homologous in the manner of their origin, it was maintained that a mineralogical nomenclature which is properly applicable to the constituents of igneous rocks is similarly applicable to the constituents of steel; and though a phase rule (temperature-concentration) diagram affords a ready means for the discussion of the behaviour of phases during their partition into other pairs of phases, a metallographic description of their structure modelled on the nomenclature usual in petrography is more manageable when the number of constituents is large.

Special analogies between igneous rocks and metals were suggested. Segregation of the phosphorus and the sulphur in steel ingots was paralleled with "differentiation-*in-situ*" as it occurs in igneous rocks. The time taken in cooling through the temperature range of active crystal growth was shown to control the texture both of igneous rocks and of metals. Viscosity as another factor controlling crystal growth was considered, and the absence of any structures in metals analogous to those developed in viscous rock magmas and in devitrifying glass—*e.g.* "spherulitic structure"—was attributed to essential differences in this respect. "Skeletal crystals," so common in metals, are characteristic of over-rapid growth and as a passing stage in the development of polyhedra are not unknown in rocks.

"Eutectic structures" in metals are like the "graphic" and "pegmatitic" structures of rocks, and their obliteration with slower cooling, both from rocks and metals, was noted.

"Cores" in "mixed crystals" of metals are analogous to "zonary banding" in non-homogeneous isomorphous minerals, and the successive crystallisation of distinct phases above and below a change-point has its parallel in the "corona structure" of some norites.

Partition of solid solutions always at the margins or along the cleavage of pre-existing crystal grains, a process so important in the heat treatment of commercial steels, finds its analogue in the orderly separation of the "schiller constituents" within the minerals of plutonic rocks. "Perthitic structure" in slow-cooled felspars seems to require a similar explanation.

From analogies such as these it was argued that the experience of the geologist may be useful to the metallurgist, and that the knowledge of the structure of metals, which for commercial purposes are manufactured under controlled conditions of temperature and of stress, may provide a key of great adaptability with which, in conjunction with his map, his hammer, and his microscope, the geologist may decipher and interpret the autobiographical secrets of the record contained in the rocks

INDUSTRIAL RESEARCH IN AMERICA.[1]

GERMANY has long been recognised as pre-eminently the country of organised research. The spirit of research is there immanent throughout the entire social structure. This is not the time or place, however, nor is it necessary before this audience, to refer in any detail to the long record of splendid achievement made by German research during the last fifty years. It is inscribed in luminous letters around the rock upon which Germany now stands secure among the nations of the world.

The virility and range of German research were never greater than they are to-day. Never before have the superb energy and calculated audacity of German technical directors and German financiers transformed so quickly and so surely the triumphs of the laboratory into industrial conquests. Never has the future held richer promise of orderly and sustained progress, and yet the pre-eminence of Germany in industrial research is by no means indefinitely assured. A new competitor is even now girding up his loins and training for the race, and that competitor is, strangely enough, the United States—that prodigal among nations, still justly stigmatised as the most wasteful, careless, and improvident of them all.

To one at all familiar with the disdain of scientific teaching which has characterised our industry, and which still persists in many quarters, this statement is so contrary to the current estimate that its general acceptance cannot be expected. It will have served its purpose if it leads to a consideration of the facts which prove the thesis.

The country of Franklin, Morse, and Rumford, of McCormick, Howe, and Whitney, of Edison, Thomson, Westinghouse, and Bell, and of Wilbur and Orville Wright, is obviously a country not wholly hostile to industrial research or unable to apply it to good purpose. It is, however, not surprising that with vast areas of virgin soil of which a share might be had for the asking, with interminable stretches of stately forest, with coal and oil and gas, the ores of metals, and countless other gifts of nature scattered broadcast by her lavish hand, our people entered upon this rich inheritance with the spirit of the spendthrift, and gave little heed to refinements in methods of production and less to minimising waste. That day and generation are gone. To-day their children, partly through better recognition of potential values, but mainly by the pressure of a greatly increased population and the stress of competition between themselves and in the markets of the world, are rapidly acquiring the knowledge that efficiency of production is a sounder basis for prosperity than mere volume of product, however great.

The long-continued and highly organised research which resulted in the development of American agricultural machinery has led to the general introduction of machines which reduce the labour cost of seven crops 681,000,000 dollars, as measured by the methods of only fifty years ago.

