous uses for it. The electric furnace makes it from simply sand and carbon, with electric energy, and plus considerable "brains."

Calcium carbide is the product of another American invention. The name was scarcely in chemical books, and the purveyors of the rarest chemicals did not have it on their lists, when Mr. Thomas Wilson, trying to make something else in the electric furnace, made this compound from ordinary lime and carbon, and started an electrochemical industry which has spread all over the civilized world. I am almost tempted to say that there is a calcium carbide works everywhere, but that would really be an exaggeration, and I will not say it. The best thing about calcium carbide is that it is easy to make; the raw materials may be found almost everywhere, and wherever power is cheap a flourishing calcium carbide industry may be built up. The curious thing about it is that its chief use is based on destroying it, acting upon it by water and forming acetylene gas. How great a boon acetylene gas has been to the bicyclist, automobilist, for lighting trains, isolated houses, stations, and towns, needs no recital before this audience; but the value of acetylene as a means of welding with the blowpipe is only commencing to be appreciated. Acetylene welding is a convenience which owes its existence entirely to the electrochemical production of calcium carbide, and the iron and steel and other metal industries are being greatly helped by its use.

Titanium carbide is not as familiar as calcium carbide. It is made in a manner similar to the production of carborundum, using titanium oxide, (rutile) and carbon. It has no uses similar to calcium carbide, nor any like silicon carbide. But electrical engineers have discovered that as arc light tips or electrodes it gives the most efficient arc light yet discovered, with a light efficiency running up to 3 candle-power per watt of electrical energy. This is probably 50 per cent. of the theoretically possible conversion of electrical energy into light energy, and is doubly as efficient as has ever before been attained. What this means for street lighting everywhere is difficult to realize; perhaps the best and most easily understood comparison is to say that the titanium carbide arc lamp is to the ordinary arc, as the tungsten filament incandescent lamp is to the carbon filament lamp; you will all grasp the scope of that statement. With acetylene lighting on one hand, and titanium arc lighting on the other, we need say no more about the influence of electrochemistry on modern illumination.

Phosphorus. I stated before that the potassium chlorate on safety matches was all being made electrochemically. We can say practically the same of phosphorus. The electric furnace enables us to distill phosphorus much more easily and safely from the natural phosphates, than the older chemical methods. Calcium carbide gives us acetylene gas, and another electrochemical furnace gives us the phosphorus to ''strike the light.''

Ferro-alloys are alloys of iron with the more expensive metals, used in manufacturing steels of various kinds. Ferro-manganese is used in practically all steel, ferro-silicon is used in almost all. Ferro-chromium, nickel, tungsten, molybdenum, boron, uranium, vanadium, are some of the alloys used to make the special alloy steels, such as find great use in rapid tool steel, automobile axles, armor plate, gun steel, etc. These alloys are of great importance to the steel industry, and are made almost exclusively in electric furnaces. The industry has flourished most in countries having cheap power, such as among the French Alps, and the importations into this country have been on a large scale. Fortunately, we are commencing at Niagara Falls, in Virginia, and in Canada, to supply ourselves with these necessities of the steel industry, and we may look forward to a steady and large domestic development of this industry. Within a few miles of this hall, a small electric furnace is now at work making ferro-tungsten to go into high-class, expensive steel. Pittsburg is going to take its share in the running of this particular electro-metallurgical industry.

Pig iron would seem to be about the last item to find a place in an address upon the electrochemical industries. But the truth must ''out'': electric furnace pig iron is now being made, and made and sold at a profit. We will hasten to admit that the furnaces are small, that they are in California and Sweden, where fuel is expensive and power is cheap, that a great deal of money has been sunk in bringing them to their present condition; but after all has been admitted, the fact remains that electric-furnace production of pig iron is not a chimera, but an accomplished fact. Pittsburg has been able to boast that she "could manufacture a ton of pig iron and put it down anywhere in the world cheaper than it could be there produced." That may be *still* true *of the kind* of pig iron which Pittsburg is able to make, but there are grades and qualities of pig iron (Swedish charcoal pig iron, for instance) which are still imported into this country and sold at double the price of our domestic pig iron. And, in the country where that charcoal pig is slowly, laboriously and skilfully made, the electric shaft furnace is able to compete with the charcoal blast furnace in producing this high quality pig iron. Dr. Haanel, of the Canadian Department of Mines, has in a recent report given us the most reliable information about the running of this furnace. The construction is peculiar, and still somewhat experimental, the full power for which the furnace was designed has not yet been available for running it, the workmen are new to their tasks, the overseers are still learning, the irregularities in the running are not yet all overcome, and many of the minor details are yet being adjusted. The furnace is still, in brief, decidedly in the formative or experimental stage. Yet, notwithstanding, Professor Odelstjerna, one of the most expert of Swedish metallurgists, states that the cost of production is $1.50 per ton less than in the Swedish blast furnaces. If that is true now, it needs little gift of prophecy to figure out at least $2.50 per ton saving when the furnace is properly run. Three similar furnaces of greater capacity, 2,500 kilowatts each, are to be erected in Norway; three similar ones are to be put up at Sault Ste. Marie, Canada. These are only the forerunners we may be sure, of dozens or perhaps even hundreds which will be built and operated within the lifetime of most of this audience. The time at our disposal forbids me describing these interesting furnaces; I can only refer to Dr. Haanel's interesting reports and to the transactions of this society, particularly to our volume xv. One surmise of my own I will, however, take time to mention: I have predicted that this electric furnace pig iron, made without the admittance or use of air blast, will be far superior to ordinary pig iron for conversion into steel, because of the absence of oxygen or, particularly, of nitrogen. *Time* will test this prediction, too.

Electric steel is at present a topic of absorbing interest and great potentialities. It was primarily a competitor of the most expensive kind of steel—crucible steel. It was first made commercially in 1900, by Mr. F. A. Kjellin of Sweden, by melting together in an electric furnace the same high-grade materials which are usually melted down in crucibles to form crucible steel. The product was made equal in quality to crucible steel, it was produced in lots of a ton or more at a melt, of very satisfactory uniformity, and with cheap water-power to furnish electricity the cost was considerably below that of crucible steel.

The steel melting pot or crucible is a siliceous vessel, holding about 100 pounds of steel, lasting only a few heats, and lifted in and out of the furnace by manual labor. The consumption of fuel to get the required melting heat is wickedly wasteful; not over five per cent. of the heat-developing power of the fuel used is efficiently utilized as heat in the melted steel, and the actual proportion is usually less than half that much. The cost of labor, crucibles and fuel is excessive, and to this must be added the high cost of the pure material which must be used—practically the purest iron which can be made.

The electric furnace is changing all this, rapidly in continental Europe, slower in Sheffield, and still slower in America; but the change is spreading surely and inevitably. Real crucible steel will soon be a thing of the past, supplanted entirely by electric furnace steel of equal quality, made and sold much more cheaply.

The electric furnaces used are of almost all types. The induction furnace was developed commercially by Kjellin in Sweden, improved, enlarged and greatly developed by his associates in Germany, combined with the Colby pattern in America, and still further modified by Hiorth in Norway. Thirty-six of these furnaces, the maximum capacity being one at Krupp's works at Essen, 8½ tons at a charge, are now built or building. The American Electric Furnace Company is organized to push their building and operation in America. The arc radiation furnace was developed by Major Stassano, an Italian artillery officer. It melts by heat radiated from powerful electric arcs. Several of these are in operation in Europe, and a gentleman managing one of the large American steel companies, who has just returned from an inspection of the different electric steel furnaces operating in Europe, tells me that he considered the Stassano furnace as doing the best work all around, of all the furnaces he saw in operation. I have seen this furnace operating smoothly and regularly, in Turin, producing steel for castings which were being sold in competition with open-hearth and Bessemer steel castings in the open market. The single arc furnace is best illustrated by the Girod furnace which is built like the body of an open-hearth furnace with the electric current entering the bath by carbon electrodes suspended above it and springing arcs to it while the current leaves the bath through metallic conductors passing through the saucer-shaped hearth below the level of the metallic surface. These furnaces work with great regularity, and a large number are operating in Europe in capacities up to 12 tons each. I am informed that the Krupp works at Essen has just contracted to put in five of these of the 12-ton size, which would confirm statements made to me by my European friends that this furnace is working the best of all the electric steel furnaces now operating in Europe. The double arc furnace, of which the Heroult furnace is the most familiar type, works with two arcs in series, the current entering the bath and leaving it also through electrodes suspended above it. The general style is that of an open-hearth furnace with electrodes passing through the roof. The current used is roughly 100 kilowatts per ton of steel capacity, and the largest so far operated is 15 tons. A three-ton furnace of this type was seen by you at the Firth-Stirling Steel Works at Demmler, yesterday, producing crucible-quality steel. The U. S. Steel Corporation has acquired licenses to operate the Heroult furnace, and has already two 15-ton furnaces in operation. Without doubt, the Heroult furnace is at the present time the most popular and successful electric steel furnace in the United States. I have not time to more than name the Keller, the Hiorth, the Harmet, the Frick—all of which are operating at this present moment, in Europe.

There are other ways of making steel than the crucible method. Bessemer steel is the cheapest, and open-hearth steel is next best. These two varieties grade into each other in quality, but between open-hearth and crucible steel there is an enormous gap in price and in quality which is destined to be bridged over by intermediate qualities of electric steel, as it becomes cheaper and is manufactured on a larger scale. This will soon become one of the large uses of the electric method, occupying a field peculiarly its own. It will enable steel manufacturers to supply steel better than the best open-hearth product at less than the price of crucible steel. I need not enlarge upon the advantages of this to a Pittsburg audience.

There are also varieties of methods of manufacture of steel, aside from the melting together of highly pure materials as in the crucible method, which are equally available in most types of the electric furnace. The Bessemer converter takes liquid pig iron as it comes from the blast furnace and by rapid oxidation by air blast converts it into steel. Mr. Heroult has tried to combine the Bessemer converter with the electric furnace, in one apparatus, the idea being to first oxidize the metal by air blast and then to finish it while electric current supplied the necessary heat. I have no information that this combination furnace is anywhere in successful operation, but the equivalent of the same operation performed first in the Bessemer converter and then on the blown metal transferred into an electric furnace for finishing, is already in regular commercial operation at the South Chicago Works of the U. S. Steel Corporation. I have had the privilege and pleasure, thanks to Mr. Heroult, of studying that operation, in company with Mr. Heroult and the editor of *Metallurgical and Chemical Engineering*. You may find a description of the process in the April number of that journal, so I will not repeat it here—except so far as to say that 15 tons of the product of the Bessemer blow, oxidized to the extent usual in the Bessemer converter, was kept melted less than two hours on the basic hearth of the electric furnace, treated with two different slags to refine it from phosphorus and sulphur, deoxidized or ''dead-melted,'' and then poured into ingots of steel intended for axles. The steel produced was of better quality than the usual corresponding open-hearth metal, and was produced at slightly less total cost. This combination process bids fair to give a new lease of life to the declining Bessemer steel industry; its economic importance is evident.

The open-hearth steel furnace is, at present, the most important of the methods of manufacturing steel—''tonnage steel.'' It makes steel from pig iron and scrap of proper quality, or from pig iron and iron ore (mill-scale), or from pig, scrap, and ore. It makes its best steel on silica hearths from high grade material low in sulphur and phosphorus, and its cheapest steel on basic hearths from almost anything. The electric furnace can do any or all of these things, and, as a general proposition, produce better steel from given materials than the open-hearth furnace. Under what circumstances it will pay to use the electric furnace instead of the open-hearth furnace would take at least one lecture to discuss; we will not go deeply into it here. In Europe, countries which have very cheap water-power, around $10 per horse-power year, and fuel costing $4 to $6 per ton, are finding the electric furnace the cheaper; with power costing $20 and coal $5, the two are about on equal terms; in Pittsburg, with power at $30 and coal at $1, the open-hearth furnace is by far the cheaper for producing such steel as it can produce. However, even here, the combination of Bessemer and electric furnace is possibly cheaper than the all open-hearth process; the combination of open-hearth and electric furnace process is quite possible and practicable, to produce crucible-quality steel on a large (tonnage) scale, and the combination of the open-hearth and electric furnace into one furnace is not only a possible combination, but is actually being "tried-out."

The latter idea is to take an open-hearth furnace, and to place electrodes in the roof. The furnace is run as an ordinary open-hearth furnace, with the electrodes withdrawn; and at the close of the open-hearth heat, gas and air are shut off entirely, the electrodes lowered into proximity to the bath, and the heat finished as an electric furnace heat. The idea is sound and practicable, and will result in the production of better steel than can be obtained from any open-hearth furnace, at but a slight advance on the cost of the open-hearth steel, say, $2 to $3 per ton.

As to the capacity for enlargement of electric steel furnaces, they started out to duplicate the crucible steel process, producing 100 pounds of melted steel at a heat, and in eight years have risen to 15 tons capacity. In Europe, an electric calcium carbide furnace of 18,000 kilowatts, capable of producing 200 tons of carbide daily, is in practical operation. A furnace of like power capacity could be built to make steel, and would be a 200-ton steel furnace or larger. We can therefore say with assurance, that with a little more experience and experiment, electrometallurgists will be able to furnish the steel maker with electric steel furnaces as large as are wanted—up to 200 tons' capacity if desired.

THE YEAST CELL AND ITS LESSONS[1]

BY W. STANLEY SMITH

It has often struck me that the debt modern science owes to that simple organism we call the yeast cell has, perhaps, never been sufficiently considered by the majority of well-educated mankind. It may be that in the haste and turmoil of industrial life many details of considerable fascination must necessarily escape our ken; it may be, alas! that some of us are content to live our lives among phenomena of which, as Sir Oliver Lodge once said, "we care nothing and know less." Be this as it may, I venture to think that an odd half-hour spent in those delightful fields of thought which envelop yeast and its simple cellular life will not prove entirely unpleasurable, nor, indeed, without some measure of intellectual profit.

I do not purpose to delve far back into the dusty records of time. It will suffice for our purpose if we place ourselves beside the old Dutchman, Van Leeuwenhoeck, and take a glance through the early microscope of 1680. In the field of vision many globules floating in a fluid will be discerned; and these, forsooth, are yeast cells seen in their naked simplicity for the first time by mortal eye. It was thus found that brewers' barm possessed a definite structure, and the primitive step in a long series of discoveries duly accomplished; but it is curious to reflect that 150 years should then intervene during which nothing of capital importance was added to our knowledge. With the advent of the nineteenth century, however, each day brought forth its measure of scientific progress. The scene, indeed, became crowded; men flocked hither and thither

---

[1] Published in *Knowledge and Scientific News* and reprinted in *Scientific American Supplement,* August 14, 1909.

declaring novel facts and fancies, and a veritable whirlpool of conflicting statement and contending argument ensued. At this distance of time the multitude grows dim; but certain figures stand out, and are conspicuous among their clamorous fellows. We must note at least four remarkable personages—by name, Schwann, de Latour, Berzelius, and Liebig. The labors of de Latour in France and Schwann in Germany were almost simultaneously crowned with eventful discovery. Yeast, they announced with no uncertain voice, is a living, breeding entity, and, moreover, is the cause of the fermentation of sugar. All this happened during the opening year of the Victorian age, and against these strange utterances many a voice was raised. Those of us who have studied the history and progress in the fermentive arts will easily recall some of the wild and fantastic guesses which were then poured forth; but among much intellectual dross there rang out the reasoned opinions of Berzelius, the Swede, and Liebig, the giant of his time. Berzelius had, without doubt, as early as 1827, and with greater certainty in 1839, regarded fermentation as dependent upon catalytic force, or, as he called it, *vis occulta,* and Liebig, whose chemico-mechanical theory held ground for some years, is best interpreted by quoting his own words, as they appear in the classic *Chemistry of Agriculture and Physiology.* "In the metamorphosis of sugar," says he, "the elements of the yeast, by contact with which its fermentation was effected, take no appreciable part in the transformation of the elements of the sugar; for in the products resulting from the action we find no component part of this substance."

Many other theories echo from out those times—theories, for the most part, utterly vanished from the ken of practical science. Albeit a strange value, a vague sense of prophecy is discernible in certain of these long-forgotten figments of scientific imagination. For instance, one might legitimately recall Mitscherlich, with his notion of contact, much akin to the action of platinum sponge, or Meissner, with his purely chemical theory, or, yet again, the strange forecast of Colin and Kaemtz, who deem the whole matter wrapped deep in the mysteries of electricity. Suffice it we have chosen enough for our wants, and it will be apparent how, in the whirligig of time, forgotten lore will suffer resurrection. In the history of science instances are, indeed, not wanting in which old theory clothed in the garb of newly-found facts itself lives anew.

The learned Gabriel Schwann was, by inclination, a physiologist, and his work on yeast must be regarded in the light of experimental means to an ambitious end. He sought in the cell the very foundation of life. "I have been unable," says he, "to avoid mentioning fermentation, because it is the most fully and exactly known operation of cells, and represents in the simplest fashion the process which is repeated by every cell of the living body." Let us place these words side by side with those uttered but the other day by the great Verworr. "It is the cell to which the consideration of every bodily function, sooner or later, drives us. In the muscle-cell lies the riddle of the heartbeat, or of muscular contraction; in the epithelial-cell, in the white blood cell, lies the problem of the absorption of food; in the gland-cell are the causes of secretion, and the secrets of the mind are slumbering in the ganglion-cell." It thus appears clear that the simple saccharomycete is typical, even as Schwann argued, of all organized life. But it is not a mere question of crude morphology; this, indeed, is but the least subtle of those analogies which the study of a yeast cell will suggest. As we gaze through the eyepiece of some sufficient microscope or better still observe the seething world of the brewers' fermenting vat, we may be tempted to ask the old, old question, Whence and Whither? What lies behind this fierce energy of decomposition, this astounding fecundity, this altogether absorbing mystery of life? These are the problems which men of science have set themselves to solve, and already they have gone far. I think that it would not be difficult to refer the latest opinions of biologists to the direct and logical result of reasoning which was primarily suggested by research on the mechanism of the yeast cell. ''Physiology's present answer to the old question,'' says a recent writer, ''is, very simply, life is a series of fermentations.'' And, if it be urged that we do not yet know what is fermentation, that we know as little of the working of the housewife's barm, or the brewer's malt, as of the life itself, there will be no one to gainsay. For, curiously enough, they seem one and the same thing.

There is a plate let in above the doorway of a house at Dôle, in the Rue des Tanneurs, on which is inscribed this simple phrase: ''Ici est né Louis Pasteur, le 27 Decembre, 1822.'' And, while I may unhesitatingly say that few more momentous events have occurred in the annals of science, I am tempted to add that Pasteur's birth was of equal moment to the whole of humanity. For what manner of man was this lowly-born tanner's son? And what was the outcome of his labors? Let Lord Lister tell us in his own grateful words. He said: ''Pasteur's researches on fermentation have thrown a powerful beam which has lightened the baleful darkness of surgery, and has transformed the treatment of wounds from a matter of uncertain, and too often disastrous, empiricism into a scientific art of sure beneficence.'' Pasteur's life has been laid bare to us by several writers, among them his son-in-law Bompas, and, in a clever little monograph, by Mrs. Percy Frankland. From the latter work we gather how Pasteur, in his youth, was much addicted to the gentle Waltonian art. Indeed, for some years he took no heed whatever of books or other dry-as-dust learning. It was not until dire necessity forced him that fishing-rod, paint-box, and other profitless joys were forsaken, and our student at the Sorbonne discovered his God-given gifts. And then a certain old woman of Arbois, in her rural wisdom, made this odd remark: ''What a pity,'' said she, ''that Louis should bury himself in a muck-heap of chemistry, for in truth he would some day have succeeded in making name and fame as a painter.''

It is a legitimate question to ask why Pasteur happened to take up the study of fermentation. The answer affords another of those happy chances which are the salt of scientific life. As a crystallographer he was bent on solving those old problems suggested by the tartaric acids. He noticed how one type of this acid deflects the beam of light to the right, another to the left. Further, he chanced to observe that certain micro-organisms exercise a selective action when sown in these solutions—thriving in one, pining in the other. Here then was a clue, for surely the contents of the cells Schwann had declared alive must control such dainty selective action. What followed in those fruitful years it were quite needless for me to recapitulate. Liebig and his molecular oscillations were forgotten by all save the faithful few, and for forty years mankind reveled in the thought that the fermentation of sugar was indissolubly connected with the life action of a living organized structure. Yet, on the crucial point, Pasteur was in error. It must not be forgotten, however, that by his classical experiments with the isomeric tartaric acids Pasteur practically laid the foundations of stereo-chemistry. The development of this fruitful branch of learning was, necessarily, slow at first, and indeed, it was not until 1873 that much headway was achieved. In that year Wislicenus pointed out the deductions of his work on lactic acid, and it seemed clear to men of science that the difference between compounds of identical structure was due to differences in the ``arrangement in space'' of atoms within the molecule. It is to the further development of this difficult subject, at the hands of Le Bel and van't Hoff, who elaborated the theory of the asymmetric carbon atom, that we largely owe our knowledge of the carbohydrates.

The new century opened with new ideas. A book dealing with experimental research on alcoholic fermentation, and relating the results of laboratory experiments dating from 1896, appeared in the year 1903. It is entitled "*Die Zymasegärung: Untersuchungen über den Inhalt der Hefezellen und die biologische Siete des Gärungsproblems.*" The authors' names are Eduard Buchner, Hans Buchner, and Martin Hahn; and it became evident something noteworthy had happened. It was briefly this: Buchner, unhampered by any prejudice concerning the connection of vitality with fermentation, betook him to see what was really inside the yeast cell. Accordingly, he mixed a small quantity of barm with very fine sand, and he then subjected the whole to enormous pressure. This hard quartz crushed the little yeast cells to merest pulp, and therefrom flowed a wonder-working fluid. It was found that Buchner's liquor effected exactly the same fermentation in a saccharine solution as did yeast itself. This research of Buchner's actually proved what was long ago conjectured by Liebig, Traube, Berthelot, and Hoppe-Seyler, namely, that the intra-molecular transformation of sugar into alcohol and carbon dioxide is due to an enzyme secreted within the yeast cell.

This capital demonstration forms a fitting climax to a long series of speculations on collateral fermentations. We will call to mind the main results achieved by toilers in these different fields of research. In the year 1841 two French chemists, Payen and Persoz, succeeded in isolating from germinating barley a substance which seemed to possess an unlimited capacity for saccharifying starch. They called this substance *diastase*. Later on, in 1860, we find Berthelot experimenting with yeast, and he isolated the substance to which Béchamp, in 1864, gave the name *zymase*. Thirty years after Donath changed this name to *invertin*, and we thus clearly have species of chemical substances which, when abstracted from living organisms, are able to effect certain well-defined fermentations. Meanwhile, it has been shown that many processes of higher life appear to be governed by these soluble, unorganized ferments, or, as Kuhne, in 1878, proposed to call them, *enzymes*. Incidentally, I should here mention that, like many other *termini technici* with which we are familiar, these expressions, ferment, diastase, enzyme, or what-not, must be understood historically; just as logic, metaphysic, analytic organon, etc., can only be apprehended and understood historically. In 1831 Leuchs discovered that saliva possessed the property of saccharifying starch, and fourteen years after Miahle isolated the ferment, and called it *salivary diastase,* a name far preferable to that bestowed upon it by Berzelius, but which remains to this day, I mean *ptyalin.* Then followed the discovery that the specific functions of the stomach, liver, and pancreas were each controlled by their specific ferments, which we shall recognize as *pepsin, rennet,* and *ptyalin.* And now, as the result of the brilliant young Gabriel Bertrand's work, we are even bid to associate the taking up of oxygen by the lungs with the necessary presence of an enzyme, which he has called, appropriately enough, *oxydase.*

It is now possible to discern the connection of Buchner's bold experiment with all this more purely physiological work. He proved that the phenomena apparent when yeast is added to the brewers' wort are identical in principle with all these other fermentive actions, and all the research of more recent years tends but to strengthen one's opinion that the most important functions in the economy of life are under the control of enzymes, or, in other words, partake of the nature of fermentation. Quite recently Dr. Harden has had something to say about zymase. His memoir is illuminating, and, if that were possible, still further opens our eyes to the complexity of the subject. He indicates the presence in yeast juice of "something" of an organic nature which is not affected at boiling temperatures, and to which it owes its power of converting sugar into alcohol and carbon dioxide. Should this nameless "something" be withdrawn from yeast juice, zymase almost loses its characteristic; but, on the other hand, if more be added, so as to swell the normal quantity, the action of zymase may be doubled or quadrupled in ratio to the quantity present. We touch here upon the difficult problems connected with the so-called co-ferments, and we are clearly on the fringe of important discoveries. Indeed, many facts are already at hand which only want of space compels us to withhold for the purposes of the present article. Some German chemists, Bredig among others, have been able to imitate very closely certain fermentations by means of finely-divided metals, such as platinum or gold, and these curious ferment-like solutions may be "poisoned," chloroformed, or killed just as if they were alive. This is all extremely odd, and most perversely mechanical; but there is something behind these phenomena which awaits correlation with vinous fermentation. Meanwhile, about three years ago the *Zeitschrift für Physikalische Chemie* published the following remarkable research, which must furnish us with all the evidence we have leisure to adduce on this occasion: In the course of his paper on the "Influence of Metals on the Hydrolysis of Cane Sugar," R. Vondrácek draws attention to the fact that authorities differ "as to the effect of metals on the well-known slow inversion of saccharose by boiling water," and proves experimentally that strips of platinum foil do not appreciably influence the rate of inversion, thus confirming the results obtained by Lindet. On the other hand saccharose (cane-sugar) is rapidly inverted by boiling water in the presence of platinum black. Sugar solutions acquire a decidedly acid reaction by heating with platinum black for fifteen minutes, and the filtrates undergo inversion on further heating. If after inverting a sugar solution by treatment with platinum black for eight hours the powder be immediately heated with a fresh solution, the latter developes no acidity, and it is not inverted more rapidly than by water alone, but the inverting property of the platinum black is restored by exposure to air. Again, platinum black which has been previously deoxidized by treatment with ammonia, has no influence on the rate of inversion by pure water. From these data it is concluded that the inversion by platinum black is due to the oxygen contained in it, which oxidizes a part of the saccharose to one or several organic acids, and thus supplies hydrogen ions to the solution.

But fermentation is destructive. The ferment of yeast splits up sugar into alcohol and carbon dioxide; pepsin resolves albuminous foodstuffs into substances of, presumably, simple molecular composition, and so all through the list we have had occasion to mention. On the other hand, side by side with this incessant destruction, life is characterized by incessant construction. These form, indeed, the two most striking and essential phenomena of the life process; the destruction, the analysis, is death; the construction, the synthesis, is life. And a constructive ferment appears, from our knowledge of enzymes, to be a plain contradiction in terms. However, even this stumbling block has apparently been removed, and it was a young Englishman, Croft-Hill, who first showed us that a constructive ferment is not only thinkable, but that it actually exists. And here again the lesson was furnished by a yeast cell. In the month of June, 1899, a paper was presented by Croft-Hill to the Chemical Society, in which it was shown that the action of the maltase of yeast (which is the enzyme charged with the special function of converting the sugar maltose into the simpler, and more readily fermentable, sugar glucose) on maltose is hindered by the presence of glucose, and is incomplete. The effects are more marked the stronger the solution of maltose. If the maltase be allowed to act on a forty per cent. solution of glucose, there is an apparently reversed hydrolytic action resulting in the formation of fifteen per cent. of maltose, at which point equilibrium occurs. The same equilibrium point is reached whether we start with a solution of maltose or glucose, so that the action is clearly a reversible one. It has often struck me that the divergent results various chemists have achieved in the study of the decomposition of starch may, perhaps, in some measure be accounted for by the action of constructive enzymes, or rather, one would be safer in saying, by the general tendency, under defined conditions, for reversionary processes to become manifest. It is rather more than twenty years ago since Dr. Wohl noted the phenomena of inversion and reversion in connection with the action of weak acids on certain complicated sugars.

If further evidence be required as to the possibility of what I have named constructive ferments, it may be found in Emmerling's work, which I mention with reserve, on amygdaline. Under the influence of one enzyme, emulsin, this substance is split up into sugar, hydrocyanic acid, and the essence of bitter almonds. But it is said that another ferment, maltase, common to yeast, will join these decomposition products together again to form the original substance.

On one very particular point, that is to say, the molecular construction of these enzymes, ferments, or diastases, the world of science is almost entirely ignorant. This question forms one of the many chemical problems of the hour, and we start with the shallow fact that they contain the simple elements found in charcoal, air, and water. Beyond this we know next to nothing. I think, however, we may console ourselves with the reflection that we are at least on the eve of important discoveries. My friend, and former "chief," Emil Fischer, of Berlin, having vied with Nature herself in the manufacture of sugars, has now turned his attention to proteid substances. The intervening gulf has already been bridged, inasmuch as Fischer has traced the connection between the configuration of a sugar and its behavior toward ferments. This is the famous "Schloss und Schlussel" theory, the happy analogy of "lock and key." It is our every-day experience that yeast cells assimilate more easily the sugars of which the molecular configuration closely resembles that of the most digestible of all carbohydrates, namely, glucose. Many of the artificially produced sugars, as for example the aldoses, gulose and talose. are quite indifferent to the fermentive efforts of yeast, and the complicated bi- and tri-saccharoses are, for the most part, resolved into simpler molecular constructions before suffering the usual decomposition.

There is a fertile field of inquiry open to investigation as to whether some of the curious by-blows of fermentive action may not lead to further discrimination between constructive and destructive fermentation. We have certainly arrived at a point, in so far as these studies are concerned, which bids us be cheery as to the future, for the modern man of science has far outstripped those learned forbears of his who, to use Sir Edward Elgar's lugubrious simile, were like "blind men in a churchyard at midnight, trying to read epitaphs in a forgotten tongue." Emil Fischer's work alone has inspired that able chemist, Dr. M. O. Forster, in saying, "It is permissible to prophesy that his contemporary researches among purine derivatives and synthetical polypeptides will culminate in dramatic results, as they have the character of a reconnaissance preceding an attack on the proteids, which chemists anticipate will share the fate of the two other principal food materials—fats and sugars." Dr. Gustav Mann, of Oxford, in his erudite work on the Chemistry of the Albuminoids (a work based on Cohnheim's treatise, but which forms a much expanded version of the original) strikes the student on its perusal as predicting the early synthesis of an enzyme. Indeed, the advances chronicled therein are potential to a singular degree; but it is not yet time for the full fruits of those hundred-fold labors, directed primarily to the elucidation of yeast and fermentation, to fall to the husbandman's sickle.

It has only been possible for me to touch upon one or two of the manifold thoughts which suggest themselves when one watches the activity of yeast. I might have mentioned the interest which was aroused by the publication of Dr. de Backer's volume, *Les Ferments Thérapeutiques,* in 1896; wherein it is noted in how anxious a manner the yeast cell will swallow up certain bacteria, pathogenic and otherwise, and it is shown how subcutaneous injections of yeast may possibly be used to destroy the germs of many dire diseases. Again, in proof of the medicinal effects these microscopical cells will occasion, I might have quoted the, perhaps hypothetical, story of the Hertfordshire farmer, who went home late one night and drank a pint of yeast in mistake for buttermilk. He arose three hours earlier next morning. Indeed, the thoughts which crowd around these simple cells partake of a character almost universal. To yeast we owe the nation's bread, and the nation's second necessity, beer; and many other needful liquors are ours through the medium of yeast. So wide is the survey that the disjointed reflections I have ventured to place before you form but a tithe of those our theme might legitimately evoke. But all these must now be passed over, and we will conclude with one modest Faust dream. If Croft-Hill is right, and the action of maltase is reversible; if Emmerling's discovery that one ferment may undo the work of another be a true interpretation of Nature, then might we not expect the same reasoning to apply, under conditions yet unknown, to those ferments which convert living protoplasm into relatively dead fatty, connective cartilage or bone tissue? Metchnikoff has declared this process is the invariable symptom of advancing years, and we may quite legitimately ask in what manner this apparent discovery of constructive ferments will ultimately affect such momentous problems.

THE CHEMICAL REGULATION OF THE PROCESSES OF THE BODY[1]

BY WILLIAM HENRY HOWELL, M. D. Ph. D.

