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## THE RELATION OF CHEMISTRY TO AGRICULTURE[1]

THE dedication of a new chemical laboratory to the service of agriculture is an event which suggests to the mind a variety of thoughts for reflection. When an institution of learning replaces a structure inadequate to its needs by one that is larger and more modern, it simply illustrates in a very concrete way the change from the old order to the new which is continually taking place in both the material and intellectual worlds. But when, as in the present instance, the dedication of a new laboratory is in commemoration of a former revered teacher and investigator of agricultural chemistry our thoughts are turned backward as well as forward. Almost unconsciously we begin to reflect upon those principles of our science which were transmitted to us by the chemists of previous generations as a basis for our own development and as a foundation for future progress.

The year 1924, which marks the completion and dedication of the Goessmann Chemistry Laboratory of the Massachusetts Agricultural College, is in many respects an anniversary in the history of agricultural chemistry. It was just one hundred years ago that Justus von Liebig established his famous laboratory at Giessen, where he began a series of epoch-making discoveries that changed the course of chemical and agricultural science. Going back another century to 1724, we find an English clergyman, Stephen Hales, in the retirement of his curacy at Teddington actively engaged in experiments to show how much nourishment plants derive from the air—a group of researches which were incorporated three years later in a well-known treatise entitled, "Vegetable Statics." Going back still another hundred years to 1624, we find a Belgian physician, Jean Baptiste van Helmont, in the intervals of his medical practice at Vilvoorden, experimenting with his newly discovered *spiritus sylvester,* or carbon dioxide. This backward glance of three centuries, to the time when New England was first being settled, takes us to the very threshold of agricultural chemistry as a science, for it was van Helmont who by means of quantitative experiments first pointed out the path of future progress and who, although himself unable to become disentangled from the obstacles of mysticism, was yet the earliest to see an opening through the thick forest of speculation in which the human mind had been vainly circling about for a period of two thousand years.

[1] Address given at the dedication of the Goessmann Chemistry Laboratory of the Massachusetts Agricultural College, Amherst, Massachusetts, October 3, 1924.

Let us pause for a moment to consider the state of agricultural chemistry as it existed prior to the work of van Helmont. Like many other sciences it had made no progress since the time of Aristotle, whose theorizing upon natural phenomena was based upon the doctrine of the four elements. The different characteristics of soils, plants and animals were explained by their variable content in earth, water, air and fire, while the growth, death and decay of living organisms were attributed to a gain or loss in one or more of these four essential elements. An excess of any one of these gave a substance a preponderating share in the properties of hot, cold, dry or wet, as the case might be. The functions of the animal organism were thus attributed to the four humors, each of which was produced from foods of the requisite elementary property, those of a warm nature, such as mustard, being more productive of bile and those of a cold nature, such as melons, being more productive of phlegm. The expression "cool as a cucumber" is simply a survival of this ancient philosophy of nutrition which had its followers well into the eighteenth century. In the same way that the humors were each produced by particular vegetables, we find the latter to require for their growth a similar adaptation of soils, those which were warm being necessary for the plants that generate bile and those which were cold being required for the plants that give rise to phlegm. Such, in substance, was the theory of agricultural chemistry that prevailed before the time of van Helmont.

It is interesting to follow the interpretation of natural processes as the ancient Greeks explained them by their theory of elements. Take the phenomena of combustion as it is described by Heron of Alexandria, one of the most skilful experimenters of antiquity. "Bodies are consumed," he writes in the introduction of his "Pneumatics," "by fire which transforms them into finer elementary substances—namely, water, air and earth. That they are actually consumed is evident from the carbonaceous residue which, although occupying the same or a little less space than before combustion, nevertheless differs greatly with respect to the weight the material had at the beginning."

