one expressed purpose underlying so much of our modern research in physics is to increase the precision with which physical phenomena may be observed. For 25 years attempts to observe the refraction of x-rays failed. About 1920 Siegbahn and Larsson, pushing measurements of wave-lengths of x-rays to higher and higher precision, found that the wave-length of Cu Ka radiation, as measured in first order reflection from a mica crystal, differed from similar measurements in the eleventh order by about 0.15 per cent. They correctly attributed this difference to refraction of the rays as they entered the crystal, a phenomenon hitherto unobserved. To-day indices of refraction for x-rays (strictly speaking, the difference between the index and unity) are measurable with a precision in excess of 1 per cent. Until a few years ago no one had succeeded in producing an x-ray spectrum by reflection from a ruled grating. Recently, by use of such a grating, Bearden has reported measurements of x-ray wave-lengths with an estimated probable error of 0.01 per cent. As is well known, the slight discrepancy between the values so obtained and those yielded by use of a crystal grating has necessitated a critical reexamination of the whole technique of x-ray spectroscopy, and perhaps requires some fundamental modifications in our concepts of crystal structure.

In 1900 Drude, in his "Theory of Optics," remarked that "this (radiation) pressure is so small that it can not be detected experimentally." Almost before Drude's book was released from the press, Lebedew in Europe announced the experimental discovery and rough measurement of this phenomenon; and within three years Nichols and Hall in America reported measurements of radiation pressure with an estimated probable error of about one quarter of 1 per cent. The bearing of these measurements on theories of radiation is too well known to need comment.

In a little over a decade, Thomson's apparatus for studying positive rays evolves into Aston's precision mass-spectrograph, in which the relative masses of atoms can be measured with a precision of the order of one part in 10,000. After observing the "fine structure" of spectral lines the spectroscopist goes on to observe "hyperfine structure." A recently reported critical examination of existing data leads to the conclusion that the most probable value of "e," the charge carried by the electron, is 4.7721×10^{-10} as e.s.u. instead of 4.774×10^{-10} as previously used. From each such extension of the precision of measurement there results either a significant modification of theory, or not infrequently a new discovery. So frequently has this happened in the history of physics that to sum up what I have said I am disposed to conclude by paraphrasing a famous saying: "Look after the next decimal place and physical theories will take care of themselves."

RESEARCH AND INDUSTRIAL ORGANIC CHEMISTRY[1]

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I EXAMINED a short time ago the advertisements in a copy of *Industrial and Engineering Chemistry* to see to what extent the pages reflected the recent development in this country of industrial organic chemistry. I found 42 organic compounds advertised which are available for large scale use. Many of these are new substances; the rest have been used but are produced now at lower prices and in a purer condition than in the past as the result of the application of new synthetic methods. In the list were several compounds of importance on account of their use as intermediates in the preparation of a great variety of technical products. A study of the methods by which these results have been reached shows clearly that chemical research of a high order is the foundation upon which the achievements rest. A broader survey of the present condition of the organic chemical industry leads to the same conclusion.

The division of engineering and industrial research of the National Research Council has as one of its important activities the study of the relation between research and industry and has demonstrated in its publications the controlling significance of this relation.

The chemical industry of the United States has grown rapidly since the world war. It stands high in the list of industries arranged according to the number of men employed, returns and capital invested; it is thus an important factor in the economics and well-being of the country. I shall limit myself in this address, however, to organic chemistry, the field in which my knowledge and chief interest lie.

The supply of many important chemical compounds used in a variety of industries was suddenly cut off when the country entered the recent war. It was

[1] Address of the retiring vice-president and chairman of Section C—Chemistry—American Association for the Advancement of Science, New Orleans, December, 1931.

necessary to manufacture without any background of experience a great variety of substances, such as dyes, pharmaceuticals, etc. The methods used in the preparation of these substances were in many cases protected by patents owned by foreign corporations. Under the circumstances the United States Government took over such patents and provided a way to make possible the manufacture of these essential materials. In order to put the patented processes into operation it was found necessary to carry out a large amount of research based on the scanty and more or less indefinite disclosures in the patents. This procedure was costly but yielded the desired results. Most important of all was the conclusion that research is a factor of prime importance in industry. The learning of this lesson by the executives of corporations who dictated policies and expenditures proceeded slowly at first, but after the results became more and more evident the conservatives were finally convinced.