At the time of Sir Charles Bell, physiologists were beginning to realize the great importance of the nervous system as a mechanism for regulating and coördinating the varied activities of the body. To use his own expression, "The knowledge of what is termed the economy of an animal body is to be acquired only by an intimate acquaintance with the distribution and uses of the nerves." Since his time experimental investigations in physiology and clinical studies upon man have combined to accumulate a large fund of information in regard to the regulations and correlations effected through nervous reflexes. No one can doubt that very much remains to be accomplished along these same lines, but in recent years we have come to understand that the complex of activities in the animal body is united into a functional harmony, not only through a reflex control exerted by the nervous system, but also by means of a chemical regulation effected through the blood or other liquids of the organism. The first serious realization of the importance of this second method of regulation came with the development of our knowledge of the internal secretions during the last decade of the nineteenth century. The somewhat meager information possessed at that time in regard to these secretions developed in the fertile imagination of Brown-Séquard to a great generalization, according to which every tissue of the body in the course

---

[1] Address of the vice-president and chairman of Section K—Physiology and Experimental Medicine, American Association for the Advancement of Science, Boston, December 28, 1909. From *Science*, January 21, 1910.

of its normal metabolism furnishes material to the blood that is of importance in regulating the activities of other tissues. This idea found a general support in the facts brought to light in relation to the physiological activities of the so-called ductless glands, and subsequently in the series of remarkable discoveries which we owe to the new science of immunology. In recent years it has been restated in attractive form by Schiefferdecker in his theory of the symbiotic relationship of the tissues of the body. According to this author we may conceive that among the tissues of a single organism the principle of a struggle for existence, which is so important as regards the relations of one organism to another, is replaced for the most part by a kind of symbiosis, such that the products of metabolism in one tissue serve as a stimulus to the activities of other tissues. If a muscle is stimulated to greater growth by an excess of functional activity the substances given off to the blood during its metabolism act favorably upon the growth of other muscles which are not directly concerned in the increased work, or upon the connective tissue surrounding and permeating the muscular mass; and conversely, the development of connective tissue from any cause aids directly by its secretions or excretions in the growth of the muscle. There is thus established a *circulus benignus* by means of which each tissue profits from the functional activity of its fellow tissues. From many sides and in many ways facts have been accumulating which tend to impress the general truth that the co-activity of the organs and tissues may be controlled through chemical changes in the liquid media of the body, as well as through nerve impulses, but in physiology at least we owe the definite formulation of this point of view to Bayliss and Starling. Through their investigations upon secretin they obtained an explicit example of how one organ controls the activity of another organ by means of a specific chemical substance given off to the blood. Other facts known in physiology in regard to the internal secretions were easily brought into line with this definite instance furnished by the secretin, and Starling's convenient term of "hormone," as a general designation for such substances, has served to give a wide currency to the conception. The word and the generalization implied by it have been adopted by investigators in many fields of biological research to explain phenomena of correlation which heretofore it has been impossible to bring under the general rubric of nervous reflexes; phenomena which in fact it has been difficult to express clearly in any precise way such as might serve to stimulate direct experimental investigation. An interesting example of this application of the term and the idea contained in it is found in the theory advanced by Cunningham to explain the development and inheritance of secondary sexual characteristics. This author constructs a system of hypothetical hormones which, if present, would account not only for the development of the secondary sexual characters, as the result of the action of specific hormones furnished by the reproductive cells, but would also make conceivable a method by which these secondary characters, like other somatogenic characters, might affect the germ cells in turn in such a definite way as to be transmitted to the following generations. It is not my purpose to criticize this or similar theories. They will doubtless serve a good purpose in stimulating and directing investigations. It does, however, seem probable that the term hormone, like some of the useful terminology of immunology, will be overworked, and that investigators may deceive themselves as well as others when they conclude that any given relationship is an example of hormone regulation. It has occurred to me that it may be useful in connection with this symposium upon the internal secretions to review very briefly the state of our knowledge in regard to the hormones, with the purpose of discussing somewhat the probable nature of their action and the extent of their distribution.

In treating this subject one must consider also the more or less nearly related instances of combined activity of a chemical sort which are expressed by such terms as chemical activators, kinases and co-ferments. These terms, like that of hormone, are relatively new, they have been brought into existence by investigators to explain or to express special reactions connected with metabolism and particularly with the action of ferments. Their precise meaning must be determined by further knowledge of the facts they are intended to describe; but something may be gained by attempting to define them as they are used in physiology at present. The word activator has reference to the fact long known that the ferments, or some of them at least, are secreted in an inactive form, a proferment, which is activated or converted to an active form by a reaction with some definite substance produced elsewhere in the body. Pepsin, for example, is secreted as pepsinogen and is activated to pepsin by the hydrochloric acid formed by other gland cells. Calcium salts are necessary for the activation of the prothrombin, and enterokinase or calcium plays a similar rôle with reference to the trypsinogen. It is to be noted that reactions of this kind are not confined to the ferments. The typical hormone, secretin, exists in the form of an insoluble prosecretin which may be activated by acids, and, according to Delezenne, calcium takes an essential part in the activation of enterokinase, in somewhat the same way as occurs with thrombin. The nature of these activating reactions is not known. The view has been proposed that the inorganic constituents involved, the hydrochloric acid and the calcium for example, act as catalyzers which accelerate a reaction that would occur without their assistance. There is, however, no evidence to show that thrombin is formed in any amount in the absence of calcium salts, nor that pepsinogen yields pepsin without the presence of acids. As Bayliss has pointed out, these reactions belong to the irreversible group, and it is possible that the activator or one of its constituents is represented in the composition of the active substance that is formed. However that may be, it is to be noted that the process of activation is an instance of chemical coördination. The pepsin formed in one kind of gland cell is activated by the acid produced in a different variety of cell. The hydrochloric acid produced in the stomach is carried into the intestin with the flow of chyme and there activates the prosecretin of the intestinal epithelium either directly or indirectly. One tissue, in other words, through its products of metabolism aids another tissue in the performance of its functional duties.

The term kinase is used at present in animal physiology in connection with two reactions only. In both cases it refers to an activating process similar to those just considered, except that the activator is a colloidal substance of unknown composition. The pancreatic juice poured into the duodenum contains its proteolytic enzyme in the form of a trypsinogen which is activated immediately by trypsin by contact with the duodenal epithelium or with the secretion furnished by this epithelium. The activating substance is designated as enterokinase. It is present normally in the intestinal juice formed in this part of the alimentary canal, or it may be obtained in extracts of the mucous membrane of the duodenum or jejunum. According to Pawlow, however, the intestinal secretion obtained by direct mechanical stimulation of the epithelium is lacking in enterokinase. This latter substance is produced in fact only under the influence of some constituent of the pancreatic juice, possibly the trypsinogen itself. In other words, it would seem that the enterokinase must itself be activated before it can fulfil its functions as an activator of the trypsinogen. The chain of inter-related processes occurring at this point in the act of digestion becomes somewhat intricate, as follows: Hydrochloric acid formed in the stomach and brought into the intestin with the chyme stimulates the epithelial cells of the intestin to form secretin and to pass it into the blood. The secretin conveyed by the blood to the pancreas stimulates this organ to secrete pancreatic juice. The pancreatic juice is carried to the duodenum and stimulates the epithelial cells to form enterokinase which then activates the trypsinogen to trypsin. Assuming that all of these steps are verified by future work, we have in this series of events an excellent example of chemical coördination, that is to say, of coördination effected by chemical stimuli conveyed from one organ to another through the liquids of the body. It may be noted in passing that the epithelial cells of the duodenum under the influence of acids or soaps form an internal secretion, the secretin, while under the influence of the pancreatic juice they produce an external secretion, the enterokinase. It is of course possible that these two different functions are subserved by separate cells, but so far as our evidence goes at present we must infer rather that one and the same epithelial cell gives either an internal or an external secretion according to the nature of the chemical stimulus acting upon it. While there can be no doubt at all of the existence of enterokinase and of its wonderful effect in activating almost instantaneously the trypsinogen of the pancreatic juice, much uncertainty prevails as to its nature and its mode of action. Pawlow thought that it belongs to the group of enzymes, and this view has been supported in an almost convincing way by the experiments of Bayliss and Starling. In accordance with this view it is found that the substance exhibits a certain degree of thermolability, being destroyed at a temperature of 67° to 70° C., although in this respect it is less sensitive than most of the well-known enzymes. From this standpoint the action of the enterokinase upon the trypsinogen would come under the general head of catalytic reactions, but here again it is to be observed that its action differs from that of the other enzymes in the great rapidity with which it is completed, a rapidity quite comparable to that of ordinary chemical reactions. Other observers (Dastre and Stassano, Hamburger and Hekma, Cohnheim) have contended that the enterokinase unites permanently and quantitatively with the trypsinogen, after the manner of an amboceptor and complement, to form a new and active compound, the trypsin, and the whole reaction has been still further complicated by the discovery (Delezenne) that the trypsinogen may be activated by calcium salts without the presence of enterokinase. The action of the calcium requires some time for its development, but when it occurs it takes place not gradually, but abruptly, just as in the case of the activation produced by enterokinase. The further fact stated by Delezenne that the enterokinase itself needs the presence of calcium salts before it acquires the property of affecting trypsinogen suggests naturally the thought that the action of the enterokinase may be at bottom another case of calcium activation. Pozerski states that in the inactive pancreatic juice obtained by injections of secretin calcium is not present; whereas in the active juice following upon the use of pilocarpin, calcium is contained, and the digestive action of the juice runs parallel with the content in calcium. But whether the enterokinase acts as a ferment, or an amboceptor, or a calcium carrier it constitutes a special type of organic activator, and this fact suggests the possibility that other processes in the body may be controlled by similar compounds. At present only one other organic activator of this kind has been described, namely, the thrombokinase of blood coagulation. This hypothetical substance is given great importance in the theory of coagulation proposed by Morawitz. According to this theory the blood corpuscles under abnormal environment yield an unknown substance of colloidal nature which, together with calcium, is necessary for the complete activation of thrombin, and therefore for the clotting of blood. A similar kinase is furnished by the tissues in general, so that blood escaping from a vessel and coming in contact with the surrounding tissues obtains from them a kinase which accelerates the process of clotting. The evidence for the existence of this kinase is far less satisfactory than in the case of the enterokinase, indeed one may have serious doubts whether the facts at present warrant the assumption that a specific organic kinase must coöperate with the calcium in activating the thrombin, but if the idea is demonstrated to be correct it will furnish another very interesting example of the way in which chemical coördination may be employed in the body. In this case the blood may be supposed to stimulate the tissue cells to form a substance not directly of importance to their own activity, but which initiates the coagulation of the blood, stops the hemorrhage and thus saves the organism from destruction. The series of events is quite parallel to that described for the pancreatic juice and the enterokinase.

In addition to the activators of the inorganic and the colloidal type there is perhaps a third kind of activation exemplified in the substances known as co-enzymes or co-ferments. This term may be used to define that kind of coöperative activity between an enzyme and some other noncolloidal substance which we see illustrated in the influence of the bile salts upon pancreatic lipase. The process differs from activation of a proferment to a ferment only in that the combination of the enzyme with its activator is dissociable instead of being permanent. By dialysis or otherwise the co-enzyme can be separated from the enzyme and the action of the two may be tested separately or in combination. Perhaps this species of activation may be more common in the animal body than we have supposed. Bierry and Giaja have shown that the amylase of pancreatic juice loses its diastatic action entirely when dialyzed, and this power or property is restored upon the addition of sodium chloride. It would seem from their experiments that the amylase is active only when combined with an acid ion, such as Cl or Br, and the transition from one form to the other, from the active to the inactive or the reverse, is easily accomplished. No one can doubt that all these forms of chemical activation are allied in a general way to the more interesting and obvious mode of chemical coördination illustrated by the hormones. Starling defines hormones as chemical messengers which formed in one organ travel in the blood stream to other organs of the body and effect correlation between the activities of the organ of origin and the organs on which they exert their specific effect. Such substances belong to the crystalloid rather than the colloid class; they therefore are thermostable and do not act as antigens when injected into the living animal. The general idea of this definition is clear and most suggestive, but in its details it is made especially to suit the case of secretion, and therefore may not fit so well for other substances of like physiological value. Conveyance through the blood stream, while certainly the most common occurrence for this class of bodies, ought not to constitute an essential part of their definition. The secretin formed in the intestinal epithelial cell is conveyed to the pancreas in the blood and brings about a correlation between the activity of this gland and that of the duodenum, but on the other hand some substance contained in the pancreatic juice and conveyed to the duodenum in the stream of secretion excites the formation of the enterokinase, and thus correlates the activity of the duodenum with that of the pancreas. The two actions seem to be so similar, except for the means of transport, that one would naturally put them in the same class. By the same reasoning we might be justified in designating the hydrochloric acid of the gastric juice as a hormone in reference to its action in causing a formation of secretin in the epithelial cells of the duodenum. One can imagine that a similar transportation may occur in the secretions of the reproductive or respiratory passages, in the cerebro-spinal fluid, as seems to be the case for a time at least with the secretion of the pars intermedia of the pituitary gland, or even along the axial stream of a nerve fiber. If, as seems to me, the idea of correlation or coördination is the essential point rather than the assumption that the product must constitute an internal secretion, we might modify the definition so far as to designate as hormones those substances in solution which, conveyed from one organ to another through any of the liquid media of the body, effect a correlation between the activities of the organ of origin and the organ on which they exert their specific effect. As regards the nature of the action of the hormones on the organ affected we know too little to make any safe generalization. In the case of the secretin it seems most probable that the hormone arouses the pancreatic cells to an act of secretion, and therefore it has in this instance the value of a chemical stimulus. But in other cases the effect of the hormone may be rather of the nature of an activation. This at least would seem to be true for the hormone, of unknown nature, given off by the pancreas and concerned in the glycolysis of sugar in the organism. The effect of the hormone adrenalin upon the musculature innervated by the sympathetic system may also be of the nature of an activation rather than of a chemical stimulation.

The substances of known composition which may be regarded as playing the rôle of hormones are few in number, three or four at most, as follows: First, the carbon dioxide formed in the tissues, particularly in muscle during contraction. It seems agreed now that the carbon dioxide acts as the normal stimulus to the respiratory center. When produced in the working muscles in such quantities as to raise perceptibly the carbon dioxide tension in the alveoli of the lungs and the blood of the pulmonary veins, the respiratory center is excited to greater activity and the excess above the normal contents is thereby removed; second, the adrenalin of the adrenal glands which in some way, directly or indirectly, makes possible the full functional activity of the involuntary musculature of the body; third, the hydrochloric acid produced in the stomach which stimulates the formation of secretion in the duodenal epithelium; and fourth, possibly the iodothyrin of the thyroid gland with its dynamogenic effect upon the neuromuscular apparatus of the body. In addition there are a number of hormones of unknown composition which have been either proved or assumed to exist, and which are held responsible for certain well-known correlations of function: The pancreatic secretin formed in the epithelium of the duodenum or jejunum which stimulates the flow of pancreatic secretion; the gastric secretin formed in the pyloric mucous membrane which gives rise to the chemical secretion of gastric juice; a secretin formed in the duodenal epithelium which stimulates the formation of intestinal juice in the following segments of the intestin; unknown hormones of pancreatic origin which determine the absorption activity of the intestinal epithelium; vaso-dilator hormones formed in tissues in functional activity and which have a specific effect upon the vessels of the functioning organ; a vaso-constricting and a diuretic hormone formed in the posterior lobe of the pituitary body; a hormone controlling the growth of the bones and connective tissues produced in the anterior lobe of the pituitary body; a hormone controlling the oxidation of sugar in the body and produced in the cells of the islands of Langerhans in the pancreas; a hormone produced in the thymus which controls possibly in some way the development of the reproductive organs; a vaso-constricting hormone formed in the kidneys; a hormone in the salivary glands which controls the flow of water from the blood capillaries in the glands; a hormone produced in the fœtus in utero which stimulates the growth of the mammary glands; a hormone in the ovary which controls the growth of the uterus and the processes of menstruation; a hormone in the ovary which controls the implantation of the fertilized ovum and the growth of placental tissue; a hormone in the testis which initiates the development of the secondary sexual characteristics in the male; hormones of an indefinite number, produced in all the tissues and acting specifically upon the determinants in the gametes in such a way as to make possible the transmission of acquired characteristics. It is evident from this summary that there is a well-developed tendency in physiology at the present day to utilize the conception of hormones to explain all relationships not otherwise intelligible. A few years ago the number of hypothetical enzymes in the body was likely to be increased whenever a new research in metabolism appeared, now the drift seems to be in the direction of manufacturing new hormones. This natural inclination to abuse a new and attractive idea will not of course prejudice us against the great importance of the suggestion which we owe to Bayliss and Starling. It is to be hoped only that no one will be tempted to give to these hypothetical hormones distinctive names, except in cases such as the secretin, adrenalin, etc., in which the substances have been isolated in some degree of purity. For once a specific name has become attached to an entirely unknown substance, it acquires henceforth an easy currency in our literature, and soon many of us unconsciously assume that the thing so designated constitutes one of the verified facts of our science. By way of example one may cite the thrombokinase which has become such a familiar term in the literature of coagulation and which not infrequently is employed by writers as though its existence were a settled fact.

Among his other valuable suggestions regarding the characteristics of the hormones, Starling has called attention to the fact that some of them act by increasing the processes of disassimilation or catabolism, while others apparently stimulate the processes of assimilation or growth. In this latter group we may include the hormones of the anterior lobe of the pituitary body, according to the present conception of the functions of that gland, and all of the hormones of the reproductive cells. These latter have in general what has been designated as a dynamogenic action, they cause hypertrophies in various organs or tissues and invoke therefore processes of synthesis rather than those of splitting and oxidation. Hypertrophy as an outcome of increased functional activity is a familiar phenomenon, but as Nussbaum remarks, the hypertrophy induced by testicular or ovarian hormones resembles rather the effect of the growth energy exhibited by the developing embryo, in that it is dependent upon influences other than those arising from functional use. What these influences may be is at present a matter of pure speculation. In his recent most interesting contributions to our knowledge of growth Rubner has been led to assume that the property of growth in the young organism is connected with certain special chemical complexes in the protoplasmic material, complexes which have nothing directly to do with the simple maintenance of the nutrition of the cell and which after adult life is reached disappear for the most part from the general soma. In line with this hypothesis one might assume that the hormones given to the blood by the reproductive cells contain such complexes which when anchored in certain tissues lead to an accelerated growth. Perhaps the clearest and most interesting experiments made upon the reproductive hormones are those reported by Nussbaum. He chose for his experiments the males of *Rana fusca* whose reproductive organs go through a cyclical period each year. At the proper period the preparation for the mating season shows itself in the hypertrophy of the seminal vesicles, of the thumb pads, and of certain muscles in the forearm. If the frog is castrated these hypertrophies do not occur, or if they have begun before the castration is performed retrogressive changes take place. On the other hand, the usual hypertrophy of the nuptial organs can be initiated in a castrated frog if pieces of the testis from another frog are introduced into the dorsal lymph sacs. The pieces thus introduced do not become grafted permanently, but are gradually absorbed and the growth of the thumb pads and of the muscles in the forearms falls off after this absorption is completed. Nussbaum believes that the stimulating effect of the testicular hormones is not exerted directly upon the tissues which show the increased growth, but rather upon the portions of the central nervous system which innervate these tissues. This belief rests upon the experimental fact that if the peripheral nerves going to the glands and papillae of the thumb pads are severed on one side the testicular hormone affects only the other intact side. This experiment and the conclusion drawn from it opens up the interesting question whether perhaps the reproductive hormones in general exert their effect through the central nervous system. This has not been the usual belief, and the experiments of Nussbaum are open to the obvious objection that the section of the peripheral nerves may have induced certain secondary changes in metabolism which indirectly antagonized the action of the testicular hormone. At present these experiments, so far as I know, have not been repeated with this objection in mind, and it is somewhat gratuitous to criticize the author's conclusions until further work is reported.

THE SCIENCE OF CHEMISTRY AND ITS DEVELOPMENT[1]

THE SCIENCE[1]

CHEMISTRY is that branch of Natural Science which deals with the various material substances that are capable of existence, with their relations to one another, and with the laws governing their various transformations.

THE NAME. The origin of the word chemistry is uncertain. *Chemia* (or *Chemie*) is the old name of Egypt, and as the art of making gold and silver was first practised in that country, the *science of chemia* may have meant originally "the science of Egypt." Later, however, at the time of the Alexandrian alchemists, the word was used to denote some substance; and as, on the one hand, the word *chemi* means "black," and, on the other hand, the first step in the transmutation of metals is known to have been a process of blackening, we conclude *chemia* may have at that time denoted the "philosopher's stone"—i.e., the substance employed in the process of blackening the metals. Similarly, in the form *al-kîmiyâ,* the term is used also by the early Arabic writers to denote, not their art, but the substance employed in that art. With them, however, the term was used in much the same sense as the word *al-iksîr,* and this suggests another possible derivation. The word *iksîr* is derived from the Greek *xeros,* which means dry. Possibly, then, the word *kîmiyâ* may have been derived from the Greek *chymos,* which means liquid; and while at one time both *iksîr* and *kîmiyâ* were used to denote a substance, the words *chymia* and *alchymy* gradually came to

---

[1] Taken from *The New International Encyclopaedia,* vol. iv, page 559. Copyright 1902, 1904, 1905, 1906, 1907, 1909 by Dodd, Mead & Co.

denote the art in which that substance was employed, the substance itself (the philosopher's stone) retaining only the name *al-iksîr*.

THE BRANCHES OF CHEMISTRY. The facts of chemistry have been grouped in a variety of ways, either in the interests of research or according to their usefulness in connection with kindred sciences or with the arts—hence such titles as Animal, Vegetable, Medical, Astronomical, Metallurgical Chemistry, etc., which in a general way explain themselves. Chemistry proper may be considered as comprising the following four branches: analytical, descriptive, general and applied. *Analytical chemistry* may be defined as the art of determining the composition of substances; under the names of technical analysis, physiological analysis, etc., many of its methods form an important part of applied chemistry. *Descriptive chemistry* deals with the chemical and physical characteristics of substances; it forms a record of the properties of substances, which are arranged, for convenience of reference or for didactic purposes, in accordance with the principles of general chemistry. The two great subdivisions of descriptive chemistry are *inorganic* and *organic* chemistry; the latter dealing with the compounds of carbon, the former with those of all the other elements. *General chemistry* includes theoretical and physical chemistry, which are usually treated together. Theoretical chemistry comprises the laws of the composition and chemical behavior of compounds; physical chemistry treats of the physical properties of compounds, of homogeneous mixtures, and of the physical phenomena (thermal, electrical, etc.) accompanying the transformations of substances in general. *Applied chemistry* comprises all the facts and methods of chemistry that find practical employment. The most important subdivisions of this branch are: (1) Biological chemistry, including the facts connected with physiological and pathological phenomena in animals and plants; (2) Agricultural chemistry, which deals with the problems of rural economy; and (3) Industrial, Technological, or Practical chemistry, which deals with the uses of chemistry in the arts and manufactures.

THE METHODS OF CHEMICAL PHILOSOPHY. Like any other science, chemistry may use two different ways of discovering and demonstrating its general principles. On the one hand—and this is the surest way—a principle may be induced from a large number of experimental observations; it is then nothing but a general statement of a general fact and is termed an *empirical* law. Thus the principle of the conservation of matter is an empirical law. Perhaps this law may suggest itself *a priori;* but as a law of science it has been induced from facts established by the balance. On the other hand, there are problems which cannot be attacked by experiment. Thus the problem of the ultimate structure of matter lies far beyond our power of direct observation; yet it is intimately connected with the correlation of substances, and therefore chemistry is compelled to consider it for purely practical reasons. In cases of this nature, chemistry, like any other science, and like speculative philosophy, makes some plausible assumption, termed an *hypothesis.* Like speculative philosophy, it developes the hypothesis, conbines it, if necessary, with other assumptions, and thus builds up a theory. But at this point, where speculative research reaches its *ne plus ultra,* the work of the scientist really begins. The general principles forming part of the theory are busily applied to phenomena capable of direct observation, and then, if their correctness is indicated by actual experiment, they become *theoretical laws.* A scientific theory has for its object, first to correlate seemingly different facts, and, secondly, to throw light on the road of investigation and lead to the establishment of new facts. Thus, the atomic theory has correlated the various substances with regard to their composition and constitution, and it has revealed the existence of innumerable compounds many of which have since been actually prepared—an achievement not unlike the discovery of Neptune by theoretical astronomy.

ALCHEMY[1]

Alchemy is to modern chemistry what astrology is to astronomy, or legend to history. In the eye of the astrologer, a knowledge of the stars was valuable as a means of foretelling, or even of influencing, future events. In like manner, the genuine alchemist toiled with his crucibles and alembics, calcining, subliming, distilling, with two grand objects, as illusory as those of the astrologer—to discover, namely, (1) the secret of transmuting the baser metals into gold and silver, and (2) the means of indefinitely prolonging human life.

Tradition points to Egypt as the birthplace of the science, and the most probable etymology of the name is, as was pointed out above, that it is connected with the most ancient and native name of Egypt, *Chemi* (the scripture Cham or Ham). The Greeks and Romans under the empire would seem to have become acquainted with it from the Egyptians; there is no reason to believe that either people had in early times either the name or the thing. *Chemia* occurs in the lexicon of Suidas, written about the eleventh century, and is explained by him to be "the conversion of silver and gold." It is to the Arabs, from whom Europe got the name and the art, that the term owes the prefixed article *al* (the); as if *chemia* had been a generic term embracing all chemical operations, such as the decocting and compounding of ordinary drugs, and *the chemia* (*al-chemy*) the term to denote the grand operation of transmuting metals—the chemistry of chemistries. The Roman Emperor Caligula is said to have instituted experiments for the producing of gold out of orpiment (sulphide of arsenic); and in the time of Diocletian, the passion for this pursuit, conjoined with magical arts, had become so prevalent in the empire that that emperor is said to have ordered all Egyptian works treating of the chemistry of

---

[1] From *The New International Encyclopaedia*, vol. i, page 289. Copyright 1902, 1904, 1905, 1906, 1907, 1909 by Dodd, Mead & Co.

gold and silver to be burned. For at that time multitudes of books on this art were appearing, written by Alexandrine monks and by hermits, but bearing famous names of antiquity, such as Democritus, Pythagoras and Hermes.

At a later period the Arabs took up the art, and it is to them that European alchemy is directly traceable. The school of polypharmacy, as it has been called, flourished in Arabia during the caliphate of Abbassides. The earliest work of this school now known is the *Summa Perfectionis,* or "Summit of Perfection", composed by Geber about the eighth century; it is consequently the oldest book on chemistry proper in the world. It contains so much of what sounds like jargon to modern ears, that Dr. Johnson ascribes the origin of the word "gibberish" to the name of the compiler. Yet, when viewed in its true light, it is a wonderful performance. It is a kind of text-book, or collection of all that was then known and believed. It appears that these Arabian polypharmacists had long been engaged in firing and boiling, dissolving and precipitating, subliming and coagulating chemical substances. They worked with gold and mercury, arsenic and sulphur, salts and acids, and had, in short, become familiar with a large range of what are now called chemicals. Geber taught that there are three elemental chemicals—mercury, sulphur and arsenic. These substances, especially the first two, seem to have fascinated the thoughts of the alchemists by their potent and penetrating qualities. They saw mercury dissolve gold, the most incorruptible of matters, as water dissolves sugar; and a stick of sulphur presented to hot iron penetrates it like a spirit, and makes it run down in a shower of solid drops, a new and remarkable substance possessed of properties belonging to neither iron nor to sulphur. The Arabians held that the metals are compound bodies, made up of mercury and sulphur in different proportions. With these very excusable errors in theory, they were genuine practical chemists. They toiled away at the art of making "many medicines" (polypharmacy) out of various mixtures of such chemicals as they knew. They had their pestles and mortars, their crucibles and furnaces, their alembics and aludels, their vessels for infusion, for decoction, for cohobation, sublimation, fixation, lixiviation, filtration, coagulation, etc. Their scientific creed was transmutation, and their methods were mostly blind gropings; and yet in this way they found out many a new substance and invented many a useful process.

From the Arabs alchemy found its way through Spain into Europe, and speedily became entangled with the fantastic subtleties of the scholastic philosophy. In the middle ages it was chiefly the monks that occupied themselves with alchemy. Pope John XXII took great delight in it, though it was after forbidden by his successor. The earliest authentic works on European alchemy now extant are those of Roger Bacon (died about 1294) and Albertus Magnus. Bacon appears rather the earlier of the two as a writer, and is really the greatest man in all the school. He was acquainted with gunpowder. Although he condemned magic, necromancy, charms and all such things, he believed in the convertibility of the inferior metals into gold, but did not profess to have ever effected the conversion. He had more faith in the elixir of life than in gold making. He followed Geber in regarding potable gold—that is gold dissolved in *aqua regia*—as the elixir of life. Urging it on the attention of Pope Nicholas IV he informed his Holiness of an old man who had found some yellow liquor (the solution of gold is yellow) in a golden vial when plowing one day in Sicily. Supposing it to be dew he drank it; he was thereupon transformed into a hale, robust and highly accomplished youth. Bacon no doubt took many a dose of this golden water himself. Albertus Magnus had a great mastery of the practical chemistry of his times. He was acquainted with alum, caustic alkali, and the purification of the noble metals by lead. In addition to the sulphur-and-mercury theory of metals, drawn from Geber, he regarded the element water as still nearer the soul of nature than either of these bodies. He appears, indeed, to have thought it the primary matter, or the radical source of all things—an opinion held by Thales, the father of Greek speculation. Thomas Aquinas also wrote on alchemy, and was the first to employ the word *amalgam.* Ramond Lully is another great name in the annals of alchemy. His writings are much more disfigured by unintelligible jargon than those of Bacon and Albertus Magnus. He was the first to introduce the use of chemical symbols, his system consisting of a scheme of arbitrary hieroglyphics. He made much of the spirit of wine (the art of distilling spirits would seem then to have been recent), imposing on it the name of *aqua vitae ardens.* In his enthusiasm he pronounced it the very elixir of life.

But more famous than all was Paracelsus (1493-1541, A.D.), in whom alchemy proper may be said to have culminated. He held that the elements of compound bodies were salt, sulphur and mercury—representing respectively earth, air and water; fire being already regarded as an imponderable—but these substances were in his system purely representative. All kinds of matter were reducible under one or the other of these typical forms; every thing was either a salt, a sulphur, or a mercury, or, like the metals, it was a "mixt" or compound. There was one element, however, common to the four; a fifth essence or "quintessence" of creation; an unknown and only true element, of which the four generic principles were nothing but derivative forms or embodiments. In other words, Paracelsus inculcated the dogma that there is only one real elementary matter—nobody knows what. This one prime element of things he appears to have believed to be the one universal solvent of which the alchemists were in quest, and to express which he introduced the term *alcahest*—a word of unknown etymology but supposed by some to be composed of two German words *all' Geist,* "all spirit." He seems to have had the notion that if this fifth essence or quintessence could be got at, it would prove to be at once the philosopher's stone, the universal medicine, and the irresistible solvent.

After Paracelsus, the alchemists of Europe became divided into two classes. The one class was composed of men of diligence and sense, who devoted themselves to the discovery of new compounds and reactions—practical workers and observers of facts, and the legitimate ancestors of the chemists of the era of Lavoisier. The other class took up the visionary and fantastical side of the older alchemy, and carried it to a degree of extravagance previously unknown. Instead of useful work, they compiled mystical trash into books, and fathered them on Hermes, Aristotle, Albertus Magnus, Paracelsus and other really great men. Their language is a farrago of mystical metaphors, full of ''red bridegrooms'' and ''lily brides'', ''green dragons'', ''ruby lions'', ''royal baths'', ''waters of life'', etc. The seven metals correspond to the seven planets, the seven cosmical angels, and the seven openings of the head—the eyes, the ears, the nostrils and the mouth. Silver was Diana, gold was Apollo, iron was Mars, tin was Jupiter, lead was Saturn, etc. They talk forever of the power of attraction, which drew all men and women after the possessor; of the alcahest, and the grand elixir which was to confer immortal youth upon the student who should prove himself pure and brave enough to kiss and quaff the golden draught. There was the great mystery, the mother of the elements, the grandmother of the stars. There was the philosopher's stone and there was the philosophical stone. The philosophical stone was younger than the elements, yet at her virgin touch the grossest calx (ore) among them all would blush before her into perfect gold. The philosopher's stone, on the other hand, was the first-born of nature, and older than the king of metals. Those who had attained full insight into the arcana of the science were styled ''wise''; those who were only striving after the light were termed philosophers; while the ordinary votaries of the art were called adepts. It was these visionaries that formed themselves into Rosicrucian societies and other secret associations. It was also in connection with this mock alchemy, mixed up astrology and magic, that quackery and imposture so abounded, as is depicted by Scott in the character of Dousterswivel in the *Antiquary.* Designing knaves would, for instance, make up large nails, some of iron and some of gold, and lacquer them so that they appeared to be common nails, and when their credulous and avaricious dupes saw them extract from what seemed to be plain iron an ingot of gold, they were ready to advance any sum that the knaves pretended to be necessary for applying the process on a large scale. It is from this degenerate and effete school that the prevailing notion of alchemy is derived—a notion that is unjust to the really meritorious alchemists who paved the way for the modern science of chemistry.