You need not to be reminded that the ubiquitous telephone is wholly a product of American research. Munchausen's story of the frozen conversation which afterward thawed out is a clumsy fable. Think of the Niagaras of speech pouring silently through the New York telephone exchanges where they are sorted out, given a new direction, and delivered audibly perhaps a thousand miles away. New York has 450,000 instruments—twice the number of those in London. Los Angeles has a telephone to every four inhabitants. Why should one care to project one's astral body when he can call up from the club in fifteen seconds? Our whole social structure has been reorganised. We have been brought together in a single parlour for conversation and to conduct affairs, because the American Telephone and Telegraph Company spends annually for research, the results of which are all about us, a sum greater than the total income of many universities.

The name of Edison is a household word in every language. The Edison method is a synonym for specialised, intense research, which knows no rest until everything has been tried. Because of that method and the unique genius which directs its application, Italian operas are heard amid Alaskan snows and in the depths of African forests; every phase of life and movement of interest throughout the world is caught, registered, transported, and reproduced, that we may have lion hunts in our drawing-rooms and the coronation in a five-cent theatre. From his laboratory have come the incandescent lamp, multiple

[1] From the presidential address delivered before the American Chemical Society at Rochester, New York, September 9, 1913, by Arthur D. Little.

telegraphy, new methods of treating ores, and a thousand other diverse inventions, the development of a single one of which has sometimes involved millions.

Such development as that of the automobile industry in America has been based upon and vitalised by an immeasurable amount of research, the range and influence of which extend through many other industries. It has accelerated the application of heat treatment more than any other agency. One tyre manufacturer spends 100,000 dollars a year upon his laboratory. The research department organised by my associates for one automobile company comprised within its staff experts in automobile design, mathematics, metallography, and heat treatments, lubrication, gaseous fuels, steel and alloys, paints and painting practice, in addition to the chemists and physicists and assistants for routine or special work.

The beautiful city the hospitality of which has so greatly added to the pleasure and success of the present meeting of our society is the home of two highly scientific industries of which any community may well be proud. The Bausch and Lomb Optical Company, through its close affiliation with the world-famed Zeiss works at Jena, renders immediately available in this country the latest results of German optical research. The Eastman Kodak Company is perhaps more generally and widely known than even the Zeiss works, and in capital, organisation, value of product, and profit of operation will bear comparison with the great German companies whose business is applied science. Like them, it spends money with a lavish hand for the promotion of technical research and for the fundamental investigation of the scientific bases on which its industry rests. As you have happily been made aware, this work is carried on in the superb new research laboratories of the company with an equipment which is probably unrivalled anywhere for its special purposes. The laboratory exemplifies a notable feature of American industrial research laboratories in that it makes provision for developing new processes, first on the laboratory scale and then on the miniature factory scale.

To no chapter in the history of industrial research can Americans turn with greater pride than to the one which contains the epic of the electrochemical development at Niagara Falls. It starts with the wonderful story of aluminium. Discovered in Germany in 1828 by Wöhler, it cost 90 dollars a pound in 1855. In 1886 it had fallen to 12 dollars. The American Castner process brought the price in 1889 to 4 dollars. Even at this figure, it was obviously still a metal of luxury with few industrial applications. Simultaneously Hall in America and Heroult in Europe discovered that cryolite, a double fluoride of sodium and aluminium, fused readily at a moderate temperature, and, when so fused, dissolved alumina as boiling water dissolves sugar or salt, and to the extent of more than 25 per cent. By electrolysing the fused solution, aluminium is obtained.

On August 26, 1895, the Niagara works of the Pittsburgh Reduction Company started at Niagara Falls the manufacture of aluminium under the Hall patents. In 1911 the market price of the metal was 22 cents, and the total annual production 40,000,000 lb.

A chance remark by Dr. George F. Kunz in 1880 on the industrial value of abrasives turned the thoughts of Acheson to the problem of their artificial production, and led to the discovery in 1891 of carborundum and its subsequent manufacture on a small scale at Monongahela City, Pennsylvania. In 1894 Acheson laid before his directors a scheme for moving to Niagara Falls—to quote his own words:—

"To build a plant for 1000 horse-power, in view of the fact that we were selling only one-half of the output from a 134 horse-power plant, was a trifle too much for my conservative directors, and they one and all resigned. Fortunately, I was in control of the destiny of the Carborundum Company. I organised a new board, proceeded with my plans, and in the year 1904, the thirteenth from the date of the discovery, had a plant equipped with a 5000 electrical horse-power, and produced more than 7,000,000 lb. of those specks I had picked off the end of the electric light carbon in the spring of 1891."