We have in this passage with its allusions to weight an early hint of the application of quantitative methods to the analysis of organic substances. Heron describes in his "Pneumatics" the most highly developed and elaborate forms of apparatus; without knowing it he had at his disposal every substance and every device necessary for establishing the true composition of the gaseous products of combustion. The only obstacle to his accomplishing this was the general acceptance of a false system of scientific inquiry, which working by the unproductive *a priori* method employed experiments to illustrate preconceived theories rather than to discover new truths. This attitude of mind, which closed the door to all progress, prevailed until the time of van Helmont, who, although himself greatly hampered by some of the inherited ideas of Greek philosophy, was yet among the first to make quantitative chemical experimentation the basis for the acquisition of new knowledge. Let us cite for comparison a combustion experiment of van Helmont which is somewhat similar to the one described by Heron.

> From 62 pounds of oak charcoal there is obtained by combustion one pound of ash. The remaining 61 pounds therefore consist of that spirit of wood (*spiritus sylvester*) which even under ignition can not escape from a closed vessel. This spirit, hitherto unknown, I call by the new name Gas. . . . Many bodies in fact contain this spirit and certain ones are entirely converted into it, not indeed because it is actually present in them as gas (since it could not be held in a compact form but would entirely escape) but it exists there as a condensed spirit, fixed like a corporeal substance from which it may be liberated by the action of a ferment, as in the case of wine, must, bread, mead, and the like.

Van Helmont's identification of the gas formed by the combustion of wood with that obtained by fermentations and by the action of acid upon limestone was one of the first important generalizations in the history of agricultural chemistry. He erred, however, in supposing this gas to be a transformation product of water, which, like the Greek philosopher Thales, he considered to be the elementary basis of all matter. But van Helmont always gave a good explanation for the truth as he saw it and it is interesting to trace the lines of his argument in a famous experiment which has been quoted by many writers upon chemistry from Boyle to the present time.

> I was able [writes van Helmont] to show by the following experiment that all vegetables are produced immediately and materially from the single element water. I took an earthen vessel in which I placed 200 pounds of soil previously dried in an oven. I then watered it with rain water and planted therein a willow branch weighing 5 pounds. After an interval of 5 years the tree which had sprung up weighed 169 pounds and some 3 ounces. The earthen vessel which was always watered when necessary with rain or distilled water was large and embedded in the ground; lest any flying dust should get mixed with the soil an iron cover plated with tin and provided with a large opening closed the mouth of the vessel. I did not determine the weight of leaves which fell during the four autumns. At the end of the experiment I dried the soil again in the vessel and obtained the same weight of 200 pounds lacking about 2 ounces. The 164 pounds of wood, bark and roots were therefore derived from water alone.

As Sir Michael Foster observes, this research is one of which an agricultural experiment station of to-day need not be ashamed. The conclusion is wrong, to be sure, but the technique is excellent. The experiment is a classic, for it marks the beginning of the quantitative methods by which future progress in agricultural chemical research was to be made.

If we trace a chronological graph for the development of agricultural chemistry we find that it proceeds from remote antiquity, with no indication of progress, in an almost horizontal line until, at the time of van Helmont, it begins to show a slight deviation upward. With the passing decades the contributors to the science occur with greater frequency and the curvature increases, approaching more and more a vertical line. Following van Helmont we note Glauber, one of the earliest advocates of mineral manures; Boerhaave, the first to investigate carefully the chemical composition of plants; Hales, to whose "Vegetable Statics" a previous reference has been made; Margraff, a great student of plant constituents and the discoverer of beet sugar; Ingenhousz and Priestley, who made the first studies upon assimilation; until finally, after passing a number of less prominent chemists, we come at the close of the eighteenth century to the name of Lavoisier, the first to give a clear explanation of respiration, the first to set forth the fundamental law of the cyclic relation between the processes of plant and animal life and the first to make calorimetric studies upon the production of animal heat. Following the constructive work of this great discoverer the names of the contributors to agricultural chemistry come so rapidly that in the thirty years subsequent to Lavoisier's death more new knowledge was acquired than in all previous time.