Priestley, Lavoisier and Scheele by the use of the balance tested the results of alchemy, and hence the fundamental ideas of modern chemistry were born; but the work had already been begun by men of genius, such as Robert Boyle, Bergmann and others. It is interesting to observe that the doctrine of the transmutability of metals—a doctrine which it was at one time thought that modern chemistry had utterly exploded—receives not a little countenance from a variety of facts every day coming to light; not to speak of the periodic law of the elements, which, while separating the elements as a class from all other chemical substances, seems to indicate the existence of unknown relations between the elements themselves.[1]

---

[1] The literature of alchemy is enormous. Those who desire to read more about it may consult the following works: H. Kopp, *Die Alchemie in älterer und neurer Zeit* (1886), see a review of it in this volume; J. von Liebig, *Familiar Letters on Chemistry* (London, 1851); F. Hofer, *Histoire de la Chimie* (Paris, 1869); M. Berthelot, *Les Origines de l'Alchimie* (Paris, 1885); etc.

History of Chemistry[1]

The history of ancient philosophy records certain theories of matter which have had a directing influence on chemical thought during later centuries. The most important ideas date from the fifth century, B.C. Empedocles (c. 490-30 B.C.), who may have derived his views from the ancient philosophers of the East, held that air, water, earth and fire are the four elements unrelated to one another and forming the basis of the universe. Aristotle (384-322 B.C.) added a fifth element, *ousia,* a purely spiritual substance pervading the infinity of space. During the Middle Ages not a little energy was lost in researches after this "fifth essence" which, by confusion of ideas, came to be regarded as a fifth elementary form of matter. To Aristotle the material elements were not altogether different from one another, but were forms of a primary substance differentiated by properties—as dry, moist, hot, cold—that were not essential to its nature. Hence, later, the alchemist's attempt to turn metals into one another, crowned by the belief that such transmutations cannot be effected by any known means. The conception of the atom dates from Democritus (c. 460-370 B.C.), who held that all bodies are made up of the atoms of one and the same substance, and that the difference exhibited by the various forms of matter are due entirely to the differences in the size and shape of the atoms. It is hardly necessary to state that if this undeveloped idea of Democritus had not furnished a suggestion that led to the building up of a useful chemical doctrine, it would deserve no mention in the history of science. It is thus clear that the ancients did nothing directly to the building up of a science of chemistry. Indeed, how much chemical knowledge can we expect to find in an age when a man like Aristotle did not hesitate

---

[1] From *The New International Encyclopaedia,* vol. iv, page 566. Copyright 1903, 1904, 1905, 1906, 1909 by Dodd, Mead & Co.

to assert that "a vessel will hold as much water when filled with ashes as when empty"?

However, the ancients knew some facts which lie within the scope of modern chemistry. Most of that knowledge was gained empirically by the Egyptians, and was by them communicated to the Jews and Phoenicians, and later to the Greeks and Romans. The metallurgy of gold, silver, copper, iron, lead, tin, mercury, and perhaps zinc, and the preparation of certain alloys, were known at quite an early date. The Egyptians had highly developed the art of making glass and of coloring it by means of certain metallic oxides, and many extant specimens of Egyptian pottery are beautifully enameled in various colors. The art of dyeing fabrics by the aid of mordants had likewise been developed at an early date, and many mineral and organic coloring matters were known to the Egyptians, Phoenicians and Jews. The Egyptians were also probably the first to compound substances for medicinal purposes.

The arts of metallurgy and of dyeing remained through the Middle Ages practically what they had been in Egypt long before the beginning of our era. Nevertheless, the alchemists, in their search after the philosopher's stone, discovered methods of preparing many new substances, perfected many processes of manipulation, and thus slowly paved the way for future investigators. Bismuth and antimony, sulphuric, hydrochloric and nitric acids, the chloride and carbonate of ammonium, the nitrates of potassium and silver, compounds of mercury, antimony and arsenic—these and many other important substances were first prepared and their properties were first studied by the alchemists. Of course the interpretation of the known facts was absurd, based as it often was upon the most groundless assumptions—for instance, the assumption that most substances, and all metals contained sulphur. As to the compounds of carbon, the alchemists did hardly anything toward laying a foundation for future organic chemistry, although they learned to concentrate aqueous acetic acid by distillation and to prepare a few metallic acetates, and were familiar with certain reactions, such as the transformation of ordinary alcohol under the influence of sulphuric acid, the formation of certain esters, etc. A number of substances derived from the organic world were also used for medical purposes; but it was not until the beginning of the ''iatrochemical'' period (*iatros,* physician) that the art of preparing substances began to be looked upon as the handmaiden of medicine. Alchemy proper had only two great objects in view—to ennoble the base metals and to prolong life indefinitely—and these remained the aim of some of the best men even to the close of the era of iatrochemistry, and even the scientific achievements of more recent times have not sufficed to banish the fancy completely.

The first great iatrochemist was Paracelsus (1493-1541), who taught that the aim of chemistry was the preparation, not of gold, but of therapeutic agents. Adopting a view current among alchemists prior to his time, he held that, every thing being composed of sulphur, mercury and salt, if the amounts of these happen to rise above or fall below the normal quantities that are in the animal body, the result is a condition of disease. Hence, disease must be combated by chemical means. Paracelsus therefore devoted himself to pharmacy and medical chemistry, and soon became famous through the many happy cures that he actually succeeded in effecting. Unfortunately the adventurous life he led, and his gross lack of modesty, aroused suspicion in many, and the bitterest opposition among the more conservative members of the medical profession, and obscured his fame and greatly diminished the sphere of his influence. Nevertheless, his great work was accomplished; pure alchemy had received at his hands the first powerful blow, pharmacy had been firmly linked to chemical science, and medicine had been aroused from the torpor of many centuries.

Following in the steps of Paracelsus came Turquet de

Mayerne (1573-1655), Andreas Libavius (?-1616), Oswald Croll, Adrian van Mynsicht, and the great Van Helmont (1577-1644). Van Helmont not only realized that the processes of life, in health and disease, are largely dependent upon chemical changes, but he abandoned the abitrary assumptions of Paracelsus concerning the chemical basis of the animal body, and his keen experimental researches imparted a powerful impulse to the development of scientific medicine. Equally if not more important was his recognition of the fact that there may be other gases than air, and that atmospheric air, "carbonic acid," hydrogen, marsh gas and "sulphurous acid" may be quite different from one another. In certain special cases Van Helmont succeeded in showing that substances are not lost, either qualitatively or quantitatively, when they enter into chemical combination, and that they may be re-obtained from the resulting compounds. Yet he believed in the possibility of making gold, and, strange to relate, among the absurdities found in his writings is the assertion that mice may be spontaneously produced in buckets filled with soiled linen and wheat flour! But if the spirit of the time permitted such beliefs, so much more deserved is his place among the best names of both chemistry and medicine. Other important names connected with iatrochemistry are those of Silvius (1614-1672) and Tachenius. Silvius was the first to grasp the similarity between the processes of respiration and combustion, and, recognizing the distinction between arterial and venous blood, he understood that the bright color of the former was due to the action of the air. Digestion, too, he considered as a purely chemical process. His pupil, Tachenius, was the first to clearly recognize that salts are substances formed by the union of acids and bases; he studied the composition and properties of many substances, invented a number of interesting qualitative tests, and even subjected a few reactions to quantitative investigation; determining, for instance, the gain in weight involved in the oxidation of lead.

The age of iatrochemistry marks a great period in chemical history. During this period, for the first time we find many thoughtful men making an endeavor to free themselves from the preconceived ideas of the past, and to approach nature in a critical spirit and with a curiosity purely scientific. With iatrochemistry was thus born the possibility of chemical progress. But this is not the only thing for which mankind is indebted to that period. For, while the iatrochemists were preparing the first material for the very foundation of future chemistry, others were busy developing industries which have since become affiliated with our science. Foremost among these men were Agricola, Palissy and Glauber. Georg Agricola (1490-1555) rendered great service to mining and metallurgy, introducing rational methods into the former and perfecting many of the processes of the latter. His splendid treatise on metallurgy, in which these processes were described for the first time, long remained the standard work on its subject. Besides, he introduced a practical system for the classification of minerals, based on their physical properties, such as color, hardness, etc. Bernhard Palissy (c. 1510-89), considering worthless and ridiculous the efforts of alchemy, devoted himself to experimental research in ceramic art, and invented a number of valuable methods of coloring and enameling articles of pottery. Johann Rudolf Glauber (1604-1668) improved many processes of dyeing and prepared a number of useful salts, including sodium sulphate ("Glauber's salt"), the chlorides of zinc, tin, arsenic, copper, lead and iron, the nitrate of ammonium, tartar emetic, etc. He even succeeded in gaining an insight in the *rationale* of certain processes; but this did not prevent him from adhering to the most fantastic of the absurdities of alchemy to the very end of his life. In connection with the iatrochemical period, reference must be made to the wonderful development of the art of making articles of glass, and to the rapid progress of the liquor industry, which had only been founded towards the end of the fifteenth century—i.e., a short time before the commencement of the period. As to scientific pharmacy, we have already stated that its beginning coincides with that of iatrochemistry, and it is hardly necessary to add that the latter enriched it with many new preparations, and with a knowledge of the medicinal properties of substances already known.

About the middle of the seventeenth century iatrochemistry came to a sudden decline. That this had to happen sooner or later is clear, if we consider that a true medical chemistry could not possibly flourish until chemistry itself was placed on a sound basis, and before anatomy and physiology had attained a stage of serious development. The iatrochemists had evidently misdirected their efforts, and if we should in our present structure of chemistry mark the parts established by them, we would find that their lasting contributions were very few. The historical importance of the period lies chiefly in the fact that with it came a revolution against traditional errors and a change in the direction of research.

In the seventeenth century we find the Englishman, Robert Boyle (1627-91), grasping truth with an insight unprecedented, and in many respects as yet unsurpassed. Boyle understood that chemistry must be treated as an independent science—i.e., primarily without reference to applications of any sort, and that only in this manner could the relationships between chemical phenomena proper be discovered. He maintained that chemists should consider as an element only a substance which, in spite of exhaustive actual efforts, they have not succeeded in decomposing. And even this method, though necessary and sufficient for the purposes of science, he did not regard as proving the elementary nature of substances beyond doubt. Still, he was inclined to consider the metals as elements, and, proving experimentally that the products of the destructive distillation of wood are compounds, he refuted the opinion—then generally prevalent—that dry distillation breaks up substances into their elements. He further defined the distinction between a chemical compound and a mixture; he maintained that the properties of a chemical compound are quite different from those of its components, and that in a mixture each retained its characteristic properties practically unaffected. Above all, he earnestly warned chemists against adopting hypotheses and general theories *a priori.* Theories are necessary; but unless they are generalizations cautiously made from observed facts, they may be dangerously misleading.

Boyle's views are now accepted universally. Had he grasped and succeeded in spreading abroad one more idea —viz., the absolute necessity of quantitative investigation— he would doubtless have become the founder of the science of chemistry—that is to say, with him would have commenced the epoch enlightened by truth and free from fundamental errors. This he did not accomplish; nor was it possible to accomplish it before the characteristics of gaseous matter came to be known better than they were in his day. And so it came about that chemists failed to appreciate his great warning against hypotheses that are not rigidly correlated with facts, and adopted a belief in a fiery "phlogiston"; thus creating a period of darkness that lasted a century. It must be remembered that the important phenomena of what we now call oxidation engaged the attention of chemists toward the end of the seventeenth century and through the entire eighteenth century. These phenomena were explained by the supposed existence of "phlogiston," a substance that may have been first produced in the mind of some alchemist, but the first clear reference to which, under the name of *terra pinquis,* we find in the works of Becher (1635-82). Stahl (1660-1734) named it phlogiston, endowed it with certain imaginary properties, and used it as the basis of a doctrine that was soon accepted throughout the civilized world.

To give a clear and precise account of this, as of any other erroneous doctrine, is a matter of considerable difficulty. For when ingenious men are dominated by error, they usually mold it in a variety of forms to give it the appearance of truth and render it consistent with itself. The phlogistonians handled their hypothesis with much dexterity. Yet their thought, lacking the character of quantitative precision, was weak; for quantitative conceptions, while already mastered by the physicists, were still in a state of confusion in the minds of the chemists. Distinguishing clearly between the weight of bodies and their specific gravity, we have no difficulty in understanding that although water vapor is lighter than air, its addition to a given body must increase the weight of the latter, because water, whether liquid or vaporized, has weight. Stahl believed that the conversion of a ''calx'' (i.e. a metallic oxide) into a metal was caused by the addition of phlogiston. He knew that the conversion was accompanied by the diminution of weight; but from this fact he only deduced that phlogiston must be ''lighter than air,'' failing to grasp that such an addition may make a body *lighter*, in the sense of producing one of lower specific gravity, but necessarily make it *heavier* in the sense of increasing its absolute weight. It is more probable, however, that Stahl understood this in a general way, but thought that the metals had a lower specific gravity than their calces. At least, Juncker, a pupil of Stahl's, asserts this about metals and calces as a matter of fact, although Boyle had long since shown experimentally that the specific gravity of metals is really higher than that of their calces. Much more extraordinary is the conception that we find in the writings of Guyton de Morveau, Macquer and others, who taught that phlogiston had *less than no weight!* Stahl conceived of phlogiston as a fiery principle, ''*materia aut principium ignis, non ipsi ignis.*'' Seeing that charcoal burns up completely, and is capable of producing metals by adding itself, as he thought, to their calces, he considered charcoal as made up almost entirely of phlogiston. Cavendish knowing that ''inflammable air'' is given off when metals are dissolved in acids, adopted the view that inflammable air (hydrogen) was phlogiston, with which metals part on coming in contact with acids. An inconvenient fact in connection with the phlogistic theory was that combustion, including the transformation of metals into calces, could only take place in the air. Stahl and his followers referred to this fact as if it were quite natural that if phlogiston was to be absorbed from metals there must be a medium capable of absorbing it. There were thoughtful men, however, who would not be satisfied with explanations of this kind. Boerhaave, whose *Elementa Chemiae* (1732) served for many years as the standard text-book of chemistry, taught distinctly that the conversion of metals into calces involved the absorption of something from the air. This he deduced by combining the fact that the presence of air was necessary with the fact that the conversion involved increase in weight. The latter fact he even freed from an erroneous explanation attached to it by Boyle, who had thought that the increase in weight was due to the absorption of heat during calcination. By the use of the balance Boerhaave showed that metals have precisely the same weight when glowing hot as when cold, and thus proved that heat has no weight. So near the truth were some. Yet none rose to combat the phlogistic theory, and all—even Boerhaave—were dominated by it more or less.

Two things were necessary to make away with phlogiston: First, a clear knowledge of some of the ordinary gases; second, a clear quantitative knowledge of some of the ordinary chemical transformations. The gases in question are carbon dioxide, oxygen and air. As to quantitative chemical knowledge, it can, of course, be acquired ultimately only by the use of the balance. Carbon dioxide (called "carbonic acid") was known since the time of Van Helmont; yet chemists were not sure but that it might be impure air, until Joseph Black isolated it and demonstrated its properties in 1755. Bergman completed the study of this gas in 1774. The presence and properties of oxygen were suspected by Boyle, Mayow (1669), Boerhaave and others; but it was first actually isolated by Priestley and Scheele in 1774. The nitrogen of the air was isolated by Rutherford in 1772. It must be remarked here that the apparatus and manipulations of "pneumatic chemistry" were gradually perfected by Boyle, Hales, Moitrel d'Elément, Black and Priestley (the latter having invented the method of collecting gases over mercury), which rendered possible the isolation of gases that are soluble in water. But the precise demonstration of the composition of gases and the introduction of the systematic use of the balance are due to the founder of quantitative chemistry, the French physician and chemist Lavoisier.

But before we proceed to further narrate the progress of chemical philosophy, it remains to enumerate briefly the achievements of chemical technology during the reign of phlogiston. In spite of this fundamental error, chemistry was making fairly rapid progress, and this naturally told on the industries. Boyle and Kunkel improved many metallugical processes and the manufacture of glass. The manufacture of iron and steel owed valuable improvements to the researches of Bergman, Gahn, Rinman and Réaumur. Stahl, Scheele, Hellot, Macquer and others introduced new dyestuffs and improved many processes of dyeing. The preparation of zinc was improved by Marggraff and its manufacture on a large scale was commenced at Bristol in 1743. The manufacture of sulphuric acid was commenced by Ward at Richmond; and in 1746 lead chambers were first introduced by Roebuck. In 1747 Marggraff discovered sugar in beets; the sugar industry, however, was not born until the beginning of the nineteenth century. Early in the eighteeth century (1703) Böttger was accidentally led to the invention of porcelain, and its manufacture commenced at Meissen in 1710; but the process was kept secret, and the manufacture was confined to Meissen until Réaumur rediscovered it by systematic research, and finally, in 1769, great porcelain works were established at Sèvres, near Paris. In the course of the period many substances were introduced as therapeutic agents, and Scheele discovered a number of important compounds of carbon.

If, after we have become accustomed to think of modern chemistry as founded in the latter part of the eighteenth century, we take up the writings of phlogistic chemists prior to that time, we may be greatly surprised to find that our general principles were not at all unknown to them. They certainly believed in the indestructibility of matter, and some of them described molecules and atoms in much the same way as we describe them at the present day. And yet their knowledge cannot be rightly considered as constituting a science. Their abstract speculations were very keen; their knowledge of chemical facts was quite extensive; but that mathematical correspondence between abstract principles and concrete phenomena which alone constitutes science did not exist. And so, even when the properties of gases were no longer unknown, all chemical knowledge remained in a state of confusion, and elements continued to be considered as compounds, compounds as elements, combinations as decompositions, and decompositions as combinations, until the work of establishing the scientific correspondence was begun by Lavoisier.

Endowed by nature with a keenly critical mind, Lavoisier acquired the habit of quantitative thinking by early training in mathematics and physics, and by subsequent association with some of the most brilliant mathematicians and physicists of his time. As early as 1770 we find him solving a problem of chemistry by a purely quantitative method. It was known, namely, that when water is kept boiling for some time in a glass vessel, there is formed in it an earthy deposit; it was therefore believed that water could be converted into "earth". Lavoisier heated water in a glass vessel, weighed the vessel before and after the operation, and found that the vessel plus the deposit after the operation weighed exactly as much as the vessel alone weighed before. He thus proved that the earthy deposit came, not from the water, but from the glass of the vessel. In 1772 he turned the same quantitative method of experimenting and reasoning to the conversion of metals into calces, and in 1774 published the following observation: "When metallic tin is heated in a sealed retort full of air, it becomes transformed into its calx; the weight of the sealed retort with its contents is exactly the same after the reaction as before; if the retort is now opened, air rushes into it and the weight is increased; the increase is equal to the difference in weight between the calx formed and the mass of metallic tin employed." From this Lavoisier concluded that the transformation of tin into its calx involved the absorption of air, and that phlogiston had nothing to do with the phenomenon. It also became evident to him that the balance of precision could serve the chemist no less than the telescope served the astronomer, and that the principle of indestructibility, which could and should be established experimentally, ought to be at the basis of all chemical reasoning. When Priestley and Scheele discovered oxygen, they thought that it was this constituent of air that was capable of absorbing phlogiston from metals; Lavoisier demonstrated that it was this constituent of air that combined with metals to form calces. He recognized that the same gas combined with sulphur, phosphorus, charcoal and other combustible substances and as he regarded the resulting compounds as acids, he gave to the gas the name oxygen (from the Greek *oxys,* acid, and *genes,* producing), and adopted the view that it was an indispensable constituent of all acids (this view was discarded half a century later). Carbonic acid he recognized as a compound of carbon and oxygen, and when Cavendish found that the sole product of the combustion of hydrogen in oxygen was water, Lavoisier understood that water was not an element, but a compound of hydrogen and oxygen, and had no difficulty in determining its quantitative composition. Carbonic acid and water he also showed to be the products of the combustion of organic substances, and soon he recognized that respiration too, was a process of organic combustion.

Logical and consistent as Lavoisier's method appears to the unprejudiced mind, it failed to appeal to some of the most eminent men of his time. Thoroughly accustomed to the inverted principles of the phlogistic doctrine, those men adhered to them as firmly as fanatics will adhere to an absurd creed, and some of them, including Priestley, himself the discoverer of oxygen, died believers in phlogiston. Nevertheless, Lavoisier lived to see the light of his system spread over the entire scientific world, and turn chaos into order. He had established a rigid correspondence between the law of indestructibility and chemical transformations, and had thus built the first bridge between an abstract principle and the world of chemical phenomena. The concept element was now correctly applied to oxygen, hydrogen, carbon, sulphur, phosphorus and the metals then known in the free state; the concept compound was correctly applied to water and the oxides of the metals. True enough, in his list of elements (1787) Lavoisier included also light and heat and the compounds potash, soda and lime; while, on the other hand, he considered the element chlorine as a compound containing oxygen. But this did not interfere with further progress. The first bridge of chemistry was firmly established, and the lingering errors were rectified (mainly by Sir Humphry Davy) early in the nineteenth century. The development of another correspondence—viz: that between the hypothesis of the atomic constitution of matter and the quantitative composition of substances—has been already noted in a preceding section of this article. Here it may be observed that the law of multiple proportions was first discovered by Richter (1762-1807), and that Proust (1754-1826) continued Richter's researches and clearly demonstrated the law in course of a controversy with Berthollet. Dalton (1804) re-discovered the law deductively and then proved it experimentally; he was thus the first to establish a rational connection between the old atomic hypothesis and the facts of chemical composition.

After the relation between the known metals and their oxides was established, Lavoisier himself, and others, began to suspect the true nature even of oxides whose metals were not yet known in the free state, and attempts began to be made to decompose these oxides so as to isolate their metallic elements. About the beginning of the nineteenth century, Sir Humphry Davy (1778-1829) undertook to investigate the effect of the galvanic current on chemical compounds. In 1807-08 he succeeded in decomposing caustic potash and caustic soda, obtaining from them the metals potassium and sodium.

About the same time Seebeck similarly decomposed the oxides of calcium, barium, strontium and magnesium, obtaining these metals in the form of their amalgams—i.e. combinations with mercury. From these amalgams Davy isolated the metals themselves and gave them their present names. From the metals Davy turned his genius to the non-metallic elements. Chlorine, known since 1774, remained unrecognized as an element, and was generally considered as the oxide of hydrochloric acid. In 1811 Davy clearly demonstrated its elementary nature; and when, soon afterwards, Courtois discovered iodine, Davy showed that this substance, too, so similar to chlorine, must be considered as an element. Davy also was the first to demonstrate clearly the elementary nature of nitrogen and even of fluorine (from the similarity of hydrofluoric to hydrochloric acid, and of the fluorides to the chlorides), although the latter element was not then known in the free state, and remained unknown until 1887. The value of Davy's contributions can be readily appreciated if we remember that the substances he was dealing with are among the commonest in the entire range of chemistry, and if we imagine how much confusion would suddenly ensue in all departments of the science if we were to forget their existence or their true nature.

Dualism. On the basis of his electrolytic investigations Davy also constructed an electro-chemical theory which was subsequently modified and extended by Berzelius. According to Davy (1807) when the atoms of different elements come into contact, they become charged with the opposite forms of electricity, by whose attractive force they are held together, constituting chemical compounds. Berzelius' theory was as follows: "The atom of each element does not become charged with electricity on coming in contact with other atoms, but is charged, whether combined with other atoms or not. With respect to the electrical charges of their atoms, the elements form an 'electro-chemical order,' oxygen being about the most electro-negative, potassium the most electro-positive of elements. All bases are produced by the combination of oxygen with electro-positive elements and all acids by the combination of oxygen with electro-negative elements. Yet bases and acids are not altogether neutral, in the former positive electricity, in the latter negative electricity, predominates. This is why bases and acids show no mutual chemical indifference, but combine to form salts. When the terminals of a sufficiently powerful galvanic battery are immersed in the solution of a salt, the base of the latter is attracted more strongly by the negative terminal than by the acid; and the acid is attracted more strongly by the positive terminal than by the base; hence electrolysis ensues, the base being deposited on the negative, the acid on the positive, terminal." In brief, Berzelius maintained (1) that oxygen is an indispensable constituent of bases, acids and salts; (2) that bases, acids and salts have a dual constitution, each being made up of an electro-positive and an electro-negative part; (3) that chemical affinity is nothing but the mutual attraction of opposite forms of electricity. In the first of these principles Berzelius followed Lavoisier, for years refusing to accept Davy's view that chlorine and nitrogen were elements, and that their compounds with hydrogen—namely hydrochloric acid and ammonia—although respectively an acid and a base, contained no oxygen. The structure of the entire theory became somewhat shaky when the correctness of Davy's views was finally recognized by all, including Berzelius himself (1820). Nevertheless, Berzelius, and with him the entire chemical world, continued to adhere to the electro-chemical theory, and thus a strictly dualistic conception of compounds continued to reign in the science. The thirties, however, brought much new evidence against Berzelius' principles. First of all it was recognized that electrolysis breaks up a salt, primarily not into two oxides, but into a free metal and an acid radicle. For example, potassium sulphate is broken up, primarily, not into K_2O and SO_3, but into 2K and the radicle SO_4. This made it evident that sulphuric acid was not SO_3, but H_2SO_4 (i.e. SO_3 chemically combined with H_2O), because the SO_4 radicle was seen to be the true acidic component of potassium sulphate. Two important conclusions thus thrust themselves upon chemists: (1) An acid is not a binary compound of oxygen with an electro-negative element, but a combination of hydrogen with an electro-negative radicle; (2) a salt is not a compound of two oxides (e.g. $K_2O.SO_3$) but a combination of a metallic element with the electro-negative radicle (e.g. SO_4) of an acid. The first of these conclusions, together with Davy's discovery that hydrochloric acid contained hydrogen but no oxygen, indicated that not oxygen, but hydrogen, is an indispensable component of acids, and this view was further strengthened by Graham's and Liebig's classical studies of the so-called polybasic acids. But so profound was Berzelius' belief in dualism, and so great was his authority, that the electro-chemical theory still continued to stand, and the conclusions just pointed out were not generally accepted for some years. The final blow to dualism came from the young organic chemistry, in which the electric theory had been applied as generally as in the inorganic branch of the science. About the middle of the thirties Laurent and Dumas made a series of important discoveries showing that chlorine and other elements could be substituted for the hydrogen or organic compounds, and that the nature of the latter was thereby affected very little. But if part of the molecule of a compound can combine with either of such electrically different atoms as those of hydrogen and of chlorine, then there is no reason for believing that that part is essentially either electro-positive or electro-negative, and hence there is no reason for believing that every compound is made up of two electrically opposite parts. The more evidence to this effect was brought forward, the more bitterly old Berzelius adhered to the electro-chemical theory. But finally it became evident to all that, as Liebig wrote, "the wheel of time cannot stand still," and "Berzelius is fighting for a lost cause"; and, thus toward the end of the thirties, electro-chemical dualism was overthrown. As a result of their struggles against dualism, chemists then fell into the opposite extreme and adopted a purely unitary view of chemical combination. The molecule of a compound was conceived to be a composite unit somewhat like the solar system, in which the planets are held together by mutual attraction, but which does not by any means consist of two essentially different parts, endowed with two opposite forms of energy. Such unitary views of combination are still prevalent in chemistry to-day. But "the wheel of time cannot stand still," and recent years have forced upon us theories which make us feel that extreme unitarism is just as inadequate as extreme dualism. The elements certainly differ in their electrical properties, and chemists have even succeeded now in expressing those differences mathematically. Electricity, while not identical with the energy that causes the mutual attraction of atoms, is yet certainly one of the factors determining that attraction. At present, however, it is impossible to tell what compromise between chemical unitarism and electro-chemical unitarism and electro-chemical dualism will ultimately be adopted.

ORGANIC CHEMISTRY. When the general principles of chemistry were established, and the atomic hypothesis had lent to the science a keen power of penetration, it became possible to approach the world of organic matter with the hope of shedding some light upon its mystery. Since then organic research occupied chemists almost exclusively during a greater part of the nineteenth century, and the result of that inquiry has been not only a vast store of empirical knowledge of organic compounds, but also a set of general principles that have strengthened the theoretical basis of the science, and have led to some of the great industrial achievements of modern times.

Early in the nineteenth century it was universally believed that organic substances could not be produced without the agency of the "force of life." Whether there is such a distinct "force" and what its relations may be to the measurable forms of energy, we do not know as yet. But we do know that organic compounds can also be produced by chemical agencies alone, without the intervention of anything else. For chemists have actually succeeded in building up from their elements many thousands of compounds that occur ready formed only in the organisms of animals and plants. The first of such compounds reproduced in the laboratory was urea, which Wöhler made artificially in 1828. The old belief, however, lingered, some chemists contending that urea could not be looked upon as a true organic compound. But when Kolbe synthesized acetic acid in 1845, and when other indisputably organic compounds were made from their elements, then all agreed that there was no essential difference between organic and inorganic compounds, and that the former were nothing but the compounds of carbon. At present many dye stuffs, drugs and perfumes, which could once be obtained only from plants, are made artificially on a large scale, and so are many valuable carbon compounds that are not known to occur ready formed at all.

While the belief in an indispensable force of life thus delayed for a time the progress of chemical synthesis, chemists early directed their attention to the problem of molecular constitution. Berzelius was led to this problem by his electro-chemical theory. But in the twenties facts became known which made its study an imperative necessity also from a purely practical standpoint. Not small was the surprise of chemists when Gay-Lussac and Liebig found, in 1823, that silver fulminate had precisely the same composition as silver cyanate. Two years later, Faraday discovered a volatile liquid hydrocarbon that had precisely the same composition as ethylene gas. Berzelius first thought it unwise to abolish, on the evidence of a few facts, what had seemed an axiom—viz. that two different compounds cannot possibly have the same composition. But when he discovered that racemic and tartaric acids, too, had the same composition, he realized that the character of a substance must depend not only on its composition, but also on its constitution—i.e., not only on the kind and number, but also on the arrangement of the atoms in its molecule. Thus was born that great problem of modern chemistry—to determine the constitution of substances from the standpoint of the atomic hypothesis.