The commercial development of carborundum had not proceeded far before Acheson brought out his process for the electric furnace production of artificial graphite and another great Niagara industry was founded. In quick succession came the Willson process for calcium carbide and the industrial applications of acetylene, phosphorus, ferro-alloys made in the electric furnace, metallic sodium, chlorine, and caustic soda, first by the Castner process, later by the extraordinarily efficient Townsend cell, electrolytic chlorates and alundum.

Perhaps even more significant than any of these great industrial successes was the Lovejoy and Bradley plant for the fixation of atmospheric nitrogen, which was perforce abandoned. It is well to recall, in view of that reputed failure, that the present-day processes for fixing nitrogen have made little, if any, improvement in yields of fixed nitrogen in a kilowatt hour over those obtained in this pioneer Niagara plant.

In the year 1800 a young assistant of Lavoisier, E. I. du Pont by name, emigrated to the United States, with others of his family, and settled on the banks of the Brandywine, near Wilmington, Delaware. He engaged in the manufacture of gunpowder. To-day the du Pont Company employs about 250 trained chemists. Its chemical department comprises three divisions: the field division for the study of problems which must be investigated outside the laboratory, and which maintains upon its staff experts for each manufacturing activity, together with a force of chemists at each plant for routine laboratory work; second, the experimental station, which comprises a group of laboratories for research work on the problems arising in connection with the manufacture of black and smokeless powder, and the investigation of problems or new processes originating outside the company; third, the Eastern Laboratory which confines itself to research concerned with high explosives. Its equipment is housed in seventy-six buildings, the majority being of considerable size, spread over fifty acres. Since no industrial research laboratory can be called successful which does not in due time pay its way, it is pleasant to record that the Eastern Laboratory is estimated to yield a profit to its company of 1,000,000 dollars a year. In addition to the generous salaries paid for the high-class service demanded by the company, conspicuous success in research is rewarded by bonus payments of stock.

The Gayley invention of the dry air blast in the manufacture of iron involves a saving to the American people of from 15,000,000 dollars to 29,000,000 dollars annually. A modern furnace consumes about 40,000 cubic feet of air a minute. Each grain of moisture in a cubic foot represents one gallon of water an hour for each 1000 cubic feet entering a minute. In the Pittsburgh district the moisture varies from 1·83 grains in February to 5·94 grains in June, and the water an hour entering a furnace varies accordingly from 73 to 237 gallons. In a month a furnace using natural air received 164,500 gallons of water, whereas with the dry blast it received only 25,524 gallons. A conservative statement, according to Prof. Chandler, is that the invention results in a 10 per cent. increase in output and a 10 per cent. saving in fuel.

Especially notable and picturesque among the triumphs of American industrial research is that by means of which Frasch gave to the United States potential control of the sulphur industry of the world. There is in Calcasieu Parish, Louisiana, a great deposit of sulphur 1000 ft. below the surface under a layer of quicksand 500 ft. in thickness. An Austrian company, a French company, and numerous American companies had tried in many ingenious ways to work this deposit, but had invariably failed. Misfortune and disaster to all connected with it had been the record of the deposit to the time when Frasch approached its problem in 1890. He conceived the idea of melting the sulphur in place by superheated water forced down a boring, and pumping the sulphur up through an inner tube. In his first trial he made use of twenty 150-h.p. boilers grouped around the well, and the titanic experiment was successful. The pumps are now discarded, and the sulphur brought to the surface by compressed air. A single well produces about 450 tons a day, and their combined capacity exceeds the sulphur consumption of the world.

An equally notable solution of a technical problem which had long baffled other investigators is the Frasch process for refining the crude, sulphur-bearing Canadian and Ohio oils. The essence of the invention consists in distilling the different products of the fractional distillation of the crude oil with metallic oxides, especially oxide of copper, by which the sulphur is completely removed, while the oils distill over as odourless and sweet as from the best Pennsylvania oil. The copper sulphide is roasted to regenerate the copper. The invention had immense pecuniary value. It sent the production of the Ohio fields to 90,000 barrels a day, and the price of crude Ohio oil from 14 cents a barrel to one dollar.

Turning from these examples of individual achievement so strongly characteristic of the genius of our people in one aspect, let us again consider for a moment that other and even more significant phase of our industrial research, namely, that which involves the coordinated and long-continued effort of many chemists along related lines.