I had an excellent opportunity in 1924–1925, as chairman of the division of chemistry and chemical technology of the National Research Council, to study the relation between research and the organic chemical industries. The investigation brought out the fact that certain great industries were not utilizing chemical research adequately. An attempt was made by the division to bring about cooperative research in certain industries. The response by executives was not, at first, encouraging. The president of a large petroleum company told me it was not the business of the chemist to meddle in the affairs of the industry. His company had millions of dollars invested in plants. It was satisfied with the results. He did not want anybody to do anything to make these plants obsolete.

A high executive in another industry told me he did not believe it good business to spend money on research to develop new products or methods. He had found it better to let some one else bear the expense of such work, most of which proved of no value. If anything worth while came out of it he could afford to buy it. What a change has come about in seven years. The two industries to which I have just referred are now spending millions of dollars in research.

The financial depression has had little influence on the research activities in chemical industries. Statistics gathered by the American Chemical Society show that few trained research men have lost their positions. One of the progressive organizations had more men on this type of work this summer than ever in the past.

A careful study of the factors involved in the relationship between research and industry is leading to a fuller appreciation of the value of results that follow the use of research as an industrial tool. At this time I shall refer to but two of these factors. The first and most important is the attitude of the executives. I have already said that this is improving, but much remains to be done. It was not long ago that the consolidation of several chemical industries into a large corporation promptly resulted in the abandonment of research and the discharge of the men who were advancing the industries involved. It was also not long ago that a chemist from Switzerland, who was well informed as to the condition of industry in his own country and in Germany, pointed out the handicap under which certain American industries function as the result of being under the control of men ignorant of chemistry. These conditions also are changing. I once expressed to a friend, who had been successful in the direction of the research of a corporation, my regret from the standpoint of science that he had been transferred to an executive position. He showed me that my attitude was wrong. In the new position he could influence the directors of the corporation to adopt a more liberal and better understanding policy in regard to research.

Some of the most brilliant industrial developments in organic chemistry have been the result of research that required from five to ten years to reach the goal. Methanol and gasoline synthesized from coal have been the reward of long-continued endeavor. It required the foresight of one who knows what research can do to enter upon such a long chase. As each success is achieved the way for future development becomes easier.

The winning of the confidence of executives in the money value of research is proceeding rapidly. It is reassuring that a large number of chemical industries has contributed annually to the American Chemical Society a substantial sum to help in the publication of *Chemical Abstracts*. Appreciation of the work done in preparing men for research in chemistry is shown by the fact that over thirty students are financed by chemical industries at Johns Hopkins University. One large corporation maintains fellowships in chemistry at about twenty educational institutions. The men receiving the aid are not restricted in regard to the subject of their researches. There is a large number of fellowships of a different type established in colleges and universities. In these the research problems are closely allied to the industries which support them. The object in these cases appears to be more the results hoped for than the training of research workers.

The increased use of research in chemical industry has resulted in the rapid growth of centralized research organizations. Under certain conditions it has been found better to use the broad background of experience of these organizations and the services of their skilful research men rather than to place the problem in a laboratory closely associated with plant operation.

The division of engineering and industrial research has done good work in helping to bring to the attention of executives of corporations the work of industrial research laboratories. The division organized and conducted two tours of inspection for executives through the laboratories of a large number of industries. It is planned to extend this service to the research organizations of Europe.

The second most important factor in the development of industry by research is, in my opinion, the personnel of the laboratories. This factor is of particular interest to those who have the responsibility of assisting in the education of research chemists. Much study of the problem involved in training minds is being carried out outside the schools of pedagogy. The American Council of Education has been endeavoring to formulate what qualities and qualifications professional scientists should possess. One of its studies has been devoted to organic research chemists. A teacher interested in helping to build an individual as near the ideal as possible sees that he can help in ways apart from the use of the old-fashioned formulas of his profession.

In recent years the methods and personnel of the industrial research laboratories have changed rapidly. The empirical approach to the solution of a problem has largely disappeared and has been replaced by coordinated investigation carried out with the use of the scientific methods and with a knowledge of the latest findings and instruments of fundamental science. The industrial laboratories keep informed as to the new knowledge resulting from research in the universities. Requests are received from such laboratories for reprints of papers which apparently are only of theoretical interest.

The change in the industrial laboratories has come about as the result of a change in personnel. I was consulted several years ago in regard to the appointment of a director of a proposed research laboratory for a chemical industry, which was conducted largely by rule-of-thumb methods. The directors insisted on the appointment of a well-informed organic chemist, preferably a university professor, who had no experience in the industry which he was expected to develop. In this case there was good judgment in the point of view.