In 1832 Liebig and Wöhler made an important discovery. A series of compounds allied to benzoic acid were transformed by them into one another, and through all the transformations a group of atoms (made up of carbon, hydrogen, and oxygen) which they named the "benzoyl radicle" remained unchanged; the molecules of benzoic acid, benzaldehyde, benzamide, and benzoyl chloride, contained that radicle in common, as if it were a single atom of some element. The discovery of benzoyl was followed by Liebig's discovery of ethyl, a radicle common to ordinary alcohol and ether, and by Bunsen's discovery of cacodyl, which is possessed in common by several compounds of arsenic. The discovery of radicles was obviously the first step toward a knowledge of the constitution of compounds. But almost from the beginning the idea of radicles became associated with certain other ideas that could not be maintained in the light of more knowledge. Berzelius subdivided organic radicles, like the elements, into electro-positive and electro-negative. On the other hand, it was generally expected that radicles would eventually be isolated and thus constitute a series of simple compounds whose molecules would bear the same relation to the substances of organic chemistry as the atoms of the elements bear to the compounds of inorganic chemistry. But when the electro-chemical theory was overthrown, while attempts to isolate radicles remained fruitless, the opinion began to spread that the theory of radicles had made of organic chemistry a science of imaginary substances, and, hence, the sooner the theory was abolished the better for the young science. But how, then, were organic compounds to be correlated? A solution of this problem was suggested by Dumas in 1839. Continuing his researches on the substitution of different elements for one another in organic compounds, Dumas found that in acetic acid hydrogen could be exchanged for chlorine, and that the resulting compound (trichlor-acetic acid) was very much like acetic acid itself. Similar facts had already been observed since 1834, by himself as well as by Laurent. It now occurred to Dumas that in correlating their substances chemists could be guided solely by the phenomena of substitution. Acetic acid and its chlorine-substitution product obviously belong to the same "type," and similar relations exist between other substances as well. If, therefore, the phenomena of substitution were investigated in connection with organic compounds in general, the result would be a grouping of compounds free from all hypothesis, but based on and exhibiting clearly their natural relationship. Such were, *in nuce,* Dumas' views, on the basis of which the celebrated "theory of types" was gradually built up in course of the fourth and fifth decades. The most important contributions to the theory were made by Gerhardt, Wurtz, Hofmann, and Williamson. Gerhardt realized that Dumas' ideas were worthy of being developed, but he also realized that this could not be done without the aid of the idea of radicles. No objection could be raised against the latter idea, once it were freed from all unnecessary associations, especially from the belief that radicles were unalterable substances capable of independent existence. To say that benzoyl chloride C_7H_5OCl; benzoic acid, $C_7H_6O_2$; and benzamide, C_7H_7ON, contain in common the benzoyl radicle—i.e. the group of atoms, C_7H_5O—was only to express what was evident from their formulae. On the other hand, the recognition of radicles must obviously lead to the discovery of the relationship of compounds, and thus, together with the phenomena of substitution, guide in grouping compounds in accordance with the idea of types. In 1849 Wurtz and Hofmann discovered a series of compounds that bore an unmistakable resemblance to ordinary ammonia, and could be considered as ammonia in which one or more hydrogen atoms were replaced by radicles. They proposed to group them together as belonging to the "ammonia type." In 1850 Williamson showed that alcohols, ethers, and acids could be referred to the "water type." Ordinary alcohol, for instance, whose formula is C_2H_6O, could be considered as water, H_2O, in which one hydrogen atom has been replaced by the ethyl radicle, C_2H_5. Ordinary ether, $C_4H_{10}O$, could be considered as water, H_2O, in which two hydrogen atoms have been replaced by two ethyl radicles, ether being thus $(C_2H_5)_2O$. Acetic acid $C_2H_4O_2$ could be considered as water, H_2O, in which one hydrogen atom has been replaced by the radicle C_2H_3O. Now, ether, $(C_2H_5)_2O$ was obtained from alcohol C_2H_5HO, by the use of dehydrating agents. Williamson therefore held, by analogy, that it ought to be possible to transform acetic acid, $C_2H_3O.HO$ into a compound $(C_2H_3O)_2O$. When in 1852, Frankland actually succeeded in effecting this transformation by the use of dehydrating agents, the usefulness of the type theory was demonstrated. For nothing is more striking proof of the value of a theory than its capacity for revealing unknown facts. To the types ammonia and water Gerhardt added the types hydrogen and hydrochloric acid, and for a time it seemed that all organic compounds could be grouped under these four simple types. It was soon found necessary, however, to introduce the ideas of "condensed types" like the condensed water type $(H_2O)_2$, "mixed types" and the type marsh gas, CH_4. In the course of the fifties the type theory thus gradually became less and less simple, and, hence, less and less valuable for the purpose of correlating organic compounds.

Meanwhile an idea of inestimable value had thrust itself upon chemists. Inspecting the typical formulas of compounds, they could not help noticing that certain radicles (e.g. methyl, CH_3, or ethyl, C_2H_5) were capable of replacing each a single atom of hydrogen; others were capable of replacing each two atoms of hydrogen, etc. In other words, some radicles were seen to be equivalent to an atom of hydrogen; others had double its combining capacity, etc. Hence the idea of the valency of radicles and atoms. Like most other general ideas, that of valency was not new. In a vague and more or less specialized form it may be found in the researches of Berzelius, Graham, Liebig, and others; and Frankland, who first clearly enunciated it, in 1852, justly points out that it was probably a vague recognition of the valency of radicles, as exhibited by the facts of substitution, that gave birth to the theory of types. Frankland's statements, however, attracted no attention. In 1858 Kekulé and Couper independently developed the same idea, the latter proposing to symbolize the combining capacity of different atoms by the dashes now generally employed in graphic formulae. Kekulé called attention to the quadrivalence of the carbon atom, as shown directly by compounds like the following: CH_4, CH_3Cl, CH_2Cl_2, $CHCl_3$, CCl_4; or indirectly by such compounds as CO_2, $COCl_2$. In the former compounds a single atom of carbon is seen to be equivalent to four atoms of hydrogen, and a single chlorine atom to a single atom of hydrogen, which is also shown by the formula of hydrochloric acid, HCl. In a compound like $COCl_2$, the oxygen atom must therefore be assumed to be divalent, and so it is directly shown to be by the formula H_2O. Kekulé soon came to the conclusion that in practically all organic compounds one carbon atom is combined with a quantity of other elements which is equivalent to four atoms of hydrogen. This gave rise to a lively controversy, the critic Kolbe especially maintaining that the valency of an element may not be the same in all of its compounds. Kekulé's view, however, was finally accepted by all, and in 1860 chemists the world over were busy determining the "structure" of organic compounds—a problem which has since occupied the attention of a majority of them almost exclusively. The theory of types, the mother of structural theory, exhibited the radicles of compounds, and thus explained those cases of isomerism in which compounds are different because they contain different radicles. Those further cases in which the radicles themselves are differently constituted it could not explain. The doctrine of valency, showing the different ways in which the atoms can be linked in the radicles, has furnished a satisfactory solution of the problem of molecular constitution, and has completely explained the fact that the molecules of different compounds may be made up of the same atoms. At first Kekulé failed to appreciate the full value of his own ideas. In the very memoir in which he states the doctrine of valency, he advances the view that this doctrine cannot by any means solve the problem of the constitution of compounds; the old problem, he thought, might possibly be solved some day by physical chemistry. Perhaps he was not altogether wrong. For now, after half a century of experience, organic chemists are beginning to complain of the inadequacy of the structural theory, even with its more recent development—stereochemistry (q.v.)—and to look forward to some broader idea, that would correlate a larger number of known phenomena and permit of foreseeing a larger number of as yet unknown facts. What that idea will be, no one can tell as yet.

General Chemistry. The doctrine of valency could not have come into existence if not for the fact that toward the end of the fifties chemists had learned the true atomic weights of the elements. Without a knowledge of the true relative weights of atoms, it would have been impossible to know their true number in molecules, and, hence, impossible to know their true valencies. Atomic weights were determined, calculated, and re-calculated ever since Dalton first established the atomic theory. Dalton himself, as stated in a previous section of this article, determined atomic weights on the basis of certain simple assumptions. Soon afterward Berzelius devoted himself to the problem with great assiduity. From the law of combining volumes, discovered by Gay-Lussac in 1808, Berzelius inferred that equal volumes of gaseous elements must contain equal numbers of particles. In 1819 Mitscherlich discovered the principle of isomorphism. (See Atomic Weights.)[1] Berzelius had carried out about two thousand analyses, and had thus determined the relative quantities of the elements contained in a great variety of compounds. By combining the principle of isomorphism with that of equal gaseous volumes, he was now able to calculate the atomic weights of the elements. Now, his principle of equal volumes was not quite correct. To him the particles of a gaseous element in the uncombined state were isolated atoms. While he distinguished between the particles of compounds and the atoms of elements, he failed to distinguish between the free particles of elements and their atoms. That the particle of an element might be made up of two or more single atoms, it would have been impossible for him to admit; for, according to his electro-chemical theory only unlike atoms could exist in combination with one another. Avogadro's memoir of 1811, in which more correct views on the subject had been advanced, therefore remained unnoticed, and Berzelius' atomic weights were for years employed by all. Nor were most of those figures wrong; for in many cases Ber-

---

[1] *New International Encyclopaedia.*

zelius' error eliminated itself, owing to the fact that the molecules of the ordinary gaseous elements are made up of equal numbers of atoms. Knowing the true atomic weights of the ordinary gaseous elements, Berzelius was able to obtain correct figures for many other elements, with the aid of the principle of isomorphism and certain other principles that need not be explained here. Thus, his figure for mercury was 200, that for phosphorus 31, that for sulphur 32 —figures practically identical with those accepted at present. In 1827, however, Dumas invented his celebrated method of determining vapor densities, and undertook to apply Berzelius' principle of equal volumes to elements which are not ordinarily gaseous. Finding that the vapor of mercury is 101 times as heavy as an equal volume of hydrogen, the vapor of phosphorus 62.8 times, and the vapor of sulphur 96 times, as heavy as hydrogen, Dumas concluded that the relative weights of their atoms must be, respectively, 101, 62.8 and 96, and not 200, 31 and 32 as Berzelius thought. The error of Berzelius' principle thus emerged in the results of Dumas. But instead of rectifying the error of his principle by introducing the concept of the molecules of elements, Berzelius only concluded that the principle was unreliable. The result was that chemists began to disagree as to the true values of the atomic weights, and many even abandoned the hope of ever knowing atomic weights altogether, and decided to use nothing but equivalents. These represented the weights of elements that were capable of combining with, or of being replaced by, unit weight of hydrogen. For example, Berzelius' view that an atom of oxygen was 16 times as heavy as an atom of hydrogen was abandoned, and as hydrogen combined with 8 times its weight of oxygen the latter was represented by its equivalent 8. But the use of equivalents was not universal, many chemists using systems in which the figures were partly equivalents, partly atomic weights, and thus for years great confusion reigned in chemical notation, the true purpose of which is to avoid confusion by exhibiting the composition of substances in the simplest and clearest possible manner. In the forties Laurent and Gerhardt became convinced that the progress of knowledge in organic chemistry was seriously impeded by the lack of a consistent system of atomic weights. Their researches soon led them to distinguish clearly between the atoms and molecules of elements, and to grasp the full value of Avogadro's principle for determining the relative weights of molecules. With the aid of this principle, Gerhardt found the true atomic weights of the elements; and, in the latter part of the fifties, his pupil Cannizzaro demonstrated clearly the consistency of the principle with all known facts. Thus was paved the way for the doctrine of valency. A few years later (in 1869) Mendeléeff and Lothar Meyer established a remarkable connection between the properties of the elements and their atomic weights (see Periodic Law)[1] and thus the correctness of the latter was confirmed in a very striking manner.

The further progress of general chemistry has been mainly in connection with the various subdivisions of physical chemistry, brief historical accounts of which may be found under the following headings: Reaction, Solution, Dissociation, Thermo-chemistry, Electro-chemistry and Laboratory.[1]

[1] *New International Encyclopaedia.*

THE AGE OF SCIENCE[1]

BY IRA REMSEN, PH. D.
President of the Johns Hopkins University

As much of the time of those who go forth from this institution to-day has been spent in the study of the sciences, it has seemed to me fitting to ask your attention to some considerations suggested by the phrase, "This is the age of science". I do not remember ever to have heard this statement questioned, much less denied, nor do I remember ever to have heard it satisfactorily explained. It sounds simple enough, and does not appear to call for explanation or comment, and yet I think it worth while to examine it a little more carefully than is customary, to see in what sense it is true. For in a sense it is true, and in a sense it is not true. The statement raises two questions which should be answered at the outset. These are: (1) What is science? and (2) In what sense is this the age of science?

First, then, what is science? Surely there can be no difficulty in answering this, and yet I fear that, if I should pass through this or any other audience with the question, I should get many different answers.

A certain lady, whom I know better than any other, has told me that, should she ever be permitted to marry a second time, she would not marry a scientific man, because scientific men are so terribly accurate. I often hear the same general idea expressed, and it is clear that accuracy is one attribute of science according to prevailing opinions. But accuracy alone is not science. When we hear a game of baseball or of whist spoken of as thoroughly scientific, I

---

[1] Commencement address delivered at Worcester Polytechnic Institute, June 9, 1904. Published in *Science* for July 15, 1904.

suppose the idea here, too, is that the games are played accurately; that is, to use the technical expression, without errors.

Again, there are those who seem to think that science is something that has been devised by the Evil One for the purpose of undermining religion. This idea is not so common as it was a few years ago, when the professors of scientific subjects in our colleges were generally objects of suspicion. The change which has come over the world in this respect within my own memory is simply astounding. In general terms an agreement has been reached between those who represent religion and those who represent science. This agreement is certainly not final, but it gives us a *modus vivendi,* and the clash of arms is now rarely heard. Religion now takes into consideration the claims of science, and science recognizes the great fundamental truths of religion. Each should strengthen the other, and in time, no doubt, each will strengthen the other.

Probably the idea most commonly held in regard to science is that it is something that gives us a great many useful inventions. The steam-engine, the telegraph, the telephone, the trolley car, dyestuffs, medicines, explosives —these are the fruits of science, and without these science is of no avail. I propose farther on to discuss this subject more fully than I can at this stage of my remarks, so that I may pass over it lightly here. I need only say now that useful inventions are not a necessary consequence of scientific work, and that scientific work does not depend upon useful applications for its value. These propositions, which are familiar enough to scientific men, are apt to surprise those who are outside of scientific circles. I hope before I get through to show you that the propositions are true.

Science, then, is not simply accuracy, although it would be worthless if it were not accurate; it is not devised for the purpose of undermining religion; and its object is not the making of useful inventions. Then what is it? One dictionary gives this definition: "Knowledge; knowledge of principles and causes; ascertained truth or facts. . . . Accumulated and established knowledge which has been systematized and formulated with reference to the discovery of general truths or the operation of general laws, . . . especially such knowledge when it relates to the physical world, and its phenomena, the nature, constitution and forces of matter, the qualities and function of living tissues, etc."

One writer says: "The distinction between *science* and *art* is that *science* is a body of principles and deductions to explain the nature of some matter. An *art* is a body of precepts with practical skill for the completion of some work. A *science* teaches us to know; an *art,* to do. In *art,* truth is a means to an end; in *science* it is the only end. Hence the practical arts are not to be classed among the sciences." Another writer says: "*Science* and *art* may be said to be investigations of truth; but one, *science,* inquires for the sake of knowledge; the other, *art,* for the sake of production; and hence *science* is more concerned with the higher truths, *art* with the lower; and *science* never is engaged, as *art* is, in productive application."

Science, then has for its object the accumulation and systematization of knowledge, the discovery of truth. The astronomer is trying to learn more and more about the celestial bodies, their motions, their composition, their changes. Through his labors, carried on for many centuries, we have the science of astronomy.

The geologist has, on the other hand, confined his attention to the earth, and he is trying to learn as much as possible of its composition and structure, and of the processes that have been operating through untold ages to give us the earth as it now is. He has given us the science of geology, which consists of a vast mass of knowledge carefully systematized and of innumerable deductions of interest and value. If the time should ever come when, through the labors of the geologist, all that can possibly be learned in regard to the structure and development of the earth shall have been learned, the occupation of the geologist would be gone. But that time will never come.

And so I might go on pointing out the general character of the work done by different classes of scientific men, but this would be tedious. We should only have brought home to us in each case the fact that, no matter what the science may be with which we are dealing, its disciples are simply trying to learn all they can in the field in which they are working. As I began with a reference to astronomy, let me close with a reference to chemistry. Astronomy has to deal with the largest bodies, and the greatest distances of the universe; chemistry, on the other hand, has to deal with the smallest particles and the shortest distances of the universe. Astronomy is the science of the infinitely great; chemistry is the science of the infinitely little. The chemist wants to know what things are made of, and, in order to find this out, he has to push his work to the smallest particles of matter. Then he comes face to face with facts that lead him to the belief that the smallest particles he can weigh by the aid of the most delicate balance, and the smallest particles he can see by the aid of the most powerful microscope, are immense as compared with those of which he has good reason to believe the various kinds of matter to be made up. It is for this reason that I say that chemistry is the science of the infinitely little.

Thus have I tried to show what science is and what it is not. Now let me turn to the second question.

In what sense is this the age of science? In the first place, it is not true that science is something of recent birth. Scientific work of one kind and another has been in progress for ages—not in all branches, to be sure—but nature has always engaged the attention of man, and we may be sure that he has always been trying to learn more about it. The science of astronomy was the first to be developed. Astrology was its forerunner. Then came chemistry in the guise of alchemy. It would be interesting to follow the development of each, and to see how from the crude observations and imaginings of the earlier generations came the clearer and broader conceptions that constitute the sciences, but time will not permit us to enter upon this subject. I cannot, however, do justice to my theme without calling your attention to one of the most serious obstacles that stood in the way of the advance of knowledge.

To make clear the nature of this obstacle, it will be best to make a comparison. A child learns a great deal in regard to his surroundings in his earliest years before he goes to school, and without the aid of his parents. He is constantly engaged in making observations and drawing conclusions, and his actions are largely guided by the knowledge thus gained. After a time school life begins, and the child then begins to study books and to acquire knowledge at second-hand. This is an entirely different process from that by which he gained his first knowledge. The latter is natural, the former is artificial. Then, too, he soon discovers that many things he sees call for explanation, and he is led to wonder what the explanation is. If he has a strong imagination, as most children have, he will probably think out some explanation. He finds that he can use his mind, and that this helps him in dealing with the facts in nature. Now comes the danger. It being much easier to think than to work, the chances are that in trying to find the explanation of things, he will give up the natural method and be satisfied with the products of his imagination. He will gradually give up dealing directly with things, and take to thinking alone. When this stage is reached his knowledge will increase very slowly, if at all.

Whether this picture of the development of a child is in accordance with the facts of life or not, it gives an idea of the mental development of mankind. First came the period of infancy, during which observations were made and much learned. Efforts were early made to explain the facts of nature. We have remnants of these explanations in old theories that have long ceased to be useful. They no doubt served a useful purpose in their day, but gradually one of the most pernicious ideas ever held by man took shape, and I am willing to characterize it as one of the most serious obstacles to the advance of knowledge. I refer to the idea that it is a sign of inferiority to work with the hands. This idea came early and stayed late. In fact, there are still on the earth a few who hold it. How did this prove an obstacle to the advance of knowledge? By preventing those who were best equipped from advancing knowledge. The learned men of the earth for a long period were thinkers, philosophers. They were not workers in nature's workshop. They tried to solve the great problems of nature by thinking about them. They did not experiment. That is to say, they did not go directly to nature and put questions to her. They speculated. They elaborated theories. During this period knowledge was not advanced rapidly. It could not be. For the only way along which advances could be made was closed.

Slowly the lesson was learned that the only way by which we can gain knowledge of nature's secrets is by taking her into our confidence. Instead of contemplating in a study, we must have contact with the things of nature either out-of-doors or in the laboratory. Manual labor is necessary. Without it we may as well give up hope of acquiring knowledge of the truth. When this important fact was forced upon the attention of men, scientific progress began and continued with increasing rapidity. At present the old pernicious idea that a man who does any kind of work with his hands is by virtue of that fact an inferior being—that idea is no longer generally held. But we have not got entirely rid of it. In a recent address I find this reference to the subject: "However the case may have been with what forty years ago was called the education of a gentleman, it seems to me to be one of the services of the scientific laboratory that it has taught to that part of mankind which has leisure and opportunities that manual skill is a thing to be held in honor both as a means for reaching mechanical results, and still more, as a way to train the mind. . . . Fifty years ago many men who called themselves educated were mere untrained, undeveloped children in manual skill, and some of them were proud of their incompetency, for nothing would have more surprised them than an assertion that their inability to help themselves with their hands was a badge of ignorance. . . . While the high character and sterling worth of the medical man has always won respect, their skill in the use of their hands was long held by those who were superior to such weakness to place them beneath the lawyers and the clergymen in the social scale.'' Recently I came upon this old idea within college walls. In the college connected with the Johns Hopkins University there are several groups of studies which lead to the degree of bachelor of arts. Group I is largely made up of the classics, and it is therefore generally called the classical group. I happened once to be dining with a gentleman whose son was a student in Group I in our college. Our professor of Latin was also present. Turning to my colleague, the professor of Latin, our host, the father of the classical student, exclaimed: ''How those fellows in Group I look down upon all the others!'' I afterward learned that this feeling undoubtedly existed among the students, those who studied the classics, especially, forming, in their own opinion at least, a well-characterized aristocracy. I have referred to these cases simply for the purpose of showing that the pernicious idea that hand-work is a sign of inferiority is not yet dead. But it has nevertheless been disappearing rapidly for some years past, and with its disappearance the development of science has kept pace. Which is the cause and which the effect it would perhaps be hard to say. At all events, the growth of every department of science has been more rapid within the last fifty years than during the preceding fifty years, though we should be doing gross injustice to our predecessors were we to belittle their work.

The fact is, I am inclined to think that there never was a more fruitful period, in chemistry at least, than the last quarter of the eighteenth century. Farther on, I shall have occasion to speak of a few of the great chemical discoveries that were made during that period. No greater discoveries have been made since. In astronomy, Newton's great work was done more than two centuries ago. An age that can boast of the discovery of the law of gravitation may fairly lay claim to the title, ''the age of science.'' Many and many a great discovery in science preceded the present age, but from what I have already said, you will see that the reason for calling this age in which we live the scientific age is found in the fact that scientific work is much more extensively carried on at present than at any time in the past, and, further, the world is beginning to reap the rewards of this work. So striking are some of these rewards that they appeal to all. The world is dazzled by them, and is to a large extent unable to distinguish between the scientific work which has made these rewards possible and the rewards themselves. The idea is prevalent that scientific work is carried on in order that rewards in the shape of practical results may be reached. I have no desire to bring my fellow-workers in science into disrepute. It would therefore perhaps be best for me to stop here; but, if you will bear with me, I will try to make it clear to you that one may be engaged in scientific work all his life, never thinking of what the world calls practical results, that he may in fact not achieve a single result that can be called practical, and yet not waste his time; and that one may hold such a worker up to admiration without running much risk of being taken for a fool. This will be my object in what I still have to say.

While I have thus far referred to science in the broadest sense, meaning the science of nature, let me now turn more especially to the science to which it has been my lot to devote my life, and let me endeavor to show by a few examples the relations that exist between work that appears to be of little practical value when first performed and results that, from the industrial point of view, are of the highest value.

I have often been embarrassed by these questions put to me in my laboratory: "What are you doing?" and "Of what use is the work?" Generally I am obliged to answer to the first, "I regret that I cannot possibly explain what I am doing. I have tried to do so in some cases, but I have been begged to stop"; and to the second, the only possible answer has been, "I do not know." I am well aware that such answers seem to show that the work is in fact of no value, and that this is the impression that my visitors carry away with them. Now I do not propose to try to justify my own work, nor to try to explain it. For the most part it has had to deal with matters that do not touch our daily lives, and therefore it cannot be made interesting, not to say intelligible. I shall, to be sure, show you how one piece of work carried out twenty years ago has become of world-wide interest, though when it was carried out it appeared as little likely to be of practical value as anything ever done. But this is anticipating.

During the latter half of the eighteenth century there lived in Sweden a poor apothecary who, in his short life, probably did more to enlarge our knowledge of chemistry than any other man. Throughout his life he had to contend with sickness and poverty. He was obliged to carry on the business of an apothecary in order to keep the wolf from entering his house—he never succeeded in keeping it from the door. His great delight was to investigate things chemically, and to find out all he could about them. It is simply astounding to the chemist to find how many discoveries of the highest importance he made. But I have not mentioned his name. I refer to the immortal Scheele. He died in the year 1786 at the age of 43, yet he will always be remembered, and those who know most of the work he did will respect him most.

Though Scheele was an apothecary, his chemical work was not practical in the ordinary sense, and it was no doubt often difficult for him to explain what he was doing. His most important discovery was that of oxygen—a discovery that was made at the same time (1774) by the English clergyman, Priestley. Chemists know that this is one of the most important discoveries ever made in the field of chemistry, and, filled with this conviction, in 1874, one hundred years after the discovery was made, the chemists of the United States made a pilgrimage to Northumberland on the Susquehanna to do honor to the memory of Priestley, who there spent the last years of his life.

But why was this discovery so important? Oxygen, to be sure, is the most widely distributed and the most abundant substance in and on the earth; it plays a controlling part in the breathing of animals, and in most of the changes that are taking place upon the earth; a knowledge of it and of the ways in which it acts has done more than anything else to give chemists an insight into chemical action in general; and therefore has contributed more than anything else to the development of chemistry. All this is no doubt true, but are these results practical? Could we go out into the world and form a company and sell stock on the basis of such a discovery? Or could the discoverer in any way realize in cash? The average man of the world would say: "No! there is nothing in it. It may be well for a few men who have not the power to compete with their fellow-men in the busy marts to devote themselves to such useless pursuits. Possibly something may come of it in time, but better something practical, something that can be converted into hard cash. That is the test, and the only fair test by which we can judge whether any particular piece of scientific work is or is not of value."

But I have already said that the discovery of oxygen was the most important discovery ever made in chemistry, and I might have added, the most valuable. In what, then, did its value consist? In the fact that it led to a more intelligent working with all things chemical. Operations that had before this discovery appeared mysterious suddenly became clear, and every one engaged in chemical work was helped in many ways. If it is not enough for us simply to gain a clearer insight into the processes around us, if we must insist upon more tangible reward, no doubt it could be shown that the discovery of oxygen has contributed largely to the material welfare of mankind—not directly perhaps, but by enlarging our knowledge of chemistry, so that it may be said that most discoveries made since 1774 have been in a way consequences of the discovery of oxygen. Indirect results are often of more value than direct ones.

But there is another discovery of Scheele's that illustrates in another way that a discovery which when made appears of little or no practical value, may eventually prove of immense practical value and become the basis of a great industry. This is the discovery of chlorine. Among the many substances examined by Scheele was one that is commonly known as black oxide of manganese. This occurs in nature in large quantity and has long been of interest to chemists. Scheele treated this with about everything he could lay his hands on, as was his way. When muriatic acid, or, as it was called by the older chemists, the spirit of salt, was poured on the black oxide of manganese, he noticed that something unusual took place. He soon became aware that a colored gas was given off, and that this gas had other properties besides that of color. It affected his eyes, nose, throat and lungs in most disagreeable ways. Many of those before me have had the experience of inhaling a little of this gas. I hope no one has inhaled much of it. It is one of the most disagreeable things chemists and students of chemistry have to deal with. And it is not only disagreeable, it is extremely poisonous. But Scheele did not stop his work because it involved discomfort and even danger. He persisted and carried it to a successful issue, and when he stopped he was able to give as satisfactory an account of the now familiar chlorine as we can give to-day. The investigation is a model. It could not have been accomplished without the enthusiasm, the patience, the knowledge and the skill possessed by Scheele. No ordinary chemist would have been equal to it. We shall not overstate the case if we say that Scheele's discovery of chlorine ranks with the most important and the most valuable of chemical discoveries. That of oxygen outranks it certainly, but chlorine falls in line not far behind.

Now, why was this an important and a valuable discovery? Primarily because it, like the discovery of oxygen, though to a less degree, aided chemists in their efforts to understand chemistry and thus to put them in a position to deal more intelligently with chemical problems of all kinds. That statement may, once for all, be made of every important chemical discovery. But while Scheele had no thought of any practical uses to which chlorine could be put, and his discovery was not at first regarded as one with a practical bearing, it proved eventually to be of the highest practical value, and to-day it plays an exceedingly important part in practical affairs. As is well known, chlorine is the great bleacher, and as such is used in enormous quantity, especially for bleaching straw, paper and different kinds of cloth. As it would be expensive and inconvenient to transport a gas, and especially such a gas as chlorine, it is locked up, as it were, by causing it to act upon lime, and the ''chloride of lime'' or ''bleaching powder'' thus formed, which readily gives up its chlorine, is a most important article of commerce, many thousands of tons being manufactured annually. Then again chlorine is one of the most efficient disinfectants, and as such it is finding more and more extensive use every year, and is plainly contributing to the welfare of man by interfering with the spread of disease. Further, it is essential to the manufacture of chloroform, and that this calls for a large quantity of chlorine will appear when it is stated that nearly nine tenths of the weight of chloroform is chlorine. Chloroform, which has been of such inestimable value as an alleviator of pain, cannot be manufactured without chlorine, and it could never have been discovered without the previous discovery of chlorine.

Finally, without attempting to give a full account of all the uses to which chlorine has been and is put for our benefit, let me mention one more application, though in doing so I may run the risk of leading some of you to the conclusion that chlorine has its dark side as well as its light. It is with some misgivings that I venture to tell you that chlorine has found extensive application in the extraction of gold from its ores, and as gold is held by some to be the root of all evil, chlorine must, by the same token, be regarded as *particeps criminis.* A few years ago I visited the gold mines in the Black Hills of South Dakota, and there I spent some time in examining the chlorination process. I could not help thinking of Scheele and his simple experiments that first brought chlorine to light. I wondered whether, if he could see the extensive applications of that greenish-yellow gas that first set him to weeping and coughing—I wondered whether his satisfaction in his work would be any greater than it must have been when the discovery was made. Compare the little room in the apothecary shop, the simple apparatus, and the apparent uselessness of the noxious gas with the great factories, the complicated machinery and the valuable applications already mentioned, and it is evident that a discovery that appears least promising from the practical point of view may be the beginning of the most valuable industries.

Before leaving this part of my subject let me take a much less important example than those already spoken of, but one that comes nearer home. Nearly twenty-five years ago in the laboratory under my charge, an investigation was being carried on that seemed as little likely to lead to practical results as any that could well be imagined. It would be quite out of the question to explain what we were trying to do. Any practical man would unhesitatingly have condemned the work as being utterly useless, and I may add that some did condemn it. There was no hope, no thought entertained by us that anything practical would come of it. But lo! one day it appeared that one of the substances discovered in the course of the investigation is the sweetest thing on earth; and then it was shown that it can be taken into the system without injury; and finally, that it can be manufactured at such a price as to furnish sweetness at a cheaper rate than it is furnished by the sugar cane or the beet. And soon a great demand for it was created, and to-day it is manufactured in surprising quantities and used extensively in all corners of the globe. Thousands have found employment in the factories in which it is now made, and it appears that in some European countries the new substance has become the sweetening agent of the poor, it being sold in solution by the drop.

It is unnecessary here to discuss the question naturally suggested by the facts just spoken of, whether the discovery of the sweet substance has benefited the human race. It would be extremely difficult, if not impossible, to answer this question. But whatever the answer, it is clear, from what has been said that the discovery was of importance from the practical point of view, and there was nothing originally in the work to suggest the possibility of a practical result in the sense in which the word practical is commonly employed.

This is the lesson that we learn over and over again as we study the great industries. Rarely have they been the results of work undertaken with the object of attaining the practical. Look at the beginnings of electricity. A piece of amber when rubbed attracts bits of pith. A frog's leg twitches after death when touched in certain ways with metals. That was all. Are such things worth investigating? No doubt the practical man said: "No; stop trifling: do something worth doing." And if he had been permitted to have his way, all the wonderful results that depend upon the applications of electricity would have been impossible. In every line, much study, much work, and much investigation are absolutely necessary before enough knowledge can be got together to make profitable, practical applications possible. During this early preparatory stage the work is of no direct interest to the purely practical man; and yet without this work the applications which he values would be impossible. Scientific work in its highest form does not pay directly. Those who devote themselves to the pursuit of pure science do not, as a rule, reap pecuniary reward. They probably enjoy their lives as much as if they did, though it is often difficult to make them believe this. But because it does not yield immediate reward to the worker, should the work stop? Surely not. Our only hope of progress in intellectual as well as practical matters lies in a continuation of this work. And even though not a single tangible, practical result should be reached, the work would be valuable. Why? Because we are all helped by knowledge. The more we know of the universe the better fitted we are to fill our places in the world. All will concede the truth of that proposition. But if this is true we have the strongest argument for scientific work, for it is only through such work that we are enlarging our knowledge. There is no other way of learning. Somebody must be adding to our stock of knowledge, or what we call progress in intellectual and material things would stop. It also seems probable that moral progress is aided by intellectual progress, though it might be difficult to make this perfectly clear. I believe it is so; though of course it does not follow that every individual furnishes evidence of the relation between intellectual and moral progress.

But, my friends, whether we will or not, scientific investigation will go on as it has been going on from the earliest times, and it will go on more and more rapidly with time. The universe is inexhaustible, and its mysteries are inexplicable. We may and must strive to learn all we can, but we cannot hope to learn all. We are finite; the mysteries we are dealing with are infinite.

THE OLD AND THE NEW ALCHEMY[1]

1. *Les Origines de l'Alchimie.* Par M. Berthelot. Paris: Georges Steinheil. 1885.

2. *Die Alchemie in älterer und neuerer Zeit.* Von Hermann Kopp. Heidelberg: Carl Winter. 1886.