Chemistry in America is essentially republican and pragmatic. Most of us believe that the doctrine science for science's sake is as meaningless and mischievous as that of art for art's sake or literature for literature's sake. These things were made for man, not for themselves, nor was man made for them. Most of us are beginning to realise that the major problems of applied chemistry are incomparably harder of solution than the problems of pure chemistry, and the attack, moreover, must often be carried to conclusion at close quarters under the stress and strain induced by time and money factors. In these circumstances it should not excite surprise that a constantly rising proportion of our best research is carried on in the laboratories of our great industrial corporations, and nowhere more effectively than in the research laboratory of the General Electric Company, under the guidance of your past president, Dr. Whitney.

Any attempt to present adequately the enormous volume of research work, much of which is of the highest grade, constantly in progress in the many scientific bureaus and special laboratories of the general government, or even to indicate its actual extent and range, is utterly beyond the limits of my attainments or of your patience. The generous policy of the Government toward research is unique in this, that the results are immediately made available to the whole people.

The United States is still essentially an agricultural country, and agriculture is, in its ultimate terms, applied photochemistry. The value of our farm property is already more than 42,000,000,000 dollars, and each sunrise sees an added increment of millions. Even small advances in agricultural practice bring enormous monetary returns.

Chief, therefore, among the government departments, in the volume of industrial research is the Department of Agriculture, which includes within its organisation ten great scientific bureaus, each inspired by an intense pragmatism and aggressively prosecuting research in its allotted field.

The research work of the Department of Agriculture is greatly augmented and given local application through the agency of sixty-four State agricultural experiment stations, established for the scientific investigation of problems relating to agriculture. These stations are supported in part by federal grants, as from the Hatch and Adams funds, and for the rest by State appropriations. Their present income exceeds 3,000,000 dollars. All are well equipped; one of them, California, includes within its plant a superb estate of 5400 acres, with buildings worth 1,000,000 dollars.

It may be said without fear of contradiction that through the combined efforts of the Department of Agriculture, the experiment stations, the agricultural colleges, and our manufacturers of agricultural machinery, there is devoted to American agriculture a far greater amount of scientific research and effort than is at the service of any other business in the world.

In the United States Patent Office Dr. Hall has developed a remarkably comprehensive index to chemical literature, which now contains 1,250,000 cards, and is open to every worker. The Bureau of Fisheries devotes 40,000 dollars to a single study, and the Geological Survey 100,000 dollars to the investigation of the mineral resources of Alaska.

The Bureau of Mines of the Department of the Interior was established to conduct on behalf of the public welfare fundamental inquiries and investigations into the mining, metallurgical, and mineral industries. Its appropriation for the current fiscal year is 662,000 dollars, of which 347,000 dollars is to be devoted to technical research pertinent to the mining industry.

Perhaps no better evidence could be adduced of the present range and volume of industrial research in America than the necessity, imposed upon the author of such a general survey as I am attempting, of condensing within a paragraph his reference to the Bureau of Standards of the Department of Commerce. Its purpose is the investigation and testing of standards and measuring instruments, and the determination of physical constants and the properties of materials. To these objects it devotes about 700,000 dollars a year to such good effect that in equipment and in the high quality and output of its work it has in ten years taken rank with the foremost scientific institutions in the world for the promotion of industrial research and the development and standardisation of the instruments, materials, and methods therein employed. Its influence upon American research and industry is already profound and rapidly extending.

I cannot better conclude this cursory and fragmentary reference to governmental work in applied science than with the words of the distinguished director of the Bureau of Standards:—

"If there is one thing above all others for which the activities of our Government during the past two or three decades will be marked, it is its original work along scientific lines, and I venture to state that this work is just in its infancy."

The present vitality and rate of progress in American industrial research is strikingly illustrated by its very recent development in special industries. It has been said that our best research is carried on in those laboratories which have one client, and that one themselves.

Twenty-five years ago the number of industrial concerns employing even a single chemist was very small, and even he was usually engaged almost wholly upon routine work. Many concerns engaged in business of a distinctly chemical nature had no chemist at all, and such a thing as industrial research in any proper sense scarcely came within the field of vision of our manufacturers. Many of them have not yet emerged from the penumbra of that eclipse, and our industrial foremen as a class are still within the deeper shadow. Meantime, however, research has firmly established itself among the foundation-stones of our industrial system, and the question is no longer what will become of the chemists. It is now what will become of the manufacturers without them.