Opportunities are rapidly decreasing for the advancement in his profession of the chemist whose scholastic experience is limited to a four years' course leading to the degree of bachelor of science. To get ahead he must put chemistry behind him and become a manager or executive. The men to-day who are developing the industry are some of the best of those who have learned the methods of research in winning the doctor's degree. It may be profitable to digress at this point to consider some of the effects of this change. For those of us who are training these men it is necessary to know what experience has shown to be the best type of preparation for this work.

The scientific background of the organic chemist of thirty years ago was largely limited to a knowledge of the properties and chemical behavior of the substances with which he had to deal. He used the physico-chemical concept of molecular weight and the laws relating to the effect of solutes on the freezing and boiling points of solutions. He was prepared to undertake the study of the structure and the synthesis of organic molecules—the major problems of the time.

The advances made in physics and physical chemistry have furnished the organic chemist with new fundamental concepts, methods and tools, which have been applied with astounding success; and other possible aids of this sort are now waiting to be used in the study and control of organic molecules. The application of thermodynamics, thermochemistry, the laws of vapor pressure, rates of reaction and their temperature coefficients, the concepts of free energy, chemical equilibrium and ionization, catalysis, x-rays, and different types of energy with varying intensity factors—these and other important facts and generalizations have broadened the methods of research in organic chemistry, and have been applied in the solution of industrial problems.

For the research chemist who enters the industrial field a knowledge is important of the principles of chemical engineering which follow from the application of those laws of physics and physical chemistry which have to do with the physical relationships between molecules.

Those who direct the education of students of organic chemistry should see to it that the preparation for future work includes training in the principles of physical chemistry and their use. It was not so long ago that one of the leading universities of the country had no requirement in physical chemistry for men awarded the doctorate in organic chemistry. Happily, conditions are improving.

The growth of the use of research in the industries based on chemistry is indicated by the rapid increase in the number of men awarded the degree of doctor of philosophy in American universities. A compilation made by the National Research Council shows that much the larger number of these degrees is in the field of chemistry. Many of the young men awarded this degree have entered industrial research laboratories, where they are happily at work on problems of great interst, are supplied with every facility and are in a congenial scientific atmosphere. Their value is clear from the compensation they receive.

The business world, apart from the industries themselves, is learning the importance of research. Some of the more progressive and larger banks seek information and advice before investments in or loans to certain corporations are made. The banker wants to know what percentage of profits is expended in research, something of the personnel and aim of the laboratory, the extent to which there is diversification in the products manufactured and the future possibilities of new ventures. Great financial loss has resulted from investments made without the judgment of well-informed experts.

There is time to make a brief survey of a few of the achievements of industrial organic research in this country, as examples of the application of the more recently applied methods of investigation. The substances considered can be conveniently grouped according to the causes which led to their investigation.

A constant aim of the manufacturer is to reduce cost. The cost of a material which is necessary in the production of a new and useful product determines whether or not the product is made and used. There are now a number of substances possessing properties that would lead to their extensive use if the cost of the intermediates required in their manufacture could be reduced a few cents per pound. Potentially large industries are waiting such reduction.

The production of certain aliphatic acids has been studied from this point of view. The price of acetic acid, which is so extensively used, is yielding to the effects of research. The search for new methods of preparation, rather than the improvement of the old, has yielded a process from calcium carbide made from coal and another based on the catalytic oxidation of alcohol by air. It is stated that with the use of alcohol the cost of the acid can be reduced to a surprisingly low figure. A search is now being made for cheap propionic acid. Success will depend on the use of a very cheap material for the source of the carbon atoms.

Several amyl alcohols prepared from the pentanes in petroleum are now available. The investigation necessary for the successful industrial use of the reactions involved required much time and skilful effort.

The modern method of preparing alcohol free from water for industrial use is a striking example of the application of the principles underlying the vapor pressure of two and three component systems.

The industrial preparation of esters, as illustrated in the case of ethyl acetate, brings out clearly how physico-chemical principles and chemical engineering solved in a very neat way a problem of organic chemistry.

A new process has recently been announced for the preparation of higher aliphatic acids and alcohols from fats as the result of reduction by hydrogen under pressure. The results in all the cases cited were produced by modern research methods. It would lead too far to amplify this statement. A consideration of the development of our knowledge as the result of the study of the chemical behavior of molecules under high pressures and at high temperatures would be of value only if furnished by a specialist in this field.

Two important aromatic intermediates, phenol and aniline, are now produced from chlorobenzene by new processes, which in the light of the older organic chemistry seemed well-nigh impossible. But the application of the newer knowledge and methods yielded a solution of the problem.