3. *Histoire de la Philosophie Hermétique.* Par N. Lenglet du Fresnoy. 3 vols. Paris. 1742.

4. *Das Letzte Aufflackern der Alchemie in Deutschland.* Von E. Schultze. Leipzig. 1897.

5. *Lives of Alchemistical Philosophers.* By Arthur Edward Waite. London. 1888.

6. *Radio-Active Transformations.* By E. Rutherford, F.R.S. London: A. Constable. 1906.

Time does indeed "bring in his revenges." Old Horace knew it, and we are experiencing the truth of his *Multa renascentur.* Thought, like the planets, has its 'stations and retrogradations.' Now and again, its course seems not unfitly symbolized by the mystic *ouroboros,* or coiled serpent. The head has overtaken the tail. Yet we do not really get back to the starting-point. There are no closed circuits in human affairs. The very earth progresses spirally. It wheels round a sun on the march, and returns no more on last year's track.

Modern physicists have not then reverted to the precise theories of Stephanus of Alexandria, still less to the practices, however legitimate in their time, of Friar Bacon or Cornelius Agrippa. But they have gained a point of view from which the search for the philosopher's stone appears less aberrant from reason than it did to their confident predecessors in the Victorian era. The attitude of science has been notably changed by the disclosure of electronic activities. Possibilities are now taken into serious account

---

[1] Published in *The Edinburgh Review* for January, 1907.

which, a very few years ago, were either ignored or derided. Especially as regards the constitution of matter, ideas have come to be prevalent which may literally be termed "revolutionary," since they curve backward irresistibly toward those entertained two thousand years ago. Thus the dogma of the immutability of material species can no longer be upheld. The chemical elements are subject to the ravages of time, and engender, through their decay, other substances equally entitled, to all seeming, with themselves, to be described as "elementary." These processes, however, which the alchemists of old sought to command, we are content to observe. They will not be hurried or controlled; they "gang their ain gate," irrespectively of laboratory conditions; all that can be done is to study the modes, and measure the rate of their undeviable advance. A few buoyant speculators are, indeed, to be found who forecast the provision of means to regulate at will, and accelerate indefinitely, radio-active transformations. When they become available, the new alchemy will be a working concern, perhaps even a profitable branch of business. But for the present, Nature keeps the management of this particular department entirely in her own hands. Man looks on with hungry eyes, but his interference is barred out.

The history of alchemy is one long mystification. It deals largely with fictitious personages. Of others, who did really "walk about the orb" in the close company of "foolery," it narrates the apocryphal adventures. Its leading authorities are mythical. Illustrious names are audaciously employed to lend some color of authenticity to its mendacious annals. These form, indeed, a jungle of fraud and falsehood. What was true in them was often purposely obscured, since the arcana of the "great art" were too sacred to be openly divulged. Its hierophants were veiled in shadow; its origin was indicated by dim traditions, transmitted by writers acquiescent and uncritical, if not uncandid.

M. Berthelot, in the work quoted at the head of this article, has done what was possible to elucidate the obscurity. His diligent labors have brought many confused facts and assertions into their proper sequence, so that we can now, at least, partially understand how the fanatics, knaves, and dupes of Gnostic Egypt came by their mysterious tenets. The superstitions and opinions they embodied proceeded from various sources, and primarily from Babylonia, the hotbed of occultism. The walls of Ecbatana, as described by Herodotus,[1] illustrate the connection. They were sevenfold, and vario-tinted, the five outer circuits being embellished with the colors distinctive of the several planets, while the inner ramparts glittered in gold and silver to represent the sun and moon. Thus, the combined arrangement, like the seven-storied temple of Nebo at Borsippa, typified the majestic succession of the celestial spheres. Now the planets, no less than the sun and moon, claimed symbolical metals. Lead was appropriated to Saturn, tin to Jupiter, iron to Mars, copper to Venus, and quicksilver (after its full acquaintance was made) to Mercury. And the relationship was looked upon as intimate and real. Each metal was not only the client, but, in a sense, the offspring of a fostering heavenly body. It grew in the bowels of the earth under its influence; it derived from it special affinities and magical properties; it incorporated the subsensual action of a celestial operative power. That the metals, then few and scarce, should be regarded with reverence is hardly to be wondered at. They were obtained with difficulty and brought from afar; they came forth from the fiercest ordeal by fire purified and vivified; they approved themselves in sundry ways as indispensable civilizing agents.

The visionary metallurgy of Babylonia had its practical counterpart in Egypt. There the arts of smelting ore and of modifying and manipulating the products established their headquarters. Ptah of Memphis was a highly efficient

---

[1] Book I, cap. 98.

divinity, far better skilled in his trade than the halting Olympian of the "Iliad." The word "chemistry," which probably perpetuates an old appellation for the Nile country, was defined by Suidas in the eleventh century as the art of making gold and silver; and the feasibility of such achievements was intimated by early experiments with a natural alloy. *Asem* (translated by the Greeks *elektros,* "shining") figures prominently in the Egyptian records; it was produced artificially, held a high place in public estimation, and so late as the fifth century A.D. was still by Olympiodorus assigned to the planet Jupiter as his representative metal. Homer employed electrum in the decoration of the palace at Sparta,[1] the renowned owners of which —no others than Menelaus and Helen—having recently arrived from Egypt, had presumably brought in their train some Egyptian craftsmen. Hesiod made it the groundwork of the Shield of Hercules; and many of the objects excavated at Mycenae and Hissarlik are composed of just the same kind of "white gold" offered by Croesus to the Delphian Treasury. With the lapse of centuries, however, its vogue declined; the yellow gold of Osiris was preferred to the blanched metal sacred to Isis; and the planetary ties of electrum were finally severed when mercury, imported by the Carthaginians from the mines of Baetica, became available for its replacement.

It had, nevertheless, done its work. Its hybrid nature, its mixed qualities, the experienced practicability of endowing silver with some of the properties of gold, started the long tradition of alchemistic illusion and imposture. Nor was the case of electrum solitary. Many alloys were known which seemed indistinguishable from pure metals, and the graduated changes in their aspect and nature due to variations in their composition were explained on the crude transmutational theory. Technological practice, then, en-

---

[1] Elsewhere in the Odyssey, ἤλεκτρος certainly means amber; but a metallic substance is clearly indicated in the passage above referred to.

couraged belief in the mutual convertibility of the "strange and rare" substances secreted, as if through some dim vital process, by the earth under favor of the spheres. There appeared, for instance, to be no reason, on the face of things, why lead should not be ennobled into silver by the cleansing action of fire, even as electrum was refined into gold, and iron, strong and lustrous, was elicited from dull earthy matter.

The transcendental hopes of Egyptian artificers were further raised and stimulated by the vague speculations of Greek philosophers. Empedocles, vanishing amid the flames of Etna, left behind him the long-lived doctrine of the four elements, or "roots of things." The varieties of matter, in his view, depended upon the variety of their composition out of earth, water, air, and fire. Moreover, the proportions of these admixtures were not supposed to be determined inexorably, once for all. Expedients might be found for their arbitrary modification. But here a logical difficulty came in. The elements imparted quality, not substance. Opposed by their qualities, they could not be opposed in substance;[1] for substance is one, although qualities are many. And qualities, to exist, must be incorporated. Aristotle evaded the crux by inventing a fifth element to serve as a basis for the rest, and his "quintessence" has, in more ways than one, obtained a kind of warrant from modern science. But the immediate importance of its introduction was that it availed to complete, and very satisfactorily to complete, the antique theory of matter. The hypothesis, in its finished shape, assumed a *materia prima* ("potential matter," in Verulam's phrase) of indeterminate character, an elusive, and barely conceivable essence, and gave it actuality by the addition, in suitable measure, of a crowd of differentiating properties—hardness, color, weight, malleability, brittleness or toughness, and so on. The scheme is frankly metaphysical; it deals through-

---

[1] M. Berthelot, *Revue des Deux Mondes,* September 1, 1893, page 322.

out with abstractions; there is scarcely a point at which it touches reality; yet it finds a sort of verification in the delicate experimental results secured at the Royal Institution and the Cavendish Laboratory. An ‘‘Urstoff’’ is implied, nay, insisted upon by an array of well-ascertained facts. Sir William Crookes identified it, a quarter of a century ago, with the ‘‘radiant matter’’ in his vacuum-tubes. It escapes irresistibly from certain substances; imprisoned and bound in the fetters of some mysterious attraction, it constitutes all. In the free state it is matter—if the name should be applied to it at all—reduced to the ranks, generalized, stripped of its distinctions, the same from whatever source derived; it is matter in potency, rather than in act, intangible, inaccessible to sense-perception, probably indifferent to the solicitations of gravity. Critically considered, it is found to consist of countless swarms of ‘‘electrons,’’ traveling with prodigious speed; and out of electrons, diversely aggregated, the chemical units or atoms of ordinary matter are apparently built up. Electrons may then fairly be regarded as the modern equivalent of the formless ‘‘protyle’’ of Greek thinkers.

The dogmas of the fundamental unity of matter, and of the ‘‘accidental’’ character of its sorts and species, evidently provided a rational justification for the toils of alchemists. But much more was needed to give their art the vigorous vitality, which enabled it, during twelve hundred years, to withstand the blasts and counterblasts of opinion. It lived and throve, not because of the truths which it misrepresented, but in virtue of the greed of gain which it encouraged, and the frauds, half visionary, half vulgar, by which its practice was sheltered and surrounded. Alchemy was from the first intertwined with the varied forms of occult belief which crept westward, through Alexandria, from the valley of the Euphrates in the early centuries of our era. Egypt in those days swarmed with Gnostics, and Gnosticism was in close alliance with every form of Oriental superstition. Pseudo-sciences, accordingly, developed, as in a forcing-house, under its influence, appropriating authority by the forgery of great names, and acquiring popularity through facile appeals to credulity and cupidity. ''Populus vult decipi; decipiatur,'' will always be the *mot d'ordre* of demagogues and charlatans.

Hermes Trismegistus, reputed to be the first alchemistic author, was a fit eponym of the ''hermetic philosophy.'' The books attributed to him were numerous, and highly cryptic; but they were held sacred, and from their dicta there was no appeal. His identity, in fact, merged into that of Thoth, the ibis-headed deity of Hermopolis, and the example of pseudonymous authorship set in his case was extensively followed to the bewilderment of posterity. The classics of alchemistic literature are, more often than not, apocryphal; their alleged authors are simulacra. Thus the Archpriest John, the successor of Hermes, seemed by his evasiveness to prefigure the slippery personality of his Abyssinian namesake. Democritus of Abdera, who came next, although endowed, as a philosopher, with the full Cartesian certainty of his own existence, played a purely fictitious part in hermetic tradition. His supposed sayings proceeded from his mouth by a trick, so to speak, of ventriloquism. One of them, reported by Julius Firmicus, has a curious Baconian ring. The famous aphorism of the *Novum Organum,* ''Natura non nisi parendo vincitur,'' was preluded by the (so-called) Democritean maxim, ''Natura, aliâ a naturâ vincitur,'' signifying that man can only indirectly control the operations of nature by providing opportunities for their working along the lines of his choice. Bacon's felicitous phrase thus happily rescued from oblivion a derelict sentence of illuminative import.

Democritus was said to have received instruction in the spagyric art from Ostanés the Mede, classed with Zoroaster by St. Augustine. Under the auspices of this mythical personage, and described by him in an imaginary treatise, the elixir vitae made its entry on the scene. The association is memorable as indicating the Chaldean origin of the "divine fluid" which became an integral part of every full-blown adept's stock-in-trade. Later on the fluid was defined to be "potable gold"; and the obscure but persistent relationship between the transmutation of metals and the cure of human ills was primitively emphasized by the inclusion of the Egyptian Cnuphis, the healing "soul of the world," among leading lights of the art, under the alias of Agathodemon.

Early lists of goldmakers were compiled with small regard to probability. They comprise the names of Plato, Aristotle, Heracleitus, Porphyry, the Emperor Heraclius, and Cleopatra, the last entry being due to a confusion of designations between her of the "bold black eyes" and a genuine artist of that name. Another female alchemist was the supposed inventor of the *bain-marie,* Mary the Jewess. Her co-religionists at Alexandria were strongly imbued with the mysticism of metallurgy; the related doctrines had an unmistakable Jewish complexion, and the Cabbala was pored over by their adherents no less attentively and devoutly than the works of Trismegistus himself.

The first historical report of an experiment in transmutation has been handed down by Pliny the Elder.[1] Caligula was the experimenter. Hoping to allay the gold-hunger which has not yet ceased to gnaw at the vitals of the sons of Adam, he built a furnace, and caused a quantity of orpiment to be calcined. The result did not come up to his expectations; king's yellow (trisulphid of arsenic), for all its deceptive glitter, did not prove to be "pay-gravel"; the outlay exceeded the intake, and the ruler who made his horse consul of Rome was, nevertheless, sane enough to withdraw his capital from a losing business. A later emperor, Anastasius of Byzantium, sent the protochemist, Johannes Isthmius, to end his fraudulent career in the fortress of Petra. Pseudo-science, too, has its "martyrs." But the tide of folly rose with the march of time, and both in France and England, in the fifteenth

---

[1] M. Berthelot, *Les Origines de l'Alchimie,* page 69.

century, the coinage was debased, with royal assent, by claimants to the possession of the "great secret."[1]

From the "house of Saturn," where it still lingered, by a belated association, in the verses of Firmicus Maternus (fourth century A.D.), alchemy was early transferred to the "house of Mercury." This is a figurative way of saying that quicksilver was substituted for lead as the substratum of its operations. The choice had originally fallen upon lead, because of its affinity to silver—an affinity possibly of far-reaching import; but it could not hold its own against the new metal, spoken of by Theophrastus about 300 B.C. as "liquid silver." An ideal recipient for the "powder of projection," it very soon displaced every other. It was not all-sufficing, but it was indispensable. Bricks might be made without straw more easily than the precious metals without mercury. Recipes for its subtilization, its "fixation," its coloration, abound in alchemistic treatises. They are for the most part unintelligible, especially when introduced with promises of transparent candor; for adepts wrote, not to disclose secrets, but to enhance the reputation of their depositaries, and they were skilled in darkening counsel, and in taking while they appeared to give. In a moment of exaltation, Raymond Lully (or rather, a personator of the "Doctor Illuminatissimus") is said to have proclaimed: "Mare tingerem, si mercurius esset!" *tingere* signifying, in technical phraseology, to transmute; the method, however, to be employed in the contemplated gigantesque performance he was prudent enough to leave in obscurity.

The Alexandrian school of science and of thought, already degraded by mysticism, received a crushing blow through the destruction of the Serapeum in 391 A.D. Its teachings were, nevertheless, propagated far and wide; those who inculcated them still led the van; and Byzantium received many of the scattered elements of Graeco-Egyptian

---

[1] E. von Meyer, *A History of Chemistry*, third English edition, page 35.

culture. Alchemistic principles especially flourished rankly within the congenial precincts of New Rome. They enlisted many adherents and encountered few opponents, their truth being (it would seem) tacitly admitted even by those who sought no profit from their momentous consequences. After the Hegira, the Arabs seized the scepter of learning, and Bagdad far and away outbid Byzantium. The followers of the Prophet, no less keen for knowledge than for conquest, assimilated indiscriminately everything cognizable by the mind of man that came in their way, and hurried down blind alleys as eagerly as along open roads. They made ideal adepts, and carried acquaintance with the wonder-working *Magisterium* with them to Spain, whence it spread to the courts, universities, monasteries, and market-places of medieval Europe. The visions of perennial wealth and health which it engendered kindled the imaginations of the ignorant; they admirably served the purposes of the diversified brood of mystery-mongers; kings and princes hoped to raise revenues *ad libitum* through the metamorphic action of their croslets and alembics; and the possibility of so doing received the sanction of the highest intellects. All the known analogies of nature seemed, five or six centuries ago, to justify the conviction that metals were transformable. It ran counter to no ascertained or imaginable law of nature; it rested upon no extravagant assumptions. The sought-for changes, looked at dispassionately, might be thought easier of realization than the processes of reduction, by which lumps of stone and clay assumed the properties of iron, copper, or mercury. Plausible in itself, alchemistic doctrine was further recommended by a choir of consonant authorities. Antiquity almost unanimously enforced it; Eastern sages, profoundly versed in the arcana of nature and art, were said to have adopted it; and the spurious character of the evidence alleged in its support was a matter of indifference in that uncritical age. Authentic or apocryphal, the names and maxims arrayed in favor of the spagyric philosophy availed equally to silence doubts. Very few expressed any. One of the rare skeptics on the subject, however, was the actual Raymond Lully, a Spanish monk stoned to death by the Moors of Africa in 1315, some three lustres before the date of the alchemistic writings attributed to him. Yet nearly all his eminent contemporaries and predecessors took an opposite view. The noble figures of Albert the Great and of St. Thomas Aquinas tower above the ranks of the Dominicans in the thirteenth century, and both admitted without hesitation the asserted facts of transmutation. Roger Bacon passed for an adept; but popular fancy ascribed to him many faculties never owned by him, and his metallurgic power, too, is perhaps legendary. However this may be, he thought it worth while to discuss, in a special treatise, designated ''Speculum Alchimiae''[1] the fabrication and properties of the ''citrine body,'' called by others the ''philosopher's stone,'' or ''grand *magisterium.*'' He did not minimize its marvels. It had efficacy, in his opinion, not only to transform into gold one million times its own weight of base metal, but also, if administered in the form of a drug, to prolong human life. Nor was he exceptionally sanguine. Votaries were to be found, more enthusiastic or more deeply initiated, who taught that the elixir could impart as well as lengthen life.

Despite this riot of unreason, knowledge intermittently advanced. Valuable items of information presented themselves unsought, and chemistry began dimly to shape itself in the foggy atmosphere of occult persuasions. Alcohol was distilled; acquaintance was made with the uses and peculiarities of metallic zinc, arsenic, and antimony; corrosive sublimate, red precipitate, oil of vitriol (sulphuric acid), and aqua fortis (nitric acid), took their places in the laboratory; while the resources of the pharmacopoeia were, from many quarters, materially enlarged. The apportionment of credit, however, for these sundry inventions is impossible. Evasive or misleading records completely

---

[1] H. Kopp, *Die Alchimie*, &c., page 23.

shroud their origin. Medieval discoverers, far from putting forward eager claims to priority in their innovations, sought to give them *éclat* by passing them off as antique. Enveloping them in the glamour of an established reputation, they fired their darts, so to speak, from under the shield of some Ajax of their choice. The early stages of chemical history hence evade exact inquiry.

The circumstance is singular and characteristic that the two latest masters in alchemy, like the majority of their far-off precursors, were elaborate impostors. Abu Musa Djabir ben Haijan, currently known as Geber, had a position assigned to him in hermetic science not inferior to that rightly occupied by Hipparchus in the history of astronomy. His writings were regarded as canonical; his decisions as indisputable. Rhazés and Avicenna designated him *magister magistrorum*; Cardan extolled him as one of the twelve greatest geniuses the world had seen, and he even now enjoys a certain nebulous fame. Yet his personality was never quite clearly defined. According to Abulfeda, an Arab geographer of the fourteenth century, he was a native of Harar in Mesopotamia; his birthplace is elsewhere located in Khorassan; Leo Africanus asserted him to have been a renegade Greek. He is variously spoken of as a Syrian disciple of Khaled, as an Indian prince, and as having died at Seville in the year 765. An astronomer of the same name, who genuinely flourished in Spain during the twelfth century, has frequently been confounded with him, and he has been credited with the invention of algebra. Nothing is certain except the spuriousness of the numerous tracts and essays circulated under his name. This has been proved by M. Berthelot from the most convincing internal evidence.[1] By a sort of regenerative process, the works and their imaginary author acquired secular renown. They mutually reinforced one another's prestige; for the accumulated productions of successive forgers had at least merit enough to add continually to the wonder that a single

---

[1] *La Chimie au Moyen-âge,* t. i. page 231.

man should have been at once so profuse and so profound. This structure of falsehood has, indeed, a nucleus of truth. M. Berthelot, at any rate, believes that he can recognize such a nucleus in some Arabic manuscripts preserved in the public libraries of Paris and Leyden. They are sufficiently primitive in purport to have been composed in the eighth century; their style is of the mystical kind proper to occultists; they lay stress on the planetary relationships of metals, and, in fact, show no appreciable deviation from the Byzantine standpoint. They might then very well have been indited by a real though insignificant Geber, amplified by subsequent accretions to the imposing dimensions of the author of the *Summa Perfectionis.* Basilius Valentinus, on the other hand, the final product of the alchemistic tradition, appears to have been a pure and gratuitous invention. The successful exertion of the mythopoeic faculty by which he came into being took effect in the full daylight of the seventeenth century. He was stated to have been born in the Upper Rhenish provinces late in the fourteenth century, to have traveled long in Spain, England, and the Low Countries, and to have ultimately entered a Benedictine convent somewhere in Germany. His rumored learning excited the curiosity of the Emperor Maximilian, who vainly attempted to localize his retreat. It was only after a hundred years had passed that the obscurity seemed to dissipate. A certain Johannes Thölde published at Frankenhausen, early in the seventeenth century, a collection of works by the author, or authors, styled Basilius Valentinus. They were remarkable enough to justify his high reputation. They showed him to have possessed great technical skill; they completed the theory of the composition of metals by adding "salt" (any principle of solidification) to the mercury and sulphur previously admitted as their ingredients; while a tract entitled "The Triumphal Car of Antimony" described several preparations of that metal clearly intended for internal use. These recipes are considered to have paved the way for the advent of true medicinal chemistry.[1] Even about the philosopher's stone he was comparatively explicit, and his dicta were received as oracles. Yet their connection with Basilius Valentinus appeared to many uncertain. Whence, it might be asked, did the manuscripts edited by Thölde come from? The question was answered in a singular fashion. Toward the middle of the century, stories coming from nowhere in particular began to be circulated to the effect that the doubtful writings had been found, according to one version, under the high altar of the Benedictine convent at Erfurt, according to another, inside one of its columns, which a flash of lightning had split open. Then, in 1675, J. M. Gudenus announced, as the upshot of inquiries made on the spot, that Basilius Valentinus, the champion of antimony, and the inventor of the trinal constitution of matter, had worn the cowl at Erfurt in 1413, and had there surreptitiously bequeathed his mysterious fame to posterity. There is little doubt that he was mistaken; but the solution of the problem offered by identifying Johannes Thölde with Basilius Valentinus is not the most probable. The supposition of multiple authorship is to be preferred. Thölde, one may believe, collected scattered writings already partially known. He gave, in a manner, epic importance to detached lays.

They could scarcely have been known, except by report, to John Dee of Mortlake, crystal-gazer and alchemist. Deluded himself, and the cause of manifold delusions to others, he submerged his originally fine faculties in a quagmire of baneful figments. Queen Elizabeth wished to make him a bishop, and invoked his aid to avert harmful effects from malicious injury done with a pin to a waxen image of her royal person, found in Lincoln's Inn Fields in 1577. The appearance, about the same time, of a great comet further excited her alarm; which having allayed, he traveled abroad in quest of remedies for her tooth-ache and rheumatic pains. Later he became the dupe of Edward

---

[1] E. von Meyer, *History of Chemistry*, page 36.

Kelley, a clever knave, who served as his spiritualistic medium and alchemistic instructor. Their joint gold-making career was not wholly unprosperous. Albert Laski, a credulous and impecunious foreign prince, hoped to retrieve his broken fortunes through the medium of the philosopher's stone. Leicester introduced him in 1583 to Dee, who entertained him at Mortlake at the Queen's expense, convinced him of his recondite powers, and at his request followed him, in the company of Kelley, to the castle of Laskoe, near Cracow. There they wasted costly materials until their host, at the end of his resources and of his patience, despatched them to Prague. Expelled thence as sorcerers, and refused admittance to Erfurt, they were assigned by Count Rosenberg in 1586 a stately residence at Tribau in Bohemia. Dee's globe of smoky glass and mirror of cannel coal were now again in requisition for the purposes of spiritualistic evocations, and Kelley, having transmuted into gold a section of a warming-pan, sent it in triumph to Queen Elizabeth; while Arthur Dee and young Rosenberg played at quoits (we are told) with pieces of gold and silver made by projection. The reputed source of this Lydian opulence was a considerable stock, discovered by Kelley amid the ruins of Glastonbury Abbey, of the "stone of the wise." But the partners inevitably fell out. Kelley, who in his golden days had been knighted, it is believed, by the Emperor, was subsequently thrown into prison at Prague, and perished in attempting to escape in 1595. Dee returned in 1589 to England, destitute of his fairy wealth, and lacking the means to produce more. He, however, still enjoyed royal favor; pensions and preferments relieved his immediate wants, and he was appointed warden of Manchester College in 1595. He resigned the post in 1604, and died four years later in extreme penury. A half-convinced charlatan, he was the victim and the plaything of the malign influences to which he surrendered himself.

Henricus Cornelius Agrippa (1486 to 1535) and Aureolus Philippus Theophrastus, commonly called Paracelsus, were both pupils in chemistry of Trithemius, Abbot of Spannheim, and were held to compete, on equal terms, for the honorable title of Trismegistus *redivivus.* Eliphas Lévi remarked of Paracelsus that he had "divined more than any one without ever completely understanding anything."[1] The facts of his life are vaguely known, having been thickly overlaid with embellishing legends. It is, nevertheless, fairly certain that he was born at Einsiedeln, in Switzerland, in 1493, as the only child of a well-thought-of physician in orthodox practice. His son was of a different stamp. Attracted in boyhood by the phantasmagoria of learning, he studied alchemy in the works of Isaac the Hollander, and imbibed from them the doctrine of the elemental triad of mercury, sulphur, and salt, which he subsequently diffused and recommended.

He entered the University of Basle at the age of sixteen. His studies were desultory, if occasionally intense. But a cap-and-gown life was not for him, he had the "hungry heart" of the born traveler, and in 1516 he set out to tramp the "open road" that has many turnings, but no terminus. Supporting himself as he went along by casting horoscopes, fortune-telling, cheiromancy, and the like, he left no European country unvisited. Not even Russia, whence he was fabled to have reached the court of the Great Cham, and to have attended the son of that shadowy potentate on an embassy to Constantinople. There he acquired, if rumor spoke truly, the secret of the "double tincture," capable both of lengthening life and of ennobling metals; and a wandering Arab made him acquainted with the mysterious "alcahest," or universal solvent. He learned also the virtues of laudanum, and soon afterward began to effect cures, the fame of which preceded him as he strolled homeward, and secured for him, in 1526, the chair of physics and surgery in his old university. Professorial

---

[1] *Histoire de la Magie,* livre v. ch. 5. Quoted by A. E. Waite, preface to *The Hermetic Writings of Paracelsus,* 1894.

dignity, however, was much to seek in his behavior. He quarrelled with the municipal authorities, or they with him; insulted his colleagues, mystified his audiences, and incurred obloquy by his extravagant self-laudations. Decried as a quack, and baited by numerous enemies, he withdrew at the end of a year from an impossible position, and resumed vagrancy in his multiple capacity of theosophist, faith-healer, conjurer, physician, and seer. He died on September 24, 1541, at the Inn of the White Horse in Salzburg, and was buried under the porch of the church of St. Sebastian. The tale of his assassination by rival practitioners was set going by Von Sömmering's discovery in 1815 of a fissure in his exhumed skull, produced, quite probably and harmlessly, by a chance stroke of the grave-digger's spade.[1] His "long sword" became legendary. Its pommel, he himself asserted, lodged his familiar spirit, and this was interpreted to mean that it contained some portion of the "Azoth," or elixir (perhaps opium in some shape), which he used as a remedy for disease. The crude popular impression in the matter was conveyed by Samuel Butler's quatrain:

> Bumbastus kept a devil's bird
> Shut in the pommel of his sword,
> That taught him all the cunning pranks
> Of past and future mountebanks.
>
> *Hudibras,* Part II. canto 3.

Yet he had real genius. His "bald pate," he truly said, sheltered thoughts that had not dawned upon Avicenna, or permeated the universities. They were, indeed, mostly fantastic, those thoughts of his, but they were often profound. A man of science was disguised in the bedizenments of wild folly that he at times deliberately put on. He attached to himself followers, such as Benedictus Figulus, who discerned his "searching and impetuous soul," and if he contemned the would-be wise, he was liberal to the

---

[1] See *Theophrastus Paracelsus. Eine kritische Studie.* Von Friedrich Mook, 1876; and *Paracelsus-Forschungen.* Von E. Schubert and Karl Sudhoff, 1889.

needs of the poor. His portrait bears the inscription composed by himself:

Alterius ne sit, qui suus esse potest.

He was incidentally, not exclusively, an alchemist. Therapeutic chemistry ranked higher in his esteem than metallurgic chemistry. Yet the creed of the adepts continued to be held widely and long. Robert Boyle, one of the chief ornaments of the Royal Society, firmly adhered to it; so did Glauber, Kunkel, Stahl, the prophet of phlogiston, and Boerhaave, eminent at the University of Leyden in the eighteenth century. Helvetius and Van Helmont fell abjectly into the trap of the delusion. Each in turn received from an unknown hand a specimen of the philosopher's stone, and each in turn verified (as he supposed) its supramundane power for the aurification of mercury or lead. Even the great Tycho Brahe had a narrow escape. It needed the celestial summons of the new star of 1572 to rescue him from the hermetic slough. Many German princes, too, favored the "Divine art." Rudolph II was styled the German Trismegistus; John the Alchemist, Burggrave of Nuremberg, practised it in person; Augustus I, Elector of Saxony, and his consort Anna of Denmark, explored its mysteries in gorgeous laboratories. Later it fell into disrepute. Its votaries foregathered with the brethren of the Rosy Cross, and many of them trod devious and dangerous ways. Some came to tragical ends. Alexander Seton, author of "Novum Lumen Chemicum," was, with futile cruelty, tortured to death at Dresden in 1603, in the hope of wringing from him a golden secret which he bequeathed, probably in good faith, to his Polish protector, Michael Sendivogius.[1] He had a fellow-sufferer, after the lapse of a century, in the Neapolitan adept Caetano, surnamed the "Conte Ruggiero," who was hanged at Berlin in 1709 on a gallows glittering, by a grim mockery, with gold tinsel. Finally, there was the strange and

---

[1] A. E. Waite, *A Golden and Blessed Casket of Nature's Marvels*, by Benedictus Figulus, Preface to English translation.

piteous case of James Price. He was a man of fortune, learning, and honor; the University of Oxford conferred upon him, in 1782, a degree of M.D. expressly for his "chemical labors," and he was a distinguished member of the Royal Society. Unfortunately, however, he followed the chimaera of transmutation, and described in a book, which was a nine days' wonder to the gaping world, his successful experiments with the white and the red tinctures for converting mercury into silver and gold respectively. Challenged to repeat them by the Royal Society, he failed to do so, and having swallowed a tumbler full of laurel-water, he died in the presence of the three delegates of that body, in August, 1783.[1] There is little or no doubt that his brain had given way, and that he was the victim, either of his own delusions or of others' fraud. Yet the *auri sacra fames* was not sated. Frederick the Great, thinking to emulate Croesus, at one time kept a lady alchemist, Frau von Pfuel, busy with powders and fluxes at Potsdam. And the Hermetic Society, founded in 1796 by two Westphalian physicians of consideration, published its transactions and avowed its purposes in the respectable columns of the *Deutscher Reichsanzeiger.*

That a cloudy intuition of truth was interwoven with this protracted history of folly and fraud, we now at last know, although most imperfectly. The discovery of radio-active transformations is of yesterday. It dates essentially from the joint investigations in 1903 of Professors Rutherford and Soddy, at the McGill University, Toronto, on the "emanation" of thorium, and expressly from June 7 of that year, when Sir William Crookes, in an address delivered at Berlin, gave vivid expression to his doubts as to "the permanent stability of matter." This is only the beginning; the end is not yet in view. A new road has been projected; but the engineering difficulties are numerous and formidable. To overcome them will be the great scientific work of the twentieth century.

[1] *Dictionary of National Biography,* vol. xlvi, page 328.