In the United States to-day the microscope is in daily use in the examination of metals and alloys in more than 200 laboratories of large industrial concerns. An indeterminate but very great amount of segregated research is constantly carried forward in small laboratories, which are either an element in some industrial organisation or under individual control. An excellent example of the quality of work to be credited to the former is found in the development of cellulose acetate by Mork in the laboratory of the Chemical Products Company, while a classic instance of what may be accomplished by an aggressive individualism plus genius in research is familiar to most of you through the myriad and protean applications of Bakelite. The rapidity of the reduction to practice of Baekeland's research results is the more amazing when one considers that the distances to be travelled between the laboratory and the plant are often, in case of new processes and products, of almost astronomical dimensions.

Reference has already been made to the highly organised, munificently equipped, and splendidly manned laboratories of the Du Pont Company, the General Electric Company, and the Eastman Kodak Company. There are in the country at least fifty other notable laboratories engaged in industrial research in special industries. The expenditure of several of them is more than 300,000 dollars each a year. The United States Steel Corporation has not hesitated to spend that amount upon a single research, and the expenses of a dozen or more laboratories probably exceed 100,000 dollars annually. One of the finest iron research laboratories in the world is that of the American Rolling Mills Company.

The steel industry in its many ramifications promotes an immense amount of research, ranging from the most refined studies in metallography to experimentation upon the gigantic scale required for the development of the Gayley dry blast, the Whiting process for slag cement, or the South Chicago electric furnace. This furnace has probably operated upon a greater variety of products than any other electric furnace in the world. Regarding the steel for rails produced therein, it is gratifying to note that after two and one-half years or more no reports of breakage have been received from the 5600 tons of standard rails made from its output.

Industrial research is applied idealism. It expects rebuffs, it learns from every stumble, and turns the stumbling-block into a stepping-stone. It knows that it must pay its way. It contends that theory springs from practice. It trusts the scientific imagination, knowing it to be simply logic in flight. It believes with F. P. Fish, that "during the next generation—the next two generations—there is going to be a development in chemistry which will far surpass in its importance and value to the human race that of electricity in the last few years—a development which is going to revolutionise methods of manufacture, and more than that, is going to revolutionise methods of agriculture"; and it believes with Sir William Ramsay that "the country which is in advance in chemistry will also be foremost in wealth and general prosperity."

Modern progress can no longer depend upon accidental discoveries. Each advance in industrial science must be studied, organised, and fought like a military campaign. Or, to change the figure, in the early days of our science, chemists patrolled the shores of the great ocean of the unknown, and, seizing upon such fragments of truth as drifted in within their reach, turned them to the enrichment of the intellectual and material life of the community. Later they ventured timidly to launch the frail and often leaky canoe of hypothesis, and returned with richer treasures. To-day, confident and resourceful, as the result of many argosies, and having learned to read the stars, organised, equipped, they set sail boldly on a charted sea in staunch ships with tiering canvas bound for new El Dorados.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

BIRMINGHAM.—The City Council has renewed the annual grant to the University. An amendment by a Socialist member opposing the renewal, on the ground that the elementary education of the city and the technical school were being starved, was defeated by seventy votes to twenty-nine.

Dr. J. E. H. Sawyer has been appointed assistant to the chair of medicine.

Mr. H. A. Scarborough has been recommended to the Commissioners of the Exhibition of 1851 for a research scholarship.

Prof. Bostock Hill is to represent the University at the congress of the Royal Sanitary Institute in July next.

CAMBRIDGE.—The work submitted by Mr. T. W. Price, of Clare College, entitled "Osmotic Pressure of Alcoholic Solutions," has been approved by the Degree Committee of the Special Board for Physics and Chemistry as a record of original research.

OXFORD.—Under the existing constitution of the University, certain seats in the Hebdomadal Council are limited to the heads of colleges and professors respectively. A statute providing for the abolition of "orders" and for throwing the whole of the seats open to members of Convocation of five years' standing, which had been passed by small majorities in Congregation, was submitted in its final stage to Convocation on March 10. The proposed statute was supported by Prof. Geldart, and opposed by the rector of Exeter, and the warden of Wadham. It was rejected on a division by 97 to 83.

The preamble of a statute providing for the establishment of an additional professorship of chemistry, to be called "Dr. Lee's Professorship," passed Congregation without a division.

THE presentation of the portrait of Sir William Ramsay, K.C.B., to University College, London, and of the replica to Lady Ramsay, will be made on Wednesday next, March 18, at 4.30, in the Botanical Theatre.

THE appeal made by Girton College for 8000*l.* by January 1, 1914, to meet conditional promises of 12,000*l.* from an anonymous benefactor and 4000*l.* from Rosalind Lady Carlisle, has been completely successful, and the purpose of the appeal, which was the extinction of a mortgage debt of 24,000*l.*, has now been achieved. The donation, we learn from the