The use of waste materials and by-products to prepare valuable substances has always been a fascinating field of endeavor to the chemist. It is only recently that outstanding results have been obtained. The wastes from oats, cottonseed and corn-stalks are now converted into chemical compounds of value.

The gases produced in the cracking of petroleum in the preparation of gasoline, until recently, were of value only as a source of heat. Years have been spent in the study of the conversion of the unsaturated hydrocarbons contained in these gases into alcohols. An application of a knowledge of the influence of the structure of hydrocarbons on the rates at which they react with sulphuric acid of varying concentrations, converted an empirical and unsatisfactory process into one that yielded purer products and compounds not obtainable by the older method. Tertiary butyl alcohol was changed from an expensive research chemical to one that can be sold in carload lots at a low price.

A third driving force behind industrial organic research is the desire to prepare substances that possess the particular physical properties required for a specific use. The change from paint to lacquers in the automobile industry brought forward the problem of solvents which led to much research in their use and their preparation.

Artificial silk and plastics have kept chemists at work for years. It is probable that new developments will soon appear. The thorough study of certain types of condensation reactions and the relation between physical properties and the length of the carbon chain in products formed by condensation have led to the production of compounds which may become important factors in the textile industry.

Synthetic rubber has lost most of its industrial significance, but fundamental research carried out by industry on the process of polymerization has led to the preparation of a product that will probably replace rubber in certain of its uses. The new material possesses properties that are superior to those of rubber from the standpoint of these uses.

The extensive development of ethylene glycol and its derivatives has added a number of compounds to the products that have found, or are waiting to find, industrial uses. The recent great expansion of the use of cellophane, after the substance had been known so long, must give hope to those who have spent much time in the development of substances that have not yet found their place.

I have but mentioned a very few of the substances that are worthy of note in a review of the part played by research in the organic chemical industry. These were chosen as examples to show to what extent research of the highest type was used. The chemist familiar with the steps by which the results were achieved is impressed by the methods by which they have been reached.

When one has reviewed the past and has endeavored to relate the causes with the results obtained, it is a pleasant mental diversion to look into the future and try to sketch the flow of events. Zest is added to this play of the imagination if an attempt is made to find new causes and new conditions that would probably lead to accelerated progress.

It is easy to see important future developments resulting from the application of known knowledge in the study of industrial problems. These developments are assured. But much lies ahead awaiting the accumulation of yet undiscovered facts and principles to be applied. As I have already indicated, industrial research chemists are using effectively the results of "pure" research, but advance is impeded by a lack of more detailed knowledge of the molecules themselves with which they are busy. Past studies have been devoted largely to the investigation of the interaction between molecules; and from the results obtained conclusions have been drawn as to the arrangement of the atoms in the molecule. The theory of structure has led to great triumphs in synthesis, but the graphic formulas we use tell us nothing of the molecules except a probable arrangement of their constituent atoms. A wide background of facts not indicated in a formula must be used in interpreting the significance of the structural relationships represented.

We know but little of how the atoms in a molecule are held together and how different atoms in relatively different positions affect the so-called bonds between the atoms, which we represent as straight lines or by two dots. I recall a statement made by Professor Remsen when he was lecturing to his students on double salts. He wrote the formula of such a salt, in the way used then, with a period between the two simple salts from which it was prepared. He pointed to the period and said, "Gentlemen, that period has been a full stop to thought." For years the lines written between atoms in a structural formula satisfied organic chemists. Lately two dots have replaced the line in an attempt to make use of the concept of electrons. I fear to some the change is satisfactory and the history of the line will be repeated.

Organic chemists should learn a lesson from the physicists. One can not use too strong or flamboyant words in expressing an appreciation of the results of ten years' intensive study of atoms. What has been accomplished has opened new roads that lead to the very heart of the atom. A similar fruitful field lies before the organic chemist in his molecules. The problem may be harder or it may be easier in some of its aspects, but it is certain that it warrants study and that the results will be repaying.

How is this new knowledge to be gained by which organic chemistry will be changed slowly from a science largely empirical to one based on principles? Is the way followed to-day the best? To what extent can the industries themselves help? In the applications of electricity, practice is working at the borderland between the known and the unknown, and the industry in its laboratories is pushing the boundary farther ahead. Have we a right to hope that those who control the policies of the research laboratories of the organic chemical industries will make possible a search for the fundamental principles underlying these industries? There has been a start in this direction, but the strong pressure toward the immediately practical application is hard to resist.