The fundamental postulate of ancient and medieval alchemy was that metals are chemical compounds. It was not an extravagant belief; the facts of technical experience accorded with it; its truth appeared incontestable until Lavoisier published, in 1787, his *Méthode de Nomenclature Chimique.* A treatise on metallic dissociation was accordingly adjudged a prize by the Copenhagen Academy of Sciences in 1780, and G. G. Kästner, professor of chemistry at the University of Heidelberg, ignorant or negligent of Lavoisier's work, suggested in 1806 the feasibility of fabricating quicksilver out of phosphorus and charcoal.[1] The integrity of the atom, on the other hand, is the most essential principle of modern chemistry, and metals are distinctively "elementary" in the nineteenth-century sense. That is to say, they are indecomposable by force or skill. Their atoms are veritable chemical units. Yet they have long been suspected to be physically divisible under conditions different from the ordinary. They show wide diversities in weight, the lead-atom, for instance, being nearly thirty times heavier than the lithium atom. Moreover, the atomic weights, to the number of nearly eighty, fall into related series, intimating the action, it is thought, of some law by which indefinitely small particles have variously collected into connected systems. The subtlety and sensitiveness, too, of luminous vibrations, together with the manifold intricacies of spectral effects, lent countenance to the opinion that atoms might be elaborate pieces of mechanism, their parts being probably in rapid motion. The paradoxical hypothesis that atoms have parts has now become a recognized truth of science. They are complex aggregates, and the aggregates are liable to go to pieces. This is the secret of radio-activity. This was the meaning of the actinic effects, due to some effluvium from a salt of uranium, detected by M. Henri Becquerel in 1896. They implicitly announced what was little short of a scientific revolution.

How far it will be carried none can foretell. As yet we

---

[1] E. Schultze, *Das Letzte Aufflackern der Alchemie,* page 42.

have learned little more than that some or all of the various forms of matter spontaneously decay, and give rise, in decaying, to other forms. The three heaviest metals, uranium, thorium, and radium, are the most conspicuous possessors of these extraordinary properties. Their intimate structure is such as to render them unstable. Each of their atoms is the seat of eventually self-destructive activities. True, their waste, although unceasing, is excessively slow. Radium, the shortest-lived of the trio, needs about 1,300 years, Professor Rutherford calculates,[1] to become half disintegrated, while 30,000 must elapse before the earth's present stock is virtually exhausted. Something will, indeed, be left; but it will not be radium. Perhaps the residuum will prove to be lead. Indications have been gathered that radium is compounded, in a transcendental manner, of helium and lead. Helium unquestionably escapes at each stage of its decay, and the conjecture is plausible that, after the fifth and last emission of helium-particles, lead remains as a *caput mortuum.*

Nor is radium itself believed to be an aboriginal substance. For unless there were a continuous source of supply, the stock would evidently have long ago become exhausted. What perishes day by day must day by day be renewed, and the renewal is, in this case, apparently effected by the exorbitantly slow transformation of uranium. The grounds for this view are: First, that the two metals never occur separately, uranium always holding a percentage of radium; secondly, that this percentage has a constant value. Its invariability clearly results from the establishment of an equilibrium between production and waste. Radium is scarce, because it is quickly dissipated. It bears within itself the seeds of destruction. Solid in appearance, it is in reality more unstable than the thinnest air. Even the substantial preservation of its materials is open to doubt. In other words, there is some probability that many of the particles flung out from its dis-

---

[1] Radio-Active Transformations, page 176.

rupted atoms cease to be matter as ordinarily understood.

The principle of the conservation of mass was heretofore regarded as the corner-stone of the chemical edifice. It assumed matter to be indestructible, and indestructible it surely is by the time-honored methods of the laboratory. Decomposition and recomposition, solution and precipitation, fractionation, distillation, calcination, leave mass exactly what it was before. Gravity is unalterable so long as the atom remains intact. But the break-up of the atom in radio-active processes lands us on a totally different plane of inquiry. Atoms are composed of ''electrons'' or unit-particles of electricity, linked together by forces of tremendous power. When the infinitesimally small, though highly intricate, systems thus formed undergo collapse through some innate defect of stability, a readjustment ensues. Some of their component electrons issue freely into the ambient ether; others group themselves anew into atoms of less heavy metals; others again into helium-atoms. But the total resulting atomic weight must be less than the weight of the original, undecomposed atom, in consequence of the subtraction of escaped electrons. Whether or no electrons gravitate is a moot point. They possess inertia; yet appear to lie outside the domain of the great universal force. In shaking off atomic bonds they would then cease to gravitate, and mass would be, *pro tanto,* diminished.[1] On the contrary supposition, there should be a loss, not of absolute, but of measurable mass; for electrons, once set at large, are not easily recaptured.

These still obscure, though significant possibilities illustrate the radical change in the views of physicists brought to pass by the investigation of radio-activity. Once more, as of old, the framework of nature has come to appear plastic. Once more we are confronted with the quintessential community of material things. We discern them as built up variously out of the same sub-elemental stuff, which, like the *materia prima* of the ancients, is subtilized

---

[1] E. Rutherford, *Radio-Activity,* second edition, page 336.

to the verge of evanescence. What we call electrons, in short, our scientific ancestors designated "protyle" conceived of as "potentially all things, and actually nothing."[1] Modern protyle has, however, been captured, and can be generated at will by the agency of electricity. No longer a metaphysical abstraction, it advances definite claims to a concrete if incomprehensible existence.

Elemental evolution, in its only cognizable form, inverts the course of organic evolution. For an ascent from homogeneity toward heterogeneity, it substitutes progress by degradation. Complex atoms are continually getting reduced to a more simple state through the shedding of their component electrons. Moreover, the shed electrons for the most part reconstitute themselves into systems, and enter upon independent atomic careers. That is to say, there result, as the permanent products of radio-active change, a metal of inferior atomic weight to the metal partially decomposed, and a gas. Now the gas has been identified by its spectrum as helium, so named by Sir Norman Lockyer in 1869, because of its abundant presence near the sun. Until 1895, when Sir William Ramsay made its hiding-place in clevite too hot to hold it, this singular substance was a mere cosmic acquaintance. The twelve years since elapsed, however, have sufficed to make its properties familiar. They are chiefly negative. It has no chemical affinities; a "rogue" element, it exists in isolation or imprisonment; it only slightly refracts light; it is electrically neutral; it remains obstinately aeriform at temperatures much below the boiling-point of hydrogen. Although of extreme terrestrial scarcity, its effusion is an unfailing concomitant of atomic decay, and from radium in particular, has been proved to go on without let or hindrance. The atoms of helium are thus framed under our eyes. We can watch an element in the making. But the process is usually far more leisurely. The evolution of metals is largely a matter of inference. It goes forward too slowly

---

[1] Fowler's *Novum Organum*, page 339, note 13.

to be directly observable. To this rule there is, we admit, one exception. The degradation of uranium into radium has become perceptible even within the brief span of recent experimental inquiry.

For the rest there is room and to spare for speculation. The metals are very curiously interrelated, both in their qualities and in their distribution. Some occur in almost inseparable companionship. Among these cognate couples are silver and lead. In Mr. Donald Murray's words: "A lead mine is a silver mine, and a silver mine is a lead mine all the world over, and yet the chemical attraction between silver and lead is slight, and the two metals are not sufficiently common to concur by chance."[1] The inference was irresistible, and has been reached by others, that silver is a disintegration product of lead. And it is interesting to remember that lead, until superseded by mercury, was accounted in alchemistic theory the "mother of metals." Now the persuasion is gaining ground that the supplies of the various elements existing in the earth are regulated by the proportion between their rates of development and dissolution. Elemental distribution does not show the extreme inequalities which would stamp it as the outcome of chance. The approximate constancy in the quantities present in all quarters of the globe of such rare metals as gold, platinum, thallium, indium, gallium, and so on, appears to intimate the working of a genetic law. It suggests that they are, in Professor Soddy's phrase, at once offspring and parent elements;[2] that they are derived from substances more highly elaborated; that they give rise, as they in turn spontaneously decompose, to others less complex, the relative speed of these ineffably slow alterations determining the amount of each product found in the earth at a given time. This remarkable hypothesis may be verified, according to Professor Soddy's anticipation, by the discovery of occluded helium in antique gold.

Thus physical science in the twentieth century has been

---

[1] *Nature*, vol. lxxiii, page 125. [2] *Ibid*, page 151.

strangely led to reoccupy some of the abandoned strongholds of the discredited horde of alchemists. We can see now that they were groping toward half-truths. And their instinct in selecting lead and mercury as initial forms of matter was so far right that both have atomic weights higher than those of gold and silver. But they erred hopelessly in pitting their feeble artifices against the imperturbable stability, measured on our time scale, of the created world. Irretrievable disaster and delusion could not but ensue from their attempts to control the uncontrollable, and to exploit inaccessible treasure stores. We know better. Radio-activity is the least manageable of natural processes. It will not be interfered with. We can only look on in wonder while it deploys its irresistible unknown forces. They reveal latent possibilities of mechanical power fabulous in amount, and within, it might be said, a hand's breadth of being industrially available; yet we are precluded from their employment.[1] Base metals, we suspect with reason, are continually becoming ennobled; but the gates of the half-seen Eldorado remain closed. Will they remain closed forever? That is an unread enigma. Should human ingenuity find means, in the future, to fling them wide, the newer alchemy will far outbid the promises of the old, and will cap its illusory performances with as yet unimaginable realities. Their accomplishment, however, will consist not in the lavish production of silver and gold, but in the subjugation of the untold energy accumulated at the beginning of the world in complex atomic systems. Nature here sits entrenched in her last fastness. The more sanguine among us anticipate its reduction. Others believe it to be impregnable. The forces that hold it will certainly not capitulate soon or easily. The siege must be prolonged and difficult; the issue is doubtful.

---

[1] See Professor Rutherford's article "Radium—the Cause of the Earth's Heat" in *Harper's Monthly* for Feb. 1905.

RADIOACTIVITY[1]

BY MADAME MARIE CURIE

A BRIEF RESUME OF OUR PRESENT KNOWLEDGE

The discovery of radioactivity is comparatively recent, going back only to 1896, the year in which the radiant properties of uranium were proved by Henri Becquerel.

The development of the science since has been extremely rapid, and among the numerous results obtained are some whose general scope is so widely extended that radioactivity constitutes to-day an independent and important branch of the physico-chemical sciences occupying a precisely defined field of its own.

In the study of radioactivity the knowledge of the chemist and that of the physicist find applications of equal importance.

If the methods of analytic chemistry are constantly employed for the extraction of radioactive substances from their mineral compounds, various methods of physical measurement, and in particular, of electrometry, are of current usage for the study of these substances.

It is particularly interesting to remark the close connection which exists between the rapid development of radioactivity and the results obtained in a series of theoretical and experimental researches upon the nature of electromagnetic phenomena, and upon the passage of the electric current through gases.

These researches, which have established with great precision the conception of the corpuscular structure of electricity, comprise the study of the cathodic and positive

---

[1] Introduction to Madame Curie's *Traité de Radio-activé,* publishers, Gauthiér-Villars. Translation in *Scientific American Supplement,* December, 1910, used by permission of the author.

rays, the discovery and study of Röntgen rays, and the study of gaseous ions. They have led to the idea of the existence of particles which carry positive or negative charges, and which may have dimensions comparable to atomic dimensions, or possibly dimensions considerably smaller.

The theory of ionization, which has been established to explain the characteristics of electric conductivity in gases, has been recognized as likely to furnish an interpretation of the conductivity acquired by a gas submitted to the action of a radioactive body; this theory has been applied to the study of radiations emitted by radioactive substances, and constitutes from this point of view a very valuable instrument of research.

Moreover, the rays of radioactive bodies present analogies to cathodic, positive, and Röntgen rays, and can often be studied by analogous methods.

It may be said that the discovery of radioactivity occurred at a time when the ground was admirably prepared.

Closely allied to physics and chemistry, and borrowing the methods of work of these two sciences, radioactivity brings to them in exchange, elements of renewal.

To chemistry it gives a new method for the discovery, the separation, and the study of the elements, as well as the knowledge of a certain number of new elements of very curious properties—first of all, radium; and finally, the idea—of capital importance—of the possibility of atomic transformations under conditions subject to the control of experience.

To physics, and above all, to modern theories of corpuscles, it brings a world of new phenomena whose study is a source of progress for these theories. One might cite, for example, the emission of particles carrying electric charges and having a considerable rapidity, whose motion does not obey the ordinary laws of mechanics, and to which one may apply, with the purpose of verifying and developing them, recent theories relative to electricity and to matter.

But though radioactivity is in close relation to physics and chemistry above all, it is not foreign to other domains of science, and in these acquires increasing importance.

Radioactive phenomena are so varied, their manifestations are so diverse and so widespread in the universe, that they should be taken into consideration in the study of the natural sciences, especially in physiology and therapeutics, in meteorology and geology.

Many laboratories actually devote themselves to the study of radioactivity. Institutes are being created for the centralization of relatively important quantities of radium, the principal instrument of research in this new domain. And by reason of these efforts the importance of the subject must still further increase.

I published in 1903 a small volume entitled *Researches Upon the Radioactive Substances,* in which was reviewed the state of the subject at that period. In 1905 appeared the excellent treatise of Professor Rutherford, which has had a more complete recent edition and has rendered great service.

In the present work I have tried to give an exposition as complete as possible of the phenomena of radioactivity, in the actual state of our present knowledge.

The plan of my first book has been preserved in part, but the work comprises a much more ample field, corresponding to the sudden development of the science.

* * * * * * * *

Radioactivity is a new property of matter which has been observed in certain substances. Nothing warrants us in actually affirming that this is a general property of matter, though this opinion presents nothing *a priori* impossible, and may even seem quite natural.

Radioactive bodies are sources of energy whose disengagement manifests itself by diverse effects: the emission of radiations, of heat, of light, of electricity.

This disengagement of energy is essentially connected with the atom of the substance; it constitutes an *atomic* phenomenon; moreover, it is *spontaneous.* These two characteristics are essential.

We have actual knowledge of bodies feebly radioactive: uranium and thorium; and of many bodies strongly radioactive: radium, polonium, actinium, radiothorium, ionium.

These bodies are found in nature in an extreme state of dilution; and this is not the effect of chance.

Among the strongly radioactive bodies, radium alone has been isolated in the state of a pure salt; in the richest minerals this body is found in the proportion of a few decigrams per ton of mineral.

Radioactive substances emit rays which have the faculty of impressing sensitive plates, of exciting phosphorescence, and of rendering gases conductors of electricity; but which do not exhibit refraction, polarization, or regular reflection.

These rays offer, therefore, analogies to cathodic, positive, and Röntgen rays. An attentive examination has proved that the ray-emission of radioactive bodies can be divided into three groups, β, α, γ, respectively analogous to the three groups of rays which have just been named, and which are formed in a Crookes tube.

The β rays are constituted by an emission of negative electrons, and the α rays by an emission of particles positively charged, while the γ rays are not charged. The emission of the rays and the β rays correspond to a spontaneous disengagement of electricity by the radioactive bodies.

The rays of these bodies produce numerous effects of various nature: chemical effects, of which the most important is the decomposition of water; physiological effects, such as the action upon the epidermis and other tissues—an action which is currently employed for medical applications. Certain radioactive substances are spontaneously luminous.

The radioactive bodies are sources of heat. Radium gives rise to a disengagement of heat of 118 cal. per gram per hour, and that without the state of the substance being appreciably altered during many years.

This extremely remarkable fact establishes a fundamental distinction between radium and ordinary elements, and is in accord with the actual conception which attributes radioactivity to a transformation of the atom.

The radioactive substances may possess a constant activity, at least, apparently, within the limits of our observations: such are uranium, thorium, radium, actinium. In other substances, e. g., in polonium, a slow diminution of activity in the lapse of time has been observed.

Lastly, radioactive phenomena of much shorter duration still, have been observed.

Thus, radium, thorium, and actinium disengage continuously radioactive gases called *emanations,* whose activity in time disappears; quite slowly in the case of radium, very rapidly in the case of thorium and actinium.

These emanations themselves produce on the exposed surfaces active deposits which also disappear in the course of a few hours or days. This is the phenomena of induced radioactivity.

We can, also, by means of suitable chemical reactions, separate from uranium or thorium radioactive substances which are continuously produced by these bodies, and whose activity disappears progressively in a few months.

All these phenomena can be explained satisfactorily by admitting the production and destruction of radioactive matter according to precisely determined laws.

The radioactive properties are in fact very varied; the diverse forms of ephemeral radioactivity are distinguished from each other by the nature of the rays emitted, and by the rapidity of the disappearance.

It may be admitted that the production or the destruction of a distinct form of radioactivity corresponds to the production or destruction of a chemically distinct substance, and since radioactivity is an atomic phenomenon, it concerns the production and destruction of atoms.

This view constitutes an extension of ideas upon the atomic nature of radioactivity, ideas which have led to the discovery of radium.

The theory of the transformation of radioactive elements which has been developed by Rutherford and Soddy is now generally adopted.

According to this theory there exist no invariable radioactive substances, but each of them undergoes in the course of time a more or less rapid progressive destruction.

A chemically simple radioactive substance is destroyed in such a manner that the rapidity of the destruction is proportional to the quantity present. Consequently this quantity decreases according to a simple exponential law, characterized by an invariable coefficient, which depends on the nature of the substance and may serve to define it.

These coefficients, or *radioactive constants,* seem independent of experimental conditions and capable of constituting standards of time.

The destruction of atoms may be compared to an explosion, at which time fragments of the atoms may be thrown off with or without an electric charge.

The resulting products may be either inactive or endowed with radioactivity, and in the latter case the newly formed atom is not itself stable, but must submit to a new *disintegration* at the end of a longer or shorter time.

When the destruction of a form of ephemeral radioactivity occurs according to a complex law, this law can always be represented by an algebraic sum of exponential terms, which is interpreted as a succession of simple transformations of limited number. Experience has shown that in this case the various terms of the series may be considered as representing simple radioactive substances of which certain ones are capable of being separated.

In pursuing the analysis of radioactive phenomena, we succeed in establishing, starting from a primary substance, a succession of terms which succeed one another in the series of radioactive transformations.

We thus obtain families of elements allied by a relationship which connects them in a common but distinct origin. Such are: the family of radium, which comprises polonium also; the family of uranium; of thorium; of actinium.

Radium itself is not a primary substance, but probably derives from uranium. We are confronted, in fact, by the existence of about thirty radioactive elements, of which many, in truth, will never be characterized as such, because they have too brief an existence.

In fact only those radioactive elements can accumulate in appreciable quantities, of which there is a continuous production, and in which the rapidity of destruction of the quantity produced is not too great.

On the other hand, the intensity of radioactive phenomena is proportional to the rapidity of destruction; and if we compare bodies of analogous ray-emission and in similar quantities, the bodies most strongly radioactive are those which have the greatest rapidity of destruction. Hence, the most strongly radioactive substances are those which we should expect to find in nature in smallest proportions, and this is borne out by experience.

Among the products of destruction of radioactive bodies is one which is particularly interesting: the gas helium, which is produced constantly by radium, actinium, polonium, uranium, and thorium.

Experience has proved that the atoms of helium emitted should be considered as particles which have lost their electric charge.

On the other hand, the α rays of the various radioactive bodies seem constituted of the same material particles. It results from this that the atom of helium forms, in all probability, one of the constituents of all, or nearly all, radioactive atoms, and perhaps a constituent of atomic structures in general.

The discovery of the production of helium by radium is due to Ramsay and Soddy and constitutes one of the most important facts in the history of radioactivity.

Certain radioactive transformations are very slow; e. g., the destruction of uranium and of thorium. The effects of the transformation are in these cases very insignificant even after many years.

But in the radioactive minerals these same transformations may have been produced during the process of time of geologic epochs, and hence the study of the mineral permits us to determine the relations of the radioactive bodies.

Inversely, if one such relation is known we can deduce from it the length of time during which the transformation has taken place in an unaltered mineral. Thus by the accumulation of helium occluded in minerals we can estimate the age of the latter.

If it were proved that all matter is more or less radioactive, the relative proportions of the elements in the minerals could be studied with the view of making evident the relations of genesis among the elements. To terminate this brief review of the domain of radioactivity I will indicate how great is the disengagement of energy by radioactive bodies.

Thus, for radium, whose rapidity of destruction is approximately known (this rapidity is such that the radium is half gone in about 2,000 years), the destruction of a gram of matter involves the disengagement of a quantity of heat equal to that which results from the combustion of 500 kilograms of carbon or 70 kilograms of hydrogen.

We must conclude that the internal energy of an atom is very great in relation to that which is brought into play at the time of the combination of atoms in a molecule. This fact is probably of a nature to explain the independence of radioactive phenomena of experimental conditions.

Among the attempts which have been made to influence these phenomena, none has yet given a positive result. Radioactivity results from the destruction of certain atoms, and this destruction appears to us as a spontaneous phenomenon.

Experience shows also that everything takes place as if the probability of the destruction was, at the same instant, the same for all the atoms of the same matter. It is thus that we interpret the exponential laws of the destruction and the divergences from this law.

It appears inevitable to admit that the destruction of an individual atom at a given moment results from particular circumstances which the state of this atom and the influence of exterior agents may cause to intervene.

Thus the determining cause of radioactive phenomena remains still unknown.

In this book the exposition of the phenomena of radioactivity properly so called has been preceded by an exposition of the theory of gaseous ions, and by a *résumé* of the most important knowledge concerning cathodic, positive, and Röntgen rays, and of the properties of electrified particles in motion. This knowledge is indispensable to the study of the subject in hand. A later chapter has been devoted to the description of methods of measurement.

After the detailed description of the discovery and preparation of radioactive substances comes the study of radioactive emanations and of induced radioactivity, and of radiations emitted by radioactive bodies.

The radioactive substances are afterward classified by families, with the study for each of them of the *ensemble* of properties and of the nature of radioactive transformations.

VISIBLE MOLECULES, CORPUSCLES AND IONS[1]

When, a hundred years ago, John Dalton gave its modern shape to the atomic theory, which may be traced back to ancient philosophy and to Democritus, nobody expected that scientists would some day isolate, or at least render visible, the single atom and molecule. The kinetic theory of gases ascribed the gas pressure to the bombardment of the walls of the confining envelope by the gas molecules. It taught us how to count and to measure the molecules. But it did not bring the probability of our ever seeing them any nearer; that looked hopeless with 3×10^{19} molecules in a cubic centimeter of a gas, and 640 trillion of atoms in a milligram of hydrogen. The recent discovery of particles one-seventeen hundredth of the size of a hydrogen atom offers problems even more difficult than those of an atom. Yet it is claimed that the visibility of the smallest particles has been demonstrated in various ways. It may be opportune to examine some of the experiments on which such claims are based.

The existence of particles smaller than the atom would not in reality contradict the atomic theory. The atomic theory does not assert that the atom is the smallest particle capable of existence. The name "atom," indeed, suggests something that cannot further be cut or divided. But the essence of the theory is that an elementary substance consists of particles or atoms peculiar to that element, and that the single atom is the smallest particle which can enter into combination. The molecule is the combination product of atoms. The atom need not necessarily be the smallest ultimate particle, and many considerations induce modern

---

[1] *Engineering*, April 8, 1910.

science to believe that the atom may itself have a constitution. The atoms of different elements differ from one another. Yet the modern scientist feels with the ancient philosopher that there may, after all, be only one kind of matter, which, being grouped in different ways, gives rise to different elements and bodies. There are certainly difficulties in the suggestion that atoms or molecules should be able to split off corpuscles, and remain substantially what they were, while, on the other hand, radium—probably an elementary metal—is able to emit radiations which turn into helium—undoubtedly a gas. But those researches are not completed yet, and meanwhile chemists continue to adhere to the atomic theory which has proved so fruitful, and to determine atomic weights with the greatest possible care.

The demonstrations of the possible visibility of molecules are based on observations partly made in less controversial fields. Colloids have furnished the first suggestion of visible molecules or groups of molecules. When mud is stirred up, the particles settle quickly again, and the turbid liquid can, by filtering, be cleared of suspended particles. The particles of an oil emulsion take a long time to settle, and run turbid through the filter. When still finer particles are prepared, for instance, by volatilizing metal electrodes immersed in liquids, the cloudy particles will not settle for many days or months, and finally it may be impossible to decide whether an emulsion or a real solution has resulted. It is quite conceivable that the transition from a suspension to a solution is too gradual to permit of a distinct line of demarkation being drawn, just as the three states of aggregation cannot rigorously be distinguished. Very small suspended particles now are in constant oscillatory movement. These movements were first observed by the botanist Brown in 1827, and are known as Brownian movements. The coarser the particles, the slower and more irregular the movements. For a long time they were ascribed to inequalities of temperature in the turbid liquid. When the ultra-microscope was brought out in Jena, the study of this curiosity assumed a direct scientific interest, and the impression gained ground that the observer really watched molecular movements akin to those which the particles of gases describe according to the kinetic theory of gases. The idea originated, we believe, with Einstein; he certainly worked out the mathematics of the problem. During the past few years J. Perrin, Gouy, Svedberg, and others have supplied apparent experimental proofs for the molecular character of the movements. Perrin counted the number of gamboge granules or particles, in a portion of his colloidal solution, measured their diameters, masses, and paths, and calculated their average kinetic energy. He concluded that the granules had the same average energy of movement as the molecules of the liquid in which they were suspended, and that they behaved thus like molecules of a very high molecular weight.

Now molecules of a high molecular weight—in other words, molecules consisting of a great number of atoms of different elements—are nothing strange to the chemist. Emil Fischer, in his famous researches on the albuminoids, has come to very high molecular weights indeed. In his four series of experiments Perrin dealt with granules whose masses varied as 1 : 3 : 8 : 27. Allowing for the coarseness of his granules and the friction in his medium (water), Perrin deduced for the number N of molecules per cubic centimeter very nearly the same figure, 3×10^{19}, to which other researches have led us. Estimates of this N, we should add, have been made by the most varied and entirely independent methods. Some of the methods give results which, it may be foreseen, should be considered as upper limits, others will yield lower limits. The average accepted value for N was, a few years ago, probably 6×10^{19}; at present scientists incline to half that value, 3×10^{19}.

The experiments of Ehrenhaft confirm those of Perrin. Ehrenhaft volatilized silver electrodes in air; the fine-dust granules thus produced exhibited the looked-for Brownian movements, and the free path was longer in air than it had been for granules of the same size in water. Perrin's calculations have, on the other hand, been questioned by Duclaux. But we appear to be justified in assuming that the observer, watching the movements of colloidal particles, sees movements similar to those which we ascribe to the invisible molecules of gases.

Another demonstration of luminous effects, ascribed to single particles, was given by Crookes in London and Regener in Berlin, seven or eight years ago, and thus before the above-mentioned experiments on colloids in which molecules are supposed to be concerned. When the α rays of radium are allowed to fall on a screen or fluorescent zinc sulphide, each particle seems to produce a flash of light like a tiny spark, and brilliant scintillations are observed. Still more instructive is the demonstration of single α particles, which Rutherford and Geiger gave in the Royal Institution two years ago. A tube containing radium bromide was held in front of the window of a long tube, several feet away from the window, so that only a few α particles—perhaps not more than one per second—would find their way to the electrometer at the far end of the tube. A sudden jerk of the electrometer indicated that a particle had struck and the number of particles shot out per second were actually counted by counting the jerks. Each α particle is supposed to represent a charged atom of helium, which turns into helium gas on losing its electric charge. Dewar has carefully determined how much helium is produced by a given weight of radium per second, and by putting that figure together with his count of the number of α particles discharged per second, Rutherford arrived at the conclusion that 1 cubic centimeter of helium is formed by 2.56×10^{19} particles—a most remarkable confirmation of the N.

Another exemplification of the visibility of molecules or, at any rate, of the discontinuity of an apparently homogenous solution, is due to the late Lobry de Bruyn, and has recently been verified by A. Coehn. It refers to the so-called Tyndall effect. A ray of light is, as such, invisible in an optically empty medium. Passed through a glass trough the beam of the lantern is hardly visible, until some turbid medium like smoke is introduced into the trough. The light cone of a lens, concentrated into pure water, leaves the water dark, when it is free of suspended particles, dust, etc. It is, of course, exceedingly difficult to free the water of all dust and floating impurities. Working with the greatest care Lobry de Bruyn succeeded in obtaining pure water, in which the light cone was hardly discernible. But when he dissolved cane sugar in this water, a luminosity was noticed. Coehn has repeated this experiment with the ultramicroscope of Zsigmondy, and the light cone then observed was quite uniform; dust particles or colloids would have shown as bright points. It would, therefore, appear that the large molecules of cane sugar, dispersed through the water, make the water sufficiently discontinuous to reflect the light.

The further endeavors of Coehn to exemplify this discontinuity in solutions in which a transport of the ions and of non-electrolytic particles, drifting with the ions, is produced by electrolysis, will be better understood by a description of some very remarkable experiments of Kossonogow, of Kjew. Kossonogow studies electrolysis with the aid of the ultra-microscope. He bends both the electrodes of his cells twice at right angles, so as to leave a channel, generally 0.2 millimeter in width, between the active surfaces, and coats the other portions of the electrodes with paraffin; the light beam is sent across this channel in which electrolysis takes place. On dissolving various salts, silver nitrate, copper sulphate, ammonium chloride, and others in water, he observed at once—before turning on the current—some luminosity and bright specks in Brownian movements. Some of the specks were no doubt dust particles. But the just-mentioned discontinuity phenomena, and further migration of the ions, were also concerned. For the luminosity increased when the current (of 10 volts, e. g.) was turned on, and the particles were distinctly seen to wander, mostly toward the cathode. If dust granules had alone been at work, the current should gradually have cleared the solution of such granules. But the directed movements were only observed when there was real electrolysis, and no movements and hardly any luminosity were seen when the solvent was not water, but a non-electrolyte, like benzol. The bright specks were, moreover, deflected from their rectilinear paths when the cell was placed in a strong magnetic field. On reversing the current, the bright specks also reversed their movements, which took place at the rate of migrating ions, and on applying alternating currents the particles seemed to be undecided which way to move.

All these observations appear to indicate that the moving particles are either ions, or other bodies or molecules, drifting together with the ions, and it has long ago been pointed out that the migrating ion would carry some of the solvent with it. The following observations of Kossonogow are of particular interest. When a certain critical potential was applied, the number of bright specks suddenly increased very much, and they crowded near the cathode, but a dark space, from 0.05 to 0.08 millimeter in width, was always left close to the cathode. This dark cathode space —so well known from experiments on the electric discharge through gases—was very well defined, and it was particularly striking when cathodes were used which were not plain, but curved in fanciful ways. The boundary of the dark space always kept parallel to the contours of the cathode. Beyond the dark space the bright particles were in lively motion; but no bright particles crossed the dark space, though the ions must traverse it to be deposited on the cathode. It looked, Kossonogow says, as if the ions lost their luminosity, together with their electric charge, when passing the dark space. When the critical potential—1 volt for silver nitrate in water—was exceeded, another crowding of the bright spots to a bright band was noticed intermediate between the electrodes. The crowding of the bright points and the dark space were also seen in copper sulphate. When silver electrodes were dipped into a colloidal solution of silver in water, the phenomenon changed. The bright spots crowded near the anode, not near the cathode, but there was no dark space separating them from the anode.

Whatever one may think of the interpretation of these phenomena, it will be conceded that the decomposition products of electrolysis are concerned in them. Whether the bright spots seen are really the ions, whether the optical discontinuity is really due to single molecules, whether the scintillations and electrometer discharges are indeed produced by single α rays—i. e., single charged helium atoms—and whether the colloidal granules represent real analogues of molecules, whether, in brief, the phenomena, which we have reviewed, really constitute effects of ultimate particles—these questions remain open, of course. Chemists may at times decline to follow physicists into some of their novel theories. But problems present themselves which were unknown to the exact science of past generations, though such questions entered into their speculations, and the perfection, especially of electrical and optical methods and instruments, of research certainly has provided us with means of conducting investigations which the past generations could hardly have hoped to attain.

THE ELECTRONIC THEORY OF MATTER[1]

BY SIR OLIVER LODGE, D. Sc., F. R. S.

In a recent number of *Harper's Magazine* Sir Oliver Lodge presents a popular account of the electronic theory, which is well worth quoting:

Our present view of an atom of matter is something like the following: Picture to one's self an individualized mass of positive electricity, diffused uniformly over a space as big as an atom—say a sphere of which 200,000,000 could lie edge to edge in an inch, or such that a million million million million could be crowded tightly together into an apothecary's grain. Then imagine disseminated throughout this small spherical region a number of minute specks of negative electricity, all exactly alike, and all flying about. vigorously, each of them repelling every other, but all attracted and kept in their orbits by the mass of positive electricity in which they are embedded and flying about. In so far as an atom is impenetrable to other atoms, its parts act on the sentinel principle, not on the crowd principle.