This rapid sketch of the progress of agricultural chemistry brings us to the year 1824, so momentous for chemistry and agriculture, when Liebig established his laboratory at Giessen, and it will repay us for a moment to consider an interesting fact relating to the career of this chemist. The first years of Liebig's activity at Geissen were spent in zealous cooperation with his friend, Wöhler, in the study of certain problems of plant and animal chemistry, the most important of these being the investigation upon amygdalin, the first of the glucosides, and that upon uric acid. It was during this very productive period of organic research, when the doctrine of compound radicles and other fundamental theories were established, that Liebig was led to consider the practical bearing of the new discoveries in chemistry upon agriculture—the oldest of the human arts. This gradual change of interest from organic to agricultural chemistry was viewed by some of Liebig's friends with apprehension. When Dumas, the victor over Liebig in the famous substitution controversy, asked his rival rather tauntingly how it happened that he came to change so completely from organic to agricultural chemistry, Liebig replied in a bantering way, "I have withdrawn from organic chemistry because with the theory of substitution as a foundation the structure of chemical science can now be built up by workmen; masters are no longer needed." This ironical retort must not be taken too literally; yet it serves to illustrate the completeness with which Liebig had transferred his attention to agricultural chemistry.

We should perhaps consider at this point the scope of the science which Liebig and his followers brought into so great a prominence during the eighteen forties and fifties. The admirers of that delightful Connecticut essayist, "Ik Marvel," will recall in his "Farm of Edgewood" a very entertaining chapter in which the author denies the existence of any such science as agricultural chemistry.

> People talk of agricultural chemistry [he writes] as if it were a special chemistry for the farmer's advantage. The truth is (and it was well set forth, I remember, in a lecture of Professor Johnson) there is no such thing as agricultural chemistry, and the term is not only a misnomer but it misleads egregiously. There is no more a chemistry of agriculture than there is a chemistry of horse-flesh, or a conchology of egg-shells. Chemistry concerns all organic and inorganic matters; and if you have any of these about your barnyards, it concerns them; it tells you—if your observation and experience can't determine—what they are. Of course it may be an aid to agriculture; and so are wet weather, and a good hoe, and grub, and commonsense and industry.''

There was always much truth concealed in the levity of "Ik Marvel" and we may indeed well ask ourselves why we speak so constantly of agricultural chemistry and so rarely of agricultural physics or agricultural meteorology. In fact, when we review the titles of the classic books upon the subject, we note an apparent hesitancy on the part of many authors to employ the term "agricultural chemistry." Gyllenberg's ancient treatise, the oldest of all, "The Natural and Chemical Elements of Agriculture," Boussingault's "Rural Economy" and Liebig's "Natural Laws of Husbandry" imply much more than chemistry; Dana's "Muck Manual," Norton's "Scientific Agriculture" and Johnson's "How Crops Grow" are similar illustrations on the part of American authors. It was principally due to the example of Davy, Lawes and Gilbert, Johnston and other English authors that the term "agricultural chemistry" came into extensive use.

Agricultural chemistry in its present generally accepted meaning treats of the composition of soils, crops and animals and of the mutual chemical relations of these in so far as they concern the production of the means of human subsistence and comfort. Like "municipal chemistry," "military chemistry" and similar general expressions, it is a comprehensive term which includes not only much of chemistry but touches also upon mineralogy, physics, meteorology, plant and animal physiology, mycology and other correlated sciences. The unqualified expression, "agricultural chemistry," is in fact so limited for the field which it is supposed to cover that we can well understand the preference of the older writers for more general terms, such as "rural economy" and "natural laws of husbandry." There is no field of applied chemistry which is broader in its scope or more comprehensive in the circle of its numerous bearings than that pertaining to agriculture. Consider for a moment the relationships of plant to soil and of animal to plant, the compensating balance between the processes of assimilation and respiration, the interplay of chemical, physical and biological forces which produce soil fertility from minerals and from the residues of plant and animal life. The comprehension in its numerous details of a science which involves such complicated factors as these requires a broadness of view that is not found in a narrow specialist. The great chemists who have been interested in husbandry, such as Saussure, Davy, Chaptal, Boussingault and Liebig, were men of broad scientific culture who were attracted to agriculture by the universal character of its appeal. The chemists who gave distinction to early agricultural research in the United States possessed a similar breadth of training. They were men of the type of Johnson, Goesmann, Hilgard and others who established the first state agricultural experiment stations and who, although chemists by profession, could realize that the greatest opportunity for service and progress in agricultural research is in the borderland where chemistry comes into contact with other sciences.