The kind of study that I have in mind is costly, and the results come slowly. How best can it be accomplished? Organization based on cooperative effort appears to be one solution of the problem. We have seen, since the war, cooperation between government and industry in Great Britain. Extensive laboratories supported by public funds and by contributions from the more important industries have yielded results which are the common property of those who have cooperated. The canners in the United States support a laboratory that has been a great success.

The method has many evident advantages and has demonstrated the value of cooperation. As far as I am informed the laboratories have been busy, almost exclusively, with practical problems. It would be a long step ahead if industry would undertake in the same spirit more fundamental investigation.

Let me present one illustration of what might be done. In 1929 over 300,000,000 barrels of crude petroleum were converted, in the United States, into commercial products by processes that involved chemical changes in the constituents of the crude oils, which differed widely in composition. The methods used in the "cracking" processes employed are based on empirical knowledge. Very little is known as to the behavior of the many individual substances, largely of unknown composition, in the complex mixtures used. If the several organizations in the industry would contribute in a cooperative spirit to the support of a laboratory to study fundamentally the molecules of hydrocarbons, the results in time would, without doubt, be of the greatest value. As little as one cent for each ten barrels cracked would yield at least $300,000 annually for such work. It is my opinion that the organization and the research program for such a laboratory could be worked out in a way to ensure successful operation. No attention should be paid to immediate applications of the results of the work, and publication of these results should be unrestricted. The utilization of the findings of the laboratory in developing processes should be undertaken by the cooperating contributors to the enterprise. A part of the available funds could be used in supporting those researches in university laboratories that had to do with aspects of the fundamental problems of the industry.

I have outlined earlier in this address the broadening of the view in regard to research of the men who control the finances of great corporations. The next advance will come when these executives learn to appreciate the dependence of applied science on "pure" science to such a degree that they will see the value of devoting a fraction of earnings—even an almost infinitesimally small fraction—to the support of the "goose that lays the golden egg."

I shall never forget a prophecy made by Elihu Thomson in an address on the electron before the American Academy of Arts and Sciences. He told the little that was known at the time of this constituent of atoms. Foreseeing the possibilities lying in this sub-atomic entity he boldly prophesied that within a few years electrical engineering would be transformed into electron engineering. The prophecy has come true and the lesson to be drawn from it is evident.

The study of the present status of industrial organic chemistry leads to the conclusion that the development of the industry is based on research in which the results of "pure" science has been applied with great success. A stage has been reached which emphasizes the need of a more fundamental knowledge of the chemical units—the molecules—which are used in building up the valuable substances produced by the industry.

SCIENTIFIC EVENTS

BRITISH VITAL STATISTICS

THE registrar-general's "Statistical Review of England and Wales for 1930," according to a summary in *The British Medical Journal,* contains statistics of population, births, marriages and divorces, registers of electors and vital statistics of the British Dominions. A table is given showing the populations of England and Wales, Scotland and Ireland as enumerated at each census from 1821 to 1921, and so estimated for each year 1891 to 1930 inclusive. The number of marriages solemnized in England and Wales during the year 1930 was 315,109, against 313,316 in the previous year. The rate in both years was 15.8 persons married per 1,000 persons living. This rate is the highest recorded since 1921, notwithstanding the present economic depression. Of the total marriages 31 per cent. were solemnized during the third quarter, or more than double the number during the March quarter. This preference for the third quarter has been constant since the beginning of the present century, prior to which the fourth quarter had been the favorite quarter for marriage. It is interesting to observe that 22 males and 699 females married at 16 years of age, the lowest legal age at which marriages may be solemnized, and that while the 22 males married females up to 23 years of age, the 699 females married males of varying ages between 16 and 49 years of age; in only five cases were the bride and bridegroom of the same age. The number of decrees nisi made absolute in respect of dissolution or annulment of marriage was 3,563, an increase of 167 over the figure for the preceding year. The births registered during the year totalled 648,811, an increase of 5,138, though the rate of 16.3 per 1,000 of the population remained the same. This increase in the number of births is probably in consequence of the high marriage rates recorded during the last two years. The proportion of the sexes in the births registered during the year was 1,044 males to 1,000 females, thus continuing the approximate proportion of recent years. There was at the end of the year 1930 a total of 157,948,940 names in the registrar-general's index available to the general public for searches in the registers of births, marriages and deaths. The statistics relating to parliamentary electors give the figures for the 1930 register for England and Wales as 12,101,108 males and 13,629,399 females, making a total of 25,730,507