There are two ways of keeping hostile people out of an open building; one is to fill it with your own supporters, another is to place an armed policeman at every door. The electrons are extremely energetic and forcible, though in bulk mere specks or centers of force. Every speck is exactly like every other, and each is of the size and weight appropriate to the electron. Different atoms, that is, atoms of different kinds of matter, are all believed to be composed in the same sort of way; but if the atoms of a substance

---

[1] Review of an article in *Harper's Magazine*, from *Scientific American Supplement*, September 17, 1904.

are such that each possesses twenty-three times as many electrons as hydrogen has, we call it sodium. If each atom has two hundred times as many as hydrogen, we call it lead or quicksilver. If it has still more than that, it begins to be conspicuously radioactive.

It would seem as if the excessive radiation which follows upon an overcrowded condition were caused by the probability of collision or encounter between the parts of an atom; just as every now and then among the stars in the sky two bodies encounter each other, and a great blaze of radiation, or temporary star, results. Even in atoms of which the parts are sparsely distributed such occurrences are not impossible, though they are less frequent, and accordingly it is to be expected that every kind of matter may be radioactive to a very small extent; a probability which is now justified for most metals, by direct experiment with very sensitive means of detection.

Indeed, so far as radiation necessarily accompanies any change of motion of an electron, and in so far as in every atom some electrons are describing orbits and are therefore subject to centripetal acceleration, a certain amount of atomic radiation is inevitable, on the electric theory of matter. In most cases it is imperceptibly small, but it must be there, and accordingly an atom must be slowly undermining its own constitution by the gradual emission of its internal or intrinsic energy in the form of ether-waves.

Thus, then, it is reasonable to expect that, every now and then, an atom will break up or collapse or divide into parts. This process has been observed by Rutherford, of Montreal. The radiation from many of the radioactive substances, on being analyzed by a magnet, is found to be separable into three parts: 1, the so-called β rays, which are the shot-off electrons already mentioned; 2, some γ rays, which appear to represent an ethereal pulse—an analogue as it were of the sound-wave caused by the explosion or act of firing; and 3, more important than either, a third kind of projectile called the α rays, which are newly-formed atoms of foreign matter or new substance. These are pitched away with extraordinary violence as the atom breaks up; they produce by their bombardment of zinc sulphide the bright little flashes seen in Crookes' spinthariscope, and they likewise generate heat when they are stopped by any obstacle. They thus keep the vessel in which they are inclosed at a temperature a degree or two above surrounding bodies, at least in the case of the most active known substances, radium and its emanation. For radium converts its own intra-atomic energy into heat at so surprising a rate that it could, if all of the heat were economized and none allowed to escape, raise its own weight of water from ordinary temperature to the boiling-point every hour.

The number of atoms breaking up in any perceptible portion of radium salt must be reckoned in millions per second; nevertheless, the proportion of atoms which are thus undergoing transformation at any one time is extremely small. If they could be seen individually most of them would appear quiescent and stable. Of every ten thousand atoms, if a single one breaks up and flings away a portion of itself once a year, that would be enough to account for all the activity observed, even in the case of so exceptionally active a substance as radium; hence the apparent stability of ordinary matter is not surprising.

The thus projected atomic fragments were measured by Rutherford, who found them deflected by a magnet in the opposite direction to the electron projectiles, and were therefore proved to be positively charged; but they are deflected so slightly that they must be very massive bodies, 1,600 times as massive as an electron, or twice the weight of hydrogen. A substance with this atomic weight is known, viz., helium: and surely enough the discoverer of helium, Sir W. Ramsay, working with Mr. Soddy, a recent colleague of Rutherford, has witnessed the helium spectrum gradually develop in a tube into which nothing but radium emanation had been put.

Matter, then, appears to be composed of positive and negative electricity and nothing else. All its newly-discovered, as well as all its long-known, properties can thus be explained—even the long-standing puzzle of "cohesion" shows signs of giving way. The only outstanding still intractable physical property is "gravitation," and no satisfactory theory of the nature of gravitation has been so far forthcoming. I doubt, however, if it is far away. It would seem to be a slight but quite uniform secondary or residual effect due to the immersion of a negative electron in a positive atmosphere. It is a mutual force between one atomic system and another, which is proportional to the number of electrons in each. It is quite doubtful whether it is displayed by an isolated, or disembodied electron, but the act of immersing an electron in its attracting atmosphere may develop it. We know too little about electricity, especially about positive electricity, to be able to justify or expand such a guess; but, as a guess and no more, I venture to throw it out; believing it to be a static residual strain effect, inherent in the constitution of each atom.

THE ETHER OF SPACE[1]

BY SIR OLIVER LODGE, D. Sc., F. R. S.

Thirty years ago Clerk Maxwell gave a remarkable lecture on "Action at a Distance." Like most other natural philosophers, he held that action at a distance across empty space is impossible; in other words, that matter cannot act where it is not, but only where it is. The question "Where is it?" is a further question that may demand attention and require more than a superficial answer. For it can be argued on the hydrodynamic or vortex theory of matter, as well as on the electrical theory, that every atom of matter has a universal, though nearly infinitesimal, prevalence, and extends everywhere, since there is no definite sharp boundary or limiting periphery to the region disturbed by its existence. The lines of force of an isolated electric charge extend throughout illimitable space. And though a charge of opposite sign will curve and concentrate them, yet it is possible to deal with both charges, by the method of superposition, as if they each existed separately without the other. In that case, therefore, however far they reach, such nuclei clearly exert no "action at a distance" in the technical sense.

Some philosophers have reason to suppose that mind can act directly on mind without intervening mechanism, and sometimes that has been spoken of as genuine action at a distance; but, in the first place, no proper conception or physical model can be made of such a process, nor is it clear that space and distance have any particular meaning in the region of psychology. The links between mind

---

[1] A Friday evening discourse at the Royal Institution of Great Britain on the 21st of February, 1908.

Published in the *North American Review* for May, 1908.

and mind may be something quite other than physical proximity, and in denying action at a distance across empty space I am not denying telepathy or other activities of a non-physical kind; for although brain disturbance is certainly physical, and is an essential concomitant of mental action, whether of the sending or receiving variety, yet we know from the case of heat that a material movement can be excited in one place at the expense of corresponding movement in another, without any similar kind of transmission or material connection between the two places: the thing that travels across vacuum is not heat.

In all cases where physical motion is involved, however, I would have a medium sought for; it may not be matter, but it must be something; there must be a connecting link of some kind, or the transference cannot occur. There can be no attraction across really empty space. And even when a material link exists, so that the connection appears obvious, the explanation is not complete; for when the mechanism of attraction is understood, it will be found that a body really only moves because it is pushed by something from behind. The essential force in nature is the *vis a tergo.* So when we have found the "traces" or discovered the connecting thread, we still run up against the word "cohesion," and ought to be exercised in our minds as to its ultimate meaning. Why the particles of a rod should follow, when one end is pulled, is a matter requiring explanation; and the only explanation that can be given involves, in some form or other, a continuous medium connecting the discrete and separated particles or atoms of matter.

When a steel spring is bent or distorted, what is it that is really strained? Not the atoms—the atoms are only displaced; it is the connecting links that are strained—the connecting medium—the ether. Distortion of a spring is really distortion of the ether. All strain exists in the ether. Matter can only be moved. Contact does not exist between the atoms of matter as we know them; it is doubtful if a piece of matter ever touches another piece, any more than a comet touches the sun when it appears to rebound from it; but the atoms are connected, as the planets, the comets and the sun are connected, by a continuous *plenum* without break or discontinuity of any kind. Matter acts on matter solely through the ether. But whether matter is a thing utterly distinct and separate from the ether, or whether it is a specifically modified portion of it —modified in such a way as to be susceptible of locomotion, and yet continuous with all the rest of the ether—which can be said to extend everywhere, far beyond the bounds of the modified and tangible portion called matter—are questions demanding, and I may say in process of receiving, answers.

Every such answer involves some view of the universal, and possibly infinite, uniform omnipresent connecting medium, the ether of space.

Let us now recall the chief lines of evidence on which the existence of such a medium is believed in, and our knowledge of it is based. First of all, Newton recognized the need of a medium for explaining gravitation. In his "Optical Queries," he shows that if the pressure of this medium is less in the neighborhood of material bodies than at great distances from them, those bodies will be driven toward each other; and that if the diminution of pressure is inversely as the distance from the dense body, the law will be that of gravitation.

All that is required, therefore, to explain gravity is a diminution of pressure, or increase of tension, caused by the formation of a matter unit—that is to say, of an electron or corpuscle; and although we do not yet know what an electron is—whether it be a strain center, or what kind of singularity it is in the ether—there is no difficulty in supposing that a slight, almost infinitesimal, strain or attempted rarefaction should have been produced in the ether whenever an electron came into being; to be relaxed again only on its resolution and destruction. Strictly speaking, it is not a real *strain,* but only a "stress" since there can be no actual *yield,* but only a pull or tension, extending in all directions toward infinity.

The tension required per unit of matter is almost ludicrously small, and yet in the aggregate, near such a body as a planet, it becomes enormous.

The force with which the moon is held in its orbit would be great enough to tear asunder a steel rod four hundred miles thick, with a tenacity of 30 tons per square inch; so that if the moon and earth were connected by steel instead of by gravity, a forest of pillars would be necessary to whirl the system once a month round their common center of gravity. Such a force necessarily implies enormous tension or pressure in the medium. Maxwell calculates that the gravitational stress near the earth, which we must suppose to exist in the invisible medium, is 3,000 times greater than what the strongest steel could stand; and near the sun it should be 2,500 times as great as that.

The question has arisen in my mind whether, if all the visible or sensible universe—estimated by Lord Kelvin as equivalent to about a thousand million suns—were all concentrated in one body of specifiable density,[1] the stress would not be so great as to produce a tendency toward ethereal disruption; which would result in a disintegrating explosion, and a scattering of the particles once more as an enormous nebula and other fragments into the depths of space. For the tension would be a maximum in the interior of such a mass; and, if it rose to the value of 10^{33} dynes per square centimeter, something would have to happen. I do not suppose that this can be the reason, but one would think there must be *some* reason, for the scattered condition of gravitative matter.

Too little is known, however, about the mechanism of gravitation to enable us to adduce it as the strongest argument in support of the existence of an ether. The oldest

---

[1] On doing the arithmetic, however, I find the necessary concentration absurdly great, showing that such a mass is quite insufficient.

valid and conclusive requisition of an ethereal medium depends on the wave theory of light, one of the founders of which was Dr. Thomas Young, at the beginning of last century.

No ordinary matter is capable of transmitting the undulations or tremors that we call light. The speed at which they go, the kind of undulation, and the facility with which they go through vacuum, forbid this.

So clearly and universally has it been perceived that waves must be waves of something—something distinct from ordinary matter—that Lord Salisbury, in his presidential address to the British Association at Oxford, criticized the ether as little more than a nominative case to the verb to undulate. It is truly *that,* though it is also truly more than that; but to illustrate that luminiferous aspect of it, I will quote a paragraph from the lecture of Clerk Maxwell's to which I have already referred:

> The vast interplanetary and interstellar regions will no longer be regarded as waste places in the universe which the Creator has not seen fit to fill with the symbols of the manifold order of His kingdom. We shall find them to be already full of this wonderful medium; so full that no human power can remove it from the smallest portion of space, or produce the slightest flaw in its infinite continuity. It extends unbroken from star to star; and when a molecule of hydrogen vibrates in the dog-star, the medium receives the impulses of these vibrations, and after carrying them in its immense bosom for several years, delivers them, in due course, regular order, and full tale, into the spectroscope of Mr. Huggins, at Tulse Hill.

This will suffice to emphasize the fact that the eye is truly an ethereal sense-organ—the only one which we possess, the only mode by which the ether is enabled to appeal to us—and that the detection of tremors in this medium—the perception of the direction in which they go, and some inference as to the quality of the object which has emitted them—cover all that we mean by "sight" and "seeing."

I pass then to another function, the electric and magnetic phenomena displayed by the ether; and on this I will only permit myself a very short quotation from the writings of

Faraday, whose whole life may be said to have been directed toward a better understanding of these ethereous phenomena. He is, indeed, the discoverer of the electric and magnetic properties of the ether of space.

Faraday conjectured that the same medium which is concerned in the propagation of light might also be the agent in electro-magnetic phenomena. He says:

> For my own part, considering the relation of a vacuum to the magnetic force, and the general character of magnetic phenomena external to the magnet, I am much more inclined to the notion that in the transmission of the force there is such an action, external to the magnet, than that the effects are merely attraction and repulsion at a distance. Such an action may be a function of the æther; for it is not unlikely that, if there be an æther, it should have other uses than simply the conveyance of radiation.

This conjecture has been amply strengthened by subsequent investigations.

One more function is now being discovered; the ether is being found to constitute matter—an immensely interesting topic, on which there are many active workers at the present time. I will make a brief quotation from Professor J. J. Thomson, where he summarizes his own anticipation of the conclusion which in one form or another we all see looming before us, though it has not yet been completely attained, and would not by all be similarly expressed:

> The *whole* mass of any body is just the mass of ether surrounding the body which is carried along by the Faraday tubes associated with the atoms of the body. In fact, all mass is mass of the ether; all momentum, momentum of the ether; and all kinetic energy, kinetic energy of the ether. This view, it should be said, requires the density of the ether to be immensely greater than that of any known substance.

Yes, far denser—so dense that matter by comparison is like gossamer, or a filmy imperceptible mist, or a Milky Way. Not unreal or unimportant—a cobweb is not unreal, nor to certain creatures is it unimportant, but it cannot be said to be massive or dense; and matter, even platinum, is not dense when compared with the ether.

Not till last year, however, did I realize what the density of the ether must really be,[1] compared with that modification of it which appeals to our senses as matter, and which, for that reason, engrosses our attention. I will return to this part of the subject directly.

Is there any other function possessed by the ether, which, though not yet discovered, may lie within the bounds of possibility for future discovery? I believe there is, but it is too speculative to refer to, beyond saying that it has been urged as probable by the authors of *The Unseen Universe,* and has been tentatively referred to by Clerk Maxwell thus:

> Whether this vast homogeneous expanse of isotropic matter is fitted not only to be a medium of physical interaction between distant bodies, and to fulfil other physical functions of which, perhaps, we have as yet no conception, but also...to constitute the material organism of beings exercising functions of life and mind as high or higher than ours are at present—is a question far transcending the limits of physical speculation.

And there for the present I leave that aspect of the subject.

I shall now attempt to illustrate some relations between ether and matter.

The question is often asked: Is ether material? That is largely a question of words and convenience. Undoubtedly the ether belongs to the material or physical universe; but it is not ordinary matter. I should prefer to say it is not "matter" at all. It may be the substance or substratum or material of which matter is composed, but it would be confusing and inconvenient not to be able to discriminate between matter on the one hand, and ether on the other. If you tie a knot on a bit of string, the knot is composed of string, but the string is not composed of knots. If you have a smoke or vortex-ring in the air, the vortex-ring is made of air, but the atmosphere is not a vortex-ring; and it would be only confusing to say that it was.

The essential distinction between matter and ether is that

---

[1] See the *Philosophical Magazine* for April, 1907.

matter *moves,* in the sense that it has the property of locomotion and can effect impact and bombardment; while ether is *strained,* and has the property of exerting stress and recoil. All potential energy exists in the ether. It may vibrate, and it may rotate, but as regards locomotion it is stationary—the most stationary body we know—absolutely stationary, so to speak; our standard of rest.

All that we ourselves can effect, in the material universe, is to alter the motion and configuration of masses of matter; we can move matter, by our muscles, and that is all we can do directly: everything else is indirect. This is worth thinking over by those who have not already realized the fact.

But now comes the question, how is it possible for matter to be composed of ether? How is it possible for a solid to be made out of fluid? A solid possesses the properties of rigidity, impenetrability, elasticity, and such like; how can these be imitated by a perfect fluid such as the ether must be? The answer is, they can be imitated by a fluid in motion;—a statement which we make with confidence as the result of a great part of Lord Kelvin's work.

It may be illustrated by a few experiments.

A wheel of spokes, transparent or permeable to matter when stationary, becomes opaque when revolving, so that a ball thrown against it does not go through, but rebounds. The motion only affects permeability to matter; transparency to light is unaffected.

A silk cord hanging from a pulley becomes rigid and viscous when put into rapid motion; and pulses or waves which may be generated on the cord travel along it with a speed equal to its own velocity, whatever that velocity may be, so that they appear very nearly to stand still. This is a case of kinetic rigidity; and the fact that the wave transmission velocity is equal to the rotatory speed of the material, is typical and important, for in all cases of kinetic elasticity these two velocities are of the same order of magnitude.

A flexible chain, set spinning, can stand up on end while the motion continues.

A jet of water at sufficient speed can be struck with a hammer, and resists being cut with a sword.

A spinning disk of paper becomes elastic like flexible metal, and can act like a circular saw. Sir William White tells me that in naval construction steel plates are cut by a rapidly revolving disc of soft iron.

A vortex-ring, ejected from an elliptical orifice, oscillates about the stable circular form, as an india-rubber ring would do; thus furnishing a beautiful example of kinetic elasticity, and showing us clearly a fluid displaying some of the properties of a solid.

A still further example is Lord Kelvin's model of a spring balance, made of nothing but rigid bodies in spinning motion. See his *Popular Lectures and Addresses,* vol. I, p. 239, being his "Address to Section A of the British Association" in 1884 at Montreal.

If the ether can be set spinning, therefore, we may have some hope of making it imitate the properties of matter or even of constructing matter by its aid. But how are we to spin the ether? Matter alone seems to have no grip of it. I have spun steel discs, a yard in diameter, 4,000 times a minute, have sent light round and round between them, and tested carefully for the slightest effect on the ether. Not the slightest effect was perceptible. We cannot spin ether mechanically.

But we can vibrate it electrically; and every source of radiation does that. An electrified body, in sufficiently rapid vibration, is the only source of ether-waves that we know; and if an electric charge is suddenly stopped, it generates the pulses known as X-rays, as the result of the collision. Not speed, but sudden change of speed, is the necessary condition for generating-waves in the ether by electricity.

We can also, it is believed, infer some kind of rotary motion in the ether; though we have no such obvious means of detecting the spin as is furnished by vision for detecting some kinds of vibration. It is supposed to exist whenever we put a charge into the neighborhood of a magnetic pole. Round the line joining the two, the ether is spinning like a top. I do not say it is spinning fast: that is a question of its density; it is, in fact, spinning with excessive slowness, but it is spinning with a definite moment of momentum. J. J. Thomson's theory makes its moment of momentum exactly equal to $e\ m$, the product of charge and pole; the charge being measured electrostatically and the pole magnetically.

How can this be shown experimentally? Suppose we had a spinning top enclosed in a case, so that the spin was unrecognizable by ordinary means, it could be detected by its gyrostatic behavior to force. If allowed to "precess" it will respond by moving perpendicularly to a deflecting force. So it is with the charge and the magnetic pole. Try to move either suddenly, and it immediately sets off at right angles to the force. A moving charge is a current, and the pole and the current try to revolve round one another—a true gyrostatic action due to the otherwise unrecognizable ethereal spin. The fact of such magnetic rotation was discovered by Faraday.

I know that it is usually worked out in another way, in terms of lines of force and the rest of the circuit; but I am thinking of a current as a stream of projected charges; and no one way of regarding such a matter is likely to exhaust the truth, or to exclude other modes which are equally valid. Anyhow, in whatever way it is regarded, it is an example of the three rectangular vectors.

The three vectors at right angles to each other, which may be labelled Current, Magnetism and Motion, respectively, or more generally E., H. and V., represent the quite fundamental relation between ether and matter, and constitute the link between Electricity, Magnetism and Mechanics. Where any two of these are present, the third is a necessary consequence. This principle is the basis of all dynamos, of electric motors, of light, of telegraphy, and of most other things. Indeed, it is a question whether it does not underlie everything that we know in the whole of the physical sciences; and whether it is not the basis of our conception of the three dimensions of space.

Lastly, we have the fundamental property of matter called inertia, which, if I had time, I would show could be explained electromagnetically, provided the ethereal density is granted as of the order of 10^{12} grams per cubic centimeter. The elasticity of the ether would then have to be of the order of 10^{33} c.g.s.; and if this is due to intrinsic turbulence, the speed of the whirling or rotational elasticity must be of the same order as the velocity of light. This follows hydrodynamically; in the same sort of way as the speed at which a pulse traveling on a flexible running endless cord, whose tension is entirely due to the centrifugal force of the motion, is precisely equal to the velocity of the cord itself. And so, on our present view, the intrinsic energy of constitution of the ether is incredibly and portentously great; every cubic millimeter of space possessing what, if it were matter, would be a mass of a thousand tons, and an energy equivalent to the output of a million horse-power station for forty million years.

The universe we are living in is an extraordinary one; and our investigation of it has only just begun. We know that matter has a psychical significance, since it can constitute *brain,* which links together the physical and the psychical worlds. If any one thinks that the ether, with all its massiveness and energy, has probably no psychical significance, I find myself unable to agree with him.

Supplementary Remarks Concerning Density of Ether

I observe that it is surmised by at least one thoughtful and friendly critic that in speaking of the immense density or massiveness of ether, and the absurdly small density or specific gravity of gross matter by comparison, I intended to signify that matter is a *rarefaction* of the ether. That, however, was not my intention. The view I advocate is that the ether is a perfect *continuum*, an absolute *plenum*, and that, therefore, no local rarefaction is possible. The ether inside matter is just as dense as the ether outside, and no denser. A material unit—say an electron—is only a peculiarity or singularity of some kind in the ether itself, which is of perfectly uniform density everywhere. What we sense as matter is an aggregate or grouping of an enormous number of such units.

How, then, can we say that matter is millions of times rarer or less substantial than the ether of which it is essentially composed? Those who feel any difficulty here should bethink themselves of what they mean by the average or aggregate density of any discontinuous system, such as a powder, or a gas, or a precipitate, or a snowstorm, or a cloud, or a Milky Way.

Lord Kelvin has estimated and, indeed, proved that the aggregate density of the whole material cosmos within recognizable gravitational reach of us must be infinitesimal; in other words, that the amount of matter in space, however prodigious it may be, must be infinitely less than the volume of space it occupies. And even of the visible cosmos—that is to say, of the material clustering within reach of our aided organs of vision—the density, though certainly not infinitesimal, is exceedingly small.

It may be clearer if I give some actual numbers. Lord Kelvin estimates the amount of matter within reach of the largest telescopes—say within a parallax of $\frac{1}{1000}$ second of arc, corresponding to a radius of 3×10^{16} kilometers—as equivalent to a thousand million of our suns; that is, to a total mass of 1.5×10^{36} tons distributed through a volume of 1.12×10^{59} cubic meters. So the density of the visible cosmos comes out of the order of 10^{-23} of that of water.

The masses themselves seem likely to be in the main distinctly of greater density than water; but grouped, or in the aggregate, they are excessively "rare"—far rarer than the residual gas in the highest-known vacuum. The whole visible cosmos is, in fact, as much rarer than what we call a high vacuum (say, the hundred-millionth of an atmosphere) as that vacuum is rarer than lead. If it be urged that it is unfair to compare an obviously discrete assemblage like the stars, with an apparently continuous substance like air or lead, the answer is that it is entirely and accurately fair; since air, and every other known form of matter, is essentially an aggregate of particles, and since it is always their average density that we mean. We do not even know for certain their individual atomic density.

The phrase, ''specific gravity or density of a powder'' is ambiguous. It may mean the specific gravity of the dry powder as it lies, like snow; or it may mean the specific gravity of the particles of which it is composed, like ice.

So also with regard to the density of matter, we might mean the density of the fundamental material of which its units are made—which would be ether; or we might, and in practice do, mean the density of the aggregate lump which we can see and handle; that is to say, of water, or iron, or lead, as the case may be.

In saying that the density of matter is small, I mean, of course, in this last, the usual, sense. In saying that the density of ether is great, I mean that the actual stuff of which these highly porous aggregates are composed is of immense, of well-nigh incredible density. It is only another way of saying that the ultimate units of matter are few and far between—i.e., that they are excessively small as compared with the distances between them; just as the planets of the solar system, or worlds in the sky, are few and far between—the intervening distances being enormous as compared with the portions of space actually occupied by lumps of matter.

Here it may be noted that it is possible to argue that the density of a *continuum* is necessarily greater than the density of any disconnected aggregate: certainly of any assemblage whose particles are actually composed of the material of the *continuum*. Because the former is ''all there,'' everywhere, without break or intermittance of any kind; while the latter has gaps in it—it is here, and there, but not everywhere.

Indeed, this very argument was used long ago by that notable genius, Robert Hooke; and I quote a passage which Professor Poynting has discovered in his collected posthumous works, and kindly copied out for me:

> As for *matter*, that I conceive in its essence to be immutable, and its essence being expatiation determinate, it cannot be altered in its quantity, either by condensation or rarefaction; that is, there cannot be more or less of that power or reality, whatever it be, within the same expatiation or content; but every equal expatiation contains, is filled, or is an equal quantity of *materia;* and the densest or heaviest, or most powerful body in the world contains no more *materia* than that which we conceive to be the rarest, thinnest, lightest, or least powerful body of all; as gold for instance, and *æther,* or the substance that fills the cavity of an exhausted vessel, or cavity of the glass of a barometer above the quicksilver. Nay, as I shall afterwards prove, this cavity is more full, or a more dense body of æther, in the common sense or acception of the word, than gold is of gold, bulk for bulk; and that because the one, viz., the mass of æther, is all æther: but the mass of gold, which we conceive, is not all gold; but there is an intermixture, and that vastly more than is commonly supposed, of æther with it; so that vacuity, as it is commonly thought, or erroneously supposed, is a more dense body than the gold as gold. But if we consider the whole content of the one with that of the other, within the same or equal quantity of expatiation, then are they both equally containing the *materia* or body.—*From the Posthumous Works of Robert Hooke, M.D., F.R.S., 1705, pages 171 and 172 (as copied in "Memoir of Dalton," by Angus Smith).*

Newton's contemporaries do not shine in facility and clearness of expression, as he himself did, but Professor Poynting interprets the above singular attempt at utterance thus:

> All space is filled with equally dense *materia.* Gold fills only a small fraction of the space assigned to it, and yet has a big mass. How much greater must be the total mass filling that space!

The tacit assumption here made is that the particles of the aggregate are all composed of one and the same continuous substance—practically that matter is made of ether; and that assumption, in Hooke's day, must have been only a speculation. But it is the kind of speculation which time is justifying—it is the kind of truth which we all feel to be in process of establishment now.

We do not depend on that sort of argument, however; what we depend on is experimental measure of the mass, and mathematical estimate of the volume, of the electron. For calculation shows that however the mass be accounted for, whether electrostatically or magnetically, or hydrodynamically, the estimate of ratio of mass to effective volume can differ only in a numerical coefficient and cannot differ as regards order of magnitude. The only way out of this conclusion would be the discovery that the negative electron is not the real or the main matter-unit, but is only a subsidiary ingredient, whereas the main mass is the more bulky positive charge. That last hypothesis, however, is at present too vague to be useful. Moreover, the mass of such a charge would in that case be unexplained, and would need a further step; which would probably land us in much the same sort of ethereal density as is involved in the estimate which I have based on the more familiar and tractable negative electron.

It may be said, why assume any finite density for the ether at all? Why not assume that, as it is infinitely continuous, so it is infinitely dense—whatever that may mean—and that all its properties are infinite?

This might be possible were it not for the velocity of light. By transmitting waves at a finite and measurable speed, the ether has given itself away, and has let in all the possibilities of calculation and numerical statement. Its properties are thereby exhibited as essentially finite—however infinite the whole extent of it may turn out to be.

UNSOLVED PROBLEMS OF CHEMISTRY[1]

BY IRA REMSEN, PH. D.

President of Johns Hopkins University

THE first duty of the chemist is to examine every kind of matter accessible to him and to determine whether it is an element or not. If it is not, and this is usually the case as regards the things found in nature, his next duty is to attack the compound in every way that is likely to lead to its decomposition, and when he reaches a substance from which he cannot get simpler ones, he calls this an element. Thus iron, copper, gold, silver, tin, hydrogen, and oxygen are elements. None of these can be decomposed by the means at present at the command of the chemist. They are like the letters of a language in some respects. Words can be decomposed or resolved into letters, but letters are the elements of language. What elements are in the earth, in the air, in water? An immense amount of work has been done that has had for its object the answering of this question. The earth has been ransacked almost from pole to pole. The air from all sorts of localities has been examined. The waters, from ocean, rivers, and springs, have been made to stand and answer the searching questions of the chemist; and animals and plants have been compelled to give up their secrets—or some of them.

What is the result? In brief, it is this: Although we find an infinite number of kinds of matter, all of these can be resolved into a comparatively small number of elements. Indeed, not more than a dozen of these elements enter into the composition of the things that are at all common. But by going into out-of-the-way corners rare things have been

---

[1] Published in *McClure's Magazine*, February, 1901.

found, and from these, in turn, rare elements have been obtained. Altogether, between seventy and eighty elements have been found. Additions are made to the list from time to time; and, occasionally, one of the substances supposed to be an element is found to be capable of decomposition, and it therefore becomes necessary to strike it from the list of elements.

Out of these simplest forms of matter everything that we see or feel, or are in any way cognizant of, is made up. But now arises the deep question: *What is an element?* To this question chemists are not able to give an answer. The relations of the elements to one another form one of the unsolved problems of chemistry. It may be that they are not related at all, but that each one is an independent form of matter. There are, however, indications of family relationships between them that have long been the subject of investigation. The elements fall into groups, the members of which resemble one another very closely in some respects. Thus, for example, phosphorus and arsenic conduct themselves, in general, alike toward other elements. They combine with them to form compounds that are very much alike—so much so that in some cases it is difficult to tell them apart. These elements are said to belong to the same family. The family traits are easily recognized in them. Similar relationships are met with throughout the entire list of elements. This subject has been beautifully worked out by the Russian chemist Mendeléef and the German, Lothar Meyer. The former, indeed, pointed out, thirty years ago, that some of the families are not complete. There were a number of vacant chairs. He was able to predict the discovery of some of these missing members and to describe them in detail. Three of these have since been discovered, and they have been found to answer the description given by Mendeléef before their discovery. Now that the way has been pointed out, it is a comparatively simple thing to predict the discovery of other elements. The vacant chairs are there, but though the elements that are eventually to occupy them are probably hidden away somewhere in the earth, they have thus far eluded the chemist.

As regards the character of the relationships that exist between the elements, it is difficult, or, rather, quite impossible, to speak with confidence. Apparently, the elements are brothers and sisters. We want to find the fathers and mothers. But it appears that they are no longer living. The plain question that we cannot help asking is: Have the elements existed from the beginning of time, or have they been formed from a smaller number of simpler forms of matter? Of course, one can speculate on such a subject, but can one speculate profitably? It may as well be acknowledged at once that we know practically nothing in regard to the origin of the elements, or of the cause of the relationships that are so easily recognized.

It has been suggested that the elements are the products of an evolutionary process that has been in progress from the beginning, and that they all owe their existence to a primordial form of matter, simpler than any one of the so-called elements. Some evidence in favor of this view seems to be furnished by the spectroscopic examination of celestial bodies. The nebulae have been shown to contain the smallest number of our chemical elements; the hotter stars are somewhat more complex; in the colored stars and the sun a large number of elements appear; while the planets are the most complex. The complexity seems to depend upon the temperature. The higher the temperature, the smaller the number of kinds of matter present. Now, may it not be that the elements known to us are derived from simpler forms, or from one single simplest form? We can only answer—it may. If this is the true conception of the relations between the elements, then "in the beginning" space must have been filled with an incandescent vapor made up of the simplest form of matter. As this has cooled, it has taken other forms, and some of these are the things we now call elements. But this shows how easy it is to relapse into the ways of our forefathers and let our imaginations run wild.

Elements of Plants and Animals

Another unsolved problem of chemistry is that presented by the fundamental constituents of plants and animals. No one knows better than the chemist that all living things are "fearfully and wonderfully made." Plants take materials of various kinds from the air and from the earth, and work them up in proper shape for their growth. In turn, animals take parts of some plants or parts of some animals, and work them up so that they become part and parcel of the animal bodies. Life and growth of plant and animal depend upon this power to convert food into other things that can take their proper places in the body. Chemical change is the beginning of life. But what are these things that are formed within the plant and animal? That is a hard question to answer; and, indeed, the answer would be confusing. All that need be said is that among these things are the fats, sugar, starch, cellulose, and a group of important compounds called proteids. Besides these, there are innumerable substances found both in plants and animals. Naturally, chemists are interested in these things, and they have given, and are giving, much time to their investigation. It is only through such study that we can hope ever to gain any conception of the changes that are taking place in living things, or of the nature of life in its various forms.

Of the substances mentioned, the fats are relatively the simplest, and they are, accordingly, pretty well understood. It is interesting to note in passing that the first and the most important chemical investigation in fats was carried out at the beginning of this century by the French chemist Chevreul, who died only a few years ago at the age of 103, having kept in harness to the last. Regarding our knowledge of fats, it is safe to say that we know enough about them to be able to see how one could, starting with carbon, hydrogen, and oxygen, which are the only elementary substances found in the fats—how one could make in the laboratory the same fats that occur in living things. No one has ever done this, but it appears highly probable that, with unlimited time at one's disposal, it could be done by making use of methods that are made use of every day in the laboratory. Not many years ago that statement would have been challenged. The constituents of plants and animals were supposed to be entirely different from the constituents of the inanimate inorganic parts of the earth, and it was further supposed that those substances which are elaborated under the influence of the life-process cannot be formed without this influence. This may be true of the most complex constituents of plants and animals, but it is certainly not true of some of the simpler of these constituents. For example, urea, one of the most characteristic substances formed in the animal body, was made in the laboratory in 1828, by a method which was entirely independent of the life-process; and since that time innumerable other substances which are characteristic products of the life-process have been made artificially. So that, as we know very well what fats are, and can make substances of the same kind in the laboratory, there is nothing out of the way in saying that the fats could probably be made artificially. Let us assume that they can be. What then?

Next in order of complexity come the so-called carbohydrates, which include the sugars, starch, and cellulose. Is it "highly probable" that the chemist can build these up out of the elements in the laboratory? Thanks to Emil Fischer, of Berlin, we can now almost say that sugar is not an unsolved problem. Within the last few years more has been done to clear up the problem of the sugars than in all preceding time put together. One of the simplest sugars has been prepared artificially in the laboratory, and the relations between the others have been, to a large extent, revealed.

But the sugars are simple things compared with starch.

Starch *is* an unsolved problem. It is of the highest importance in Nature. Its wide distribution among plants and the part that it plays as a constituent of foods show this. What is it? Of course, if we say it is a carbohydrate, we have made the whole subject clear! The truth is we know very little about it, in spite of the large amount of work that has been done on it. In what has been done there is little promise of success, though the chemical optimist hopes, even in the face of starch. I confess to being a moderate optimist. If asked why I hope in this case, I could only answer, "I hope—that is all."

Let us take the next step. This brings us to cellulose, a substance of very great importance for all plants. It forms, as it were, their skeletons. Just as animals are built upon a basis of bone, so plants are built upon a basis of cellulose. It is that constituent of plants that gives them form and that enables them to resist the disintegrating influences to which they are subject in Nature. When a piece of wood is treated with certain active substances, "chemicals" as they are called by the outside world, many of the constituents are destroyed and removed, and, finally, what is known as wood-pulp remains. This is mainly cellulose. As is well known, large quantities of paper are made from this pulp. Paper is, in fact, more or less pure cellulose. Every plant contains cellulose, and without it the plants could not exist. It seems as though a chemist ought to feel humiliated to have to confess that even less is known about cellulose than about starch. There appears to be some reason for believing that it is distantly related to starch, but that is about all we can say. It is probably enormously complicated. To be sure, it contains only the three elements, carbon, hydrogen, and oxygen, but these three elements can combine with one another in thousands of different ways, forming, on the one hand, relatively simple products, and, on the other, products of such complexity that before them the chemist can only stand and wonder. Cellulose belongs to the latter class.

The Awesome Proteids

Finally, let us remove our hats and shoes, and, bowing low, ask with bated breath: What about the proteids? What about them, indeed? Let us, rather, go back to cellulose and starch and recover our courage and our heads. This atmosphere is stifling. I always feel like running away when any one begins to talk about proteids in my presence, and here I am, trying to write something about them. I ought to be ashamed of myself. Quoting from a text-book of physiology: "These [proteids] form the principal solids of the muscular, nervous, and glandular tissues, of the serum of blood, of serous fluids, and of lymph." That tells the story. What could we do without them? It is not for me to say what we know about proteids. In my youth I had a desire to attack these dragons, but now I am afraid of them. Fortunately, there is no occasion here for enlarging upon them. I only want to make clear the fact that they are unsolved problems of chemistry; and, let me add, they are likely to remain such for generations to come. Yet every one who knows anything about chemistry and physiology knows that these proteids must be understood, before we can hope to have a clear conception of the chemical processes of the human body. Fortunately for us, there are always some chemists who delight in working upon the most difficult problems and are not willing to take "No" for an answer. So that there is always some one working on the proteids, and something is coming of it.

In the field of synthetic chemistry perhaps the most important problem among those that are unsolved is that presented by *protoplasm.* I have recently heard of a school, and a primary school at that, where the small children are introduced to the mysteries of life by being told "all about" protoplasm. If I were a pupil in that school, I might be able to tell my readers what protoplasm is, but, as I have not that privilege, I shall have to acknowledge that I know very little about it. In fact, it is a substance, or a mixture of substances, with which the chemist can do very little. Great interest has been taken in all that pertains to protoplasm, because it is so directly connected with life. The simplest organisms are the *amœbæ*. These may be regarded as representing life reduced to its lowest form. Now an *amœbæ* "is wholly or almost wholly protoplasm." "It lives, moves, eats, grows, and, after a time, dies, having been, during its whole life, hardly anything more than a minute lump of protoplasm"—(Foster). Regarded as a chemical substance, it contains the elements oxygen, hydrogen, nitrogen, carbon, and sulphur in fairly constant proportions. It would be a great day for chemistry if a chemist should succeed in putting together, and causing to unite, the above-named elements in the proportions in which they are present in protoplasm, and he should find that he had made protoplasm artificially. If this artificial protoplasm should move and eat and grow, he would deserve to be ranked with Pygmalion of old. What are the prospects?

In the first place, protoplasm does not appear to be a single substance, but a mixture of substances. It contains something that is derived from a proteid, something else derived from a fat, and still a third something derived from a carbohydrate.. Perhaps these three things are chemically united with one another, and not simply mixed. The problem presented to the chemist is one of the greatest difficulty. It would be necessary for him to determine exactly what proteid, what fat, and what carbohydrate are essential to the existence of protoplasm; then to bring these together, and show that the substance thus obtained is identical with protoplasm. This might be accomplished, and yet the protoplasm obtained not be a living thing; for there is dead, as well as living protoplasm. There is no evidence that any chemist is engaged in attempts to make protoplasm in the laboratory. Possibly some are dreaming of this problem, but dreams are generally harmless, and sometimes they are pleasant, and, indeed, useful. Before we can understand, if we ever are to understand, the difference between a living and a dead tissue, we must understand what protoplasm is, and our chances of solving the problem presented by this important basis of life are extremely poor. Still, we may hope to get nearer its solution by continued investigation, and we shall have to be satisfied with small returns for our labor.

Chemistry has to deal with the composition of things, and the changes in the composition of things, and all that pertains to these subjects. Changes in composition are often brought about by raising the temperature. To take a comparatively simple, though not a familiar, example, water is a compound of the elements hydrogen and oxygen. When this is heated, it is converted into water-vapor. When this vapor is heated to 4,500 degrees Fahrenheit, it is resolved into hydrogen and oxygen. At this temperature the compound, water, cannot exist. On the other hand, when hydrogen and oxygen are brought together at ordinary temperatures, they do not combine to form water, unless a spark or a flame is brought in contact with the mixture, when a violent explosion occurs, and this is the signal of the chemical union of the two elements to form water. Again, when wood is heated, it gives off gases and liquids, and at last there is nothing left but charcoal, which is one form of the element carbon. It is plain that some substances, that can exist at ordinary temperature, are decomposed—that is to say, they cannot exist—at high temperatures. This is, in fact, true of many of the substances familiar to us. But heat not only decomposes compounds; it also, if not too intense, causes elements to combine to form compounds. In the laboratory and in the factory heat is constantly being employed for the purpose of bringing about, or aiding, chemical action. The blast-furnace, from which comes all our iron, is a good example. The object in view is the separation of the metal, iron, from its ores. The ores consist of iron in combination with oxygen and, sometimes, other things; but it is the oxygen that gives the principal difficulty. When the compound of iron and oxygen is heated with something that, under the circumstances, has the power to combine with the oxygen and escape with it in the form of a gas, the iron is left behind. Charcoal or coke is used for this purpose. At high temperatures, these substances, which are different forms of the element carbon, take the oxygen from the iron, and the metal liberated sinks to the bottom of the furnace in the molten state, while the gaseous compound of carbon and oxygen passes out of the top of the furnace. The oxygen changes partners. It is to be observed that the iron ore might be mixed with the charcoal, and the mixture allowed to stand at ordinary temperatures for any length of time, without separation of iron. Heat is necessary, and a good deal of it, to cause the charcoal to unite with the oxygen and carry it off into space.

Heat being an important factor in chemical acts, the question suggests itself: What will be the effect upon chemical processes if the temperature is raised much above the range within which we ordinarily work? And at the same time the complementary question will suggest itself: What will be the effect of lowering the temperature much below that at which we ordinarily work?

EXTREMES OF TEMPERATURE

Until within the last few years the highest temperatures attainable were reached by the aid of the so-called compound blowpipe, which is an instrument for burning hydrogen, or some other combustible gas, in oxygen under pressure. By the aid of this instrument platinum was melted and, in one case, silver was boiled. But now the introduction of powerful electric currents has made the production of much higher temperatures possible, and marvelous results have been reached. M. Moissan, of Paris, has for some time been engaged in studying the chemical effects of high temperatures, and to him we owe almost all we know of chemistry at these temperatures. He has made use of a simple contrivance, which he calls an electric furnace. In this he has subjected many things to temperatures as high as from 6,000 to 7,000 degrees Fahrenheit. It is a pity that Dante could not have taken a course in chemistry under M. Moissan. These temperatures, notwithstanding their great height, are suggestive of the lower regions. This work has opened up a new world to chemists, and has shown them that there are many unsolved problems to be found here. Things that unite readily at ordinary high temperatures do not act at all at these higher temperatures; and things that do not act at all at the former act vigorously at the latter. There is no end of what may be learned in this new field.

Just as it is desirable to know how things act upon one another at high temperatures, so it is equally desirable to know how they act at low temperatures. Curiously enough, work in this direction has kept pace with that in the opposite direction, referred to in the last paragraph. Within the last year or two, the attention of everybody has been directed to low temperatures by the interesting work that has been done on liquid air. It is well known that air can now be liquefied on the large scale, and that liquid air is an article of commerce. This brings low temperatures to our door, for it is only necessary to expose the liquid in an open vessel to produce a temperature of about 300 degrees below zero, Fahrenheit! Then, further, Dewar has recently succeeded in liquefying and, indeed, solidifying hydrogen —a much more difficult feat than liquefying air—and with the solid thus produced he has reached the temperature 432 degrees below zero, Fahrenheit! There is no serious difficulty then, at present, in studying chemical action at temperatures in the neighborhood of 300 degrees below zero. The first results are not reassuring. Things are not very lively down there, to say the least. It may be that all chemical action ceases below a certain temperature, but we do not, as yet, know enough about this subject to justify us in speaking with confidence about it. Countless experiments yet unborn will have to be tried. In thinking of the possibilities, we are confronted with what appears to be a paradox. It has been pointed out that high temperature, in many cases, has the effect of decomposing substances. This shows that these substances are more stable at low temperatures than at the ordinary temperatures. In other words, if heat causes the constituents to separate, cold might apparently cause them to unite more firmly. But, if this is so, why do not substances act upon each other readily at low temperatures? It may be that the constituents are so firmly held together that they cannot move about among one another, as they must in order to combine. The water that is frozen in a glacier does not act like water at ordinary temperatures. It is, as it were, chained up and prevented from obeying the laws of water.

The Great Unsolved

In what I have thus far had to say, I have kept in view certain problems which do not necessarily call for much speculation. It would, however, hardly be fair to leave the speculative side of chemistry entirely out of consideration. Sometimes young pupils are introduced to chemistry through the atom. Only very young, or very ignorant, persons can talk with confidence about atoms. The further one goes into the mysteries of chemistry, the more mysterious appears the atom. In fact, the atom is the great unsolved problem of chemistry. But this is subtle. What is an atom? Ah! that is the question. It has been a favorite subject of thought from the earliest days. Up to the beginning of the ninteenth century, however, it was nothing but a metaphysical plaything. The wits of generations of philosophers have been sharpened by efforts to decide whether matter is infinitely divisible or not. Take a piece of, say, iron. No matter what its size may be, it can be broken up into smaller pieces; and each of the pieces thus obtained can be still further subdivided. Now, how far can this process of subdivision be carried? Is there any limit? The atomists held that, after a time, particles would be reached so small that they could not be made smaller. But their opponents said, "No! this is inconceivable. Matter must be infinitely divisible." As neither side could prove the other wrong, the question under discussion was well adapted to the purposes of controversy.

The atom of to-day is a scientific abstraction. Many facts have been brought to light that make it appear certain that matter is not continuous—is not capable of infinite subdivision. Dalton, the Quaker schoolmaster of Manchester, was the first one to bring the atom down to the earth and make it a useful idea. How he did this cannot be shown here. Suffice it to say, the *atomic theory* proposed by Dalton in the early years of the century lives to-day, and is stronger than it has ever been, notwithstanding the efforts that have been made to show that it is built upon sand. It has been, and is to-day, an extremely useful theory. Whether it will always continue to be so is another question, and one that need not bother us. It is believed that each elementary substance—that is to say, each chemical element—consists of minute particles that are not broken up in the course of chemical changes. These particles that remain intact are the atoms of chemistry. Some such theory is absolutely necessary to account for the fundamental laws of chemistry.

Into what thin air we enter, when we begin to speak of the properties of the individual atom, will appear when it is stated that, according to the calculations of Lord Kelvin, the molecule of hydrogen, which is at least twice as large as its atom, is of such size that it would take 50,000,000 of them placed in a row to occupy an inch! To be sure, most atoms are larger than those of hydrogen, but there are few so large that it would not be necessary to have about a million of them to occupy an inch. What sense is there in talking about such things? We shall never be able to see them, or to prove that they exist. True, but the conception of the atom has been of great help to chemists, and, as long as it continues to be helpful, it will be clung to.

If the views held by the majority of chemists are true, the science of chemistry is the science of atoms. The astronomer has to deal with infinite distances and the largest masses in the universe. The chemist, on the other hand, has to deal with the shortest distances and the minutest particles of matter. The astronomer uses the telescope, but there is no microscope that can carry us to the atom. The astronomer observes points of light, follows their motions, and works out the laws that govern them. The chemist has troubles of another kind. He cannot deal directly with single atoms. No matter how small a quantity of an element he may use in his experiment, he has to deal with a large number of atoms. Every time he performs an experiment millions of atoms come into play. He studies his substances before action and after action. New substances are formed, and he concludes that the atoms have arranged themselves in different ways. What he *knows* is that new substances with new properties are formed. He knows this whether atoms are realities or not, but the atom helps him to form a picture of what probably takes place throughout the masses with which he is dealing. The atoms are as far removed from the intellectual gaze of the chemist as the most remote stars from the eye of the astronomer.

Yet the chemist talks about the way in which atoms are combined with one another; and he draws figures, and constructs models to show it all. And he doesn't do this for his amusement, but because he is helped by it. He talks in the language of chemistry, as the mathematician talks in the language of mathematics. Some day he will, no doubt, understand the language better. Probably the language itself will be changed, and that which he now uses will seem like the prattle of an infant.

One other side of chemistry must be turned into view before I can close. I am not sure that I can make myself intelligible in what I still have to say, but I shall try. Thus far, in what has been said about chemical acts, the material side has been kept in view. The relations between the elements; the artificial preparation of the substances that enter into the composition of living things; the changes in the composition of matter at high and at low temperatures; and, finally, the atom—these are the subjects dealt with. But, whenever a chemical act takes place, there are changes in the temperature and in the electrical condition of the substances involved, in addition to the changes in composition. It is while in action that chemical substances are most interesting. Generally we have to content ourselves with observations before and after an act, but we should learn a great deal more about the nature of the act, if we could make observations while it is in progress. We should find it very difficult, if not impossible, to learn the law of falling bodies, if we could only observe bodies before and after they have fallen; but by observing them in the act of falling we can, without difficulty, deduce the law

Laws of Chemical Change

Generally speaking, chemical acts are so rapid that it is impossible to make observations during their course. Much progress has been made in this field during the past fifteen or twenty years, and some of the great laws of chemical action have been discovered. What has been learned is, however, only enough to whet the appetite of chemists. To illustrate in another way what is meant by making observations during a chemical act, let us take the case of gunpowder. This usually consists of charcoal, sulphur, and saltpeter. A spark is sufficient to cause the chemical act that is accompanied by the explosion. We can collect everything that is formed, and show what changes in composition have taken place. But we should like to know something about the act itself, and yet, plainly, observations during the act cannot be numerous, or especially instructive. And so it is with most common chemical changes that are studied in the laboratory. We get only snap-shots at them. If we could only get a series of pictures at short intervals, we might, by combining these afterward, get some idea of what is taking place during the act. Fortunately, there are ways of controlling certain classes of chemical acts and reducing their speed, so that observations can be made during their progress; and much has been learned in this way. Here is a great field for further study, and it presents many unsolved problems.

Finally, a few words about water. It is said that a well-known chemist some years ago made a bet that a certain company of chemists could not name a chemical subject that would not, in turn, suggest to him a profitable chemical investigation. Thereupon, after much deliberation, the challenged company suggested "water," on the assumption that this has been thoroughly worked over, and does not present unsolved problems. The result was a beautiful investigation of some of the properties of water. Every one knows that water is the most abundant substance on the earth. It also plays a more important part in the changes that are taking place on the earth than any other substance. We are only beginning to learn how it acts. That it dissolves many things is well known, but let us not be misled because this phenomenon is so common and so familiar. Put a little salt in water. What becomes of it? It disappears. There is no solid substance in the vessel. We may bandy phrases as we please, but we cannot tell what has become of the salt. We can get the salt out of the water by boiling the solution and letting the water pass off as steam, when the salt will be left behind. As we put the salt in and take it out, we have been accustomed until recently to think of the salt as being present in the solution as such. One of the most important advances in chemistry made of late years is that which leads to the conception that, in dilute solutions at least, there is little, if any, salt present; that, in some way, the water decomposes it into particles highly charged with electricity. These particles are called *ions.* This idea has thrown a great deal of light upon important problems of chemistry, but it has suggested many new ones Some substances—for example, sugar—do not act like salt when dissolved in water. Why this difference? Then, too, some liquids which are good solvents do not act at all like water. What is it in water that distinguishes it from most other liquids, such as alcohol and ether, enabling it to tear many substances asunder? These are questions that are now very much to the front. Rapid progress is being made, and we may look for important discoveries in this field in the near future.[1]

---

[1] This article was first published in 1901. The reader may profitably consider the dates of discoveries and investigations that are given in this book. He will see how active and varied have been the efforts of scientists, in recent years especially, to solve the problems of Nature, how ingenious have been their methods of attack, and how with the solution of each one the field broadens and the new problems become more difficult and more fascinating.—Ed.

REGARDING ADDITIONAL READING

THE articles contained in this volume first appeared in the following publications: *North American Review, Iron Age, Journal of the Society of Arts, Science, Popular Science Monthly, Edinburgh Review,* St. Louis *Globe-Democrat, Scientific American Supplement, Harper's Monthly, Engineering, Prometheus, American Machinist, Kosmos, Knowledge, Scientific News, New International Encyclopaedia, McClure's Magazine* and *Transactions of the American Electrochemical Society.*

Those who wish to read more along general scientific lines will find other interesting articles by referring to the files of these magazines. See for instance, the following: ''The Renaissance of the Alchemists,'' *North American Review,* July, 1906. ''Chemistry and the World's Food—the Fixation of Nitrogen,'' *Harper's Monthly,* April, 1906. ''The Chemistry of the Steam Boiler,'' *Scientific American Supplement,* December 11, 1909. ''Flower Pigments,'' *Scientific American Supplement,* April 10, 1909. Messrs. Munn & Company, 361 Broadway, New York City, will send upon request a complete index to the *Scientific American Supplement,* from which readable articles may be found upon almost any subject in pure and applied science. Individual numbers of the *Supplement* may be purchased at ten cents each. By referring to the volume of the *New International Encyclopaedia* entitled ''Courses for Reading and Study,'' one will find references to topics which will enable him to inform himself upon almost any subject whatsoever, and he will also find directions for pursuing an interesting and systematic course of private study. At the end of the encyclopaedic articles there is given the names of books which treat fully the topics under consideration. The forthcoming eleventh edition of the *Encyclopaedia Britannica* should also be consulted.

For a brief though broad view of the progress of Science, one may read profitably *The Progress of the Century,* by various authors, and *The Story of Nineteenth Century Science,* by H. S. Williams, or others books of similar import.

It is true that interest and profit come through reading about matter and its manifestations, but the greatest inspiration comes through reading of the lives and work of men whose labors have built up our present body of knowledge or applied it to human needs. Certain considerations prevented such from being included in this volume, but the reader is referred to Thorpe's *Essays in Historical Chemistry* and to the popular sketches that have appeared in many magazines; a number of these have been reprinted in the *Scientific American Supplement;* among them are the following: Becquerel, *Supplement* No. 1705; Berthelot, 1328 and 1632; Bessemer, 1161; Bunsen, 1241 and 1254; Cavendish, 1554; Crookes, 1672; Mendeléeff, 1627; Alfred Nobel, ''His Life and Will,'' 1361 and 1463. The *New International Encyclopaedia* contains sketches of the work of most of the prominent men, among whom the following have done much in the field of Chemistry: van Helmont, Becher, Stahl, Black, Priestley, Cavendish, Lavoisier, Dalton, Berzelius, Davy, Bertholet, Bergman, Avogadro, Gay-Lussac, Mitscherlich, Liebig, Wöhler, Chevreul, Dumas, Laurent, Gerhardt, Gmelin, Sainte-Claire Deville, Cannizzaro, Graham, Kolbe, Bunsen, Roscoe, Berthelot, Wurtz, Hofmann, Regnault, Pasteur, Baeyer, Mendeléeff, Schorlemmer, Fischer, van 't Hoff, Ostwald, Nernst, Arrhenius, Crookes, Dewar, and others.

A LIST OF WORKS ON CHEMISTRY

Published by The Macmillan Company

RAMSAY. **Experimental Proofs of Chemical Theory for Beginners.** By William Ramsay, Ph.D., LL.D., Sc.D., F.R.S. London, 1884. Second Edition, 1893. Reprinted, 1900, 1908. *Cloth, 18mo, 143 pages, $ .60 net*

DONINGTON. **A Class Book of Chemistry.** By G. C. Donington, City of London School. *Cloth, 12mo, 399 pages, $ .90 net*

LENGFELD. **Inorganic Chemical Preparations.** By Felix Lengfeld, Assistant Professor of Inorganic Chemistry in the University of Chicago. New York, 1899. Reprinted 1905. *Cloth, 12mo, 57 pages, $ .60 net*

BENEDICT. **Chemical Lecture Experiments.** By Francis Gano Benedict, Ph.D. New York, 1901. *Cloth, 12mo, 436 pages, $2.00 net*

PERKIN & LEAN. **Introduction to the Study of Chemistry.** By W. H. Perkin, Lr., Ph.D., F.R.S., and Bevan Lean, D.Sc., B.A. London, 1896. Seventh reprint, 1906. *Cloth, 12mo, 334 pages, $ .75 net*

NERNST. **Theoretical Chemistry from the Standpoint of Avogadro's Rule and Thermodynamics.** By Prof. Walter Nernst, Ph.D., of the University of Göttingen. Revised in accordance with the fourth German edition. London, 1895. Second English edition, 1904. *Cloth, 8vo, 771 pages, $4.50 net*

OSTWALD. **The Scientific Foundations of Analytical Chemistry.** Treated in an elementary manner. By Wilhelm Ostwald. Translated with the author's sanction by George M. Gowan. London, 1895. Third Edition, 1908. *Cloth, 12mo, 247 pages, $2.00 net*

CHESNEAU. **Theoretical Principles of the Methods of Analytical Chemistry, based upon Chemical Reactions.** By M. G. Chesneau. Authorized translation by A. T. Lincoln, Ph.D., Assistant Professor of Chemistry, Rensselaer Polytechnic Institute, and D. H. Carnahan, Ph D., Associate Professor of Romance Languages, University of Illinois. New York, 1910. *Cloth, 8vo, 184 pages, $1.75 net*

JONES. **Practical Inorganic Chemistry for Advanced Students.** By Chapman Jones, F.I.C., F.C.S., etc. London, 1898. Latest reprint, 1906. *Cloth, 12mo, 239 pages, $ .60 net*

BASKERVILLE & CURTMAN. **Qualitative Chemical Analysis.** By Professor Charles Baskerville and Dr. L. J. Curtman, College of the City of New York. New York, 1910. *Cloth, 8vo, 200 pages, $1.40 net*

NOYES. **A Detailed Course of Qualitative Chemical Analysis of Inorganic Substances.** With Explanatory Notes by Arthur A. Noyes, Ph.D. New York, 1899. *Cloth, 8vo, 89 pages, $1.25 net*

MORGAN. **Qualitative Analysis.** As a laboratory basis for the study of general inorganic chemistry. By William Conger Morgan, Ph.D., Assistant Professor of Chemistry in the University of California. New York, 1906. Reprinted, 1907. *Cloth, 8vo, 351 pages, $1.90 net*

SCOTT. **An Introduction to Chemical Theory.** By Alexander Scott. Second Edition. *Cloth, 8vo, 272 pages, $2.00 net*

A List of Works on Chemistry—*Continued*

GATTERMAN. **The Practical Methods of Organic Chemistry.** By Ludwig Gatterman, Ph.D. Translated by William B. Schober, Ph.D. The second American from the fourth German edition. New York, 1896, 1901. Sixth reprint, 1910. *Cloth, 8vo, 350 pages, $1.60 net*

SHERMAN. **Methods of Organic Analysis.** By Henry C. Sherman, Ph.D., Adjunct Professor of Analytical Chemistry in Columbia University. New York, 1905. *Cloth, 8vo, 245 pages, $1.75 net*

HAAS. **Laboratory Notes on Organic Chemistry** (for Medical Students). By Paul Haas, St. Thomas's Hospital, London. *Cloth, 12mo, 128 pages, $ .80 net*

COHEN. **Theoretical Organic Chemistry.** By Julius B. Cohen, Ph.D., B.Sc. London, 1902. Latest reprint, 1907. *Cloth, 12mo, 578 pages, $1.50 net*

COHEN. **Practical Organic Chemistry for Advanced Students.** By Julius B. Cohen, Ph.D., B.Sc. London, 1900. Second Edition, 1908. *Cloth, 12mo, 456 pages, $ .80 net*

LASSAR-COHEN. **A Laboratory Manual of Organic Chemistry.** A compendium of laboratory methods for the use of chemists, physicians and pharmacists. By Dr. Lassar-Cohen. *Cloth, 8vo, 403 pages, $2.25 net*

LACHMAN. **The Spirit of Organic Chemistry.** An introduction to the current literature of the subject. By Arthur Lachman, Professor of Chemistry in the University of Oregon. With an introduction by Paul C. Greer, M.D., Ph.D., Professor of General Chemistry in the University of Michigan. New York, 1899. Second reprint, 1909. *Cloth, 12mo, 229 pages, $1.50 net*

MANN. **Chemistry of the Proteids.** By Gustav Mann, M.D., B.Sc., University Demonstrator of Physiology, Oxford. London, 1906. *Cloth, 8vo, 606 pages, $3.75 net*

LE BLANC. **A Text Book of Electro-Chemistry.** By Max Le Blanc, University of Leipzig. Translated by Willis R. Whitney, Ph.D., of the General Electric Company, and John W. Brown, Ph.D., of the National Carbon Company. New York, 1907. Reprinted, 1910. *Cloth, 8vo, 335 pages, $2.60 net*

BLOUNT. **Practical Electro-Chemistry.** By Bertram Blount, F.L.C., Assoc. Inst. C.E. London, 1901. Second Edition. Revised, 1906. *Cloth, 8vo, 394 pages, $3.25 net*

THOMPSON. **Applied Electro-Chemistry.** By M. DeKay Thompson, of the Massachusetts Institute of Technology. New York, 1911. *Cloth, 8vo, 329 pages, $2.10 net*

NEUMANN. **The Theory and Practice of Electrolytic Methods of Analysis.** By Dr. Bernhard Neumann. Translated by John B. C. Kerslaw, F.I.C. London, 1878. *Cloth, 8vo, 254 pages, $3.00 net*

A LIST OF WORKS ON CHEMISTRY—*Continued*

BARTHEL. **Methods used in the Examination of Milk and Dairy Products.** By Dr. CHR. BARTHEL, Stockholm. Translation by W. Goodwin, M.Sc., Ph.D. London, 1910. *Cloth, 8vo, 260 pages, $1.90 net*

SNYDER. **Human Foods and their Nutritive Value.** By HARRY SNYDER, B.S., Professor of Agricultural Chemistry, University of Minnesota, and Chemist of the Minnesota Experiment Station. New York, 1909. *Cloth, 12mo, 362 pages, $1.25 net*

ROLFE. **The Polariscope in the Chemical Laboratory.** An introduction to polarimetry and related methods. By GEORGE WILLIAM ROLFE, A.M., Instructor in Sugar Analysis in the Massachusetts Institute of Technology. New York, 1905. *Cloth, 12mo, 320 pages, $1.90 net*

YOUNG. **Fractional Distillation.** By SIDNEY YOUNG, D.Sc., F.R.S., Professor of Chemistry in University College, Bristol. London, 1903. *Cloth, 12mo, 284 pages, $2.60 net*

MELDOLA. **The Chemistry of Photography.** By RAPHAEL MELDOLA, F.R.S., etc. London, 1899. Latest reprint, 1901. *Cloth, 12mo, 382 pages, $2.00 net*

DERR. **Photography for Students of Physics and Chemistry.** By LOUIS DERR, M.A., S.B., Associate Professor of Physics in the Massachusetts Institute of Technology. New York, 1906. Reprinted 1909. *Cloth, 12mo, 247 pages, $1.40 net*

FRAPS. **Principles of Dyeing.** By G. S. FRAPS, Ph.D., Assistant Professor of Chemistry, North Carolina College of Agriculture and Mechanic Arts. New York, 1903. *Cloth, 12mo, 270 pages, $1.60 net*

SCHULTZ & JULIUS. **A Systematic Survey of the Organic Colouring Matters.** Founded on the German of Drs. G. SCHULTZ and P. JULIUS. Revised throughout and greatly enlarged by Arthur G. Green, F.I.C., F.C.S. London. *Cloth, 8vo, 290 pages, $7.00 net*

LEWKOWITSCH. **Chemical Technology and Analysis of Oils, Fats and Waxes.** By Dr. J. LEWKOWITSCH, M.A., F.I.C., Consulting Chemist to the city and guilds of London Institute. Fourth Edition. Entirely rewritten and enlarged. 3 vols. London, 1909.
Cloth, 8vo, Vol. I 542 pages, Vol. II 812 pages, Vol. III 406 pages, $15.00 net

LEWKOWITSCH. **Laboratory Companion to Fats and Oils Industries.** By Dr. J. LEWKOWITSCH, M.A., F.I.C. London, 1909. *Cloth, 8vo, 197 pages, $1.90 net*

GUTTMAN. **Manufacture of Explosives.** By OSCAR GUTTMAN, Assoc. M. Inst. C.E., F.I.C. In two volumes. London, 1895.
Cloth, 8vo, Vol. I 348 pages, Vol. II 444 pages, the set, $9.00 net

HERMAN. **Chemistry of Food and Nutrition.** By HENRY C. SHERMAN, Ph.D., Professor of Organic Analysis in Columbia University. *Cloth, 12mo, 355 pages, $1.50 net*

PUBLISHED BY
THE MACMILLAN COMPANY
64-66 Fifth Avenue, New York