No better illustration can be given of the qualities necessary for producing a successful agricultural chemist than is furnished by the career of Dr. Goessmann. His intimate schooling in the fundamentals of organic chemistry and his technical experience in sugar and salt manufacture enabled him to give agricultural research a practical as well as a scientific trend. Probably no chemist ever succeeded so well as he in the difficult task of combining these two mutually repellent spheres of activity—regulatory work and scientific research—so that we find him simultaneously engaged in inspecting and analyzing commercial fertilizers and in investigating the physiological effect of special chemical manures upon the carbohydrate content of different fruits. His researches upon sorghum and sugar beets, fruit culture, ensilage making, vegetable production, forage crops and animal feeding gave an impress to the character of the work which many experiment stations took up in the early years of their formation. No one had a clearer idea than he of the importance of constantly correlating the work of the field with that of the laboratory or a keener realization of the varied applications of chemistry to all the phases of agricultural research.

As we compare the achievements of Goessmann and his compeers with those of later workers it would seem as if chemists, with the passing of these pioneers, no longer exerted a controlling influence in agricultural science. The first directors of our state experiment stations were mostly chemists, and the problem of chemical fertilizers, to which they gave so much attention, was successfully solved. Has chemistry, with the solution of this great practical problem, ceased to play an important rôle in American agricultural research or have other sciences, hitherto neglected, attained a more commanding position? A brief survey of American agricultural research may help us to answer this question.

According to the latest compilation of the Office of Experiment Stations of the U. S. Department of Agriculture, there are 5,240 research projects now being conducted by the different state experiment stations. Of these, approximately 31 per cent. are classified as relating to field crops, 17 per cent. to horticulture, 9 per cent. to plant pathology, and 8 per cent. to entomology. Over 60 per cent. of the research projects of our agricultural experiment stations relate to crop production or protection, while only about 20 per cent. pertain to the production, nutrition and diseases of farm animals. The major stress which is placed upon crops by our experiment stations is rightly directed, the approximate total value of farm crops and animal products for the United States during 1923 being, respectively, ten and six billion dollars. Of the remaining agricultural projects classified by the Office of Experiment Stations, approximately 10 per cent. relate to soils and fertilizers and 10 per cent. to a miscellaneous group, comprising agricultural economics, engineering, technology, forestry, chemistry, bacteriology and meteorology. In this large list of over 5,000 projects only 76, or 1.4 per cent., are classified under chemistry, these relating principally to the composition of plant and animal products and to methods of chemical analysis. This statistical review of American agricultural research is sufficient to show that although chemists may possibly excel in point of numbers upon the staffs of our agricultural colleges and experiment stations the final aims of agricultural research are but seldom chemical in themselves.

This brief survey we have made does not indicate, however, the proportion of agricultural research projects in which chemistry plays a cooperating part. If the various projects under soils, fertilizers, insecticides, nutrition, etc., which in any way invoke the assistance of chemistry be enumerated, they are found to make up over 20 per cent. of the total. A careful review of the situation shows that the rôle of chemistry in agricultural research is not diminishing but increasing, although the results are neither so spectacular nor so strikingly remunerative as in the days of fertilizer examination. Agrarians, horticulturalists, entomologists, pathologists, technologists and other agricultural specialists are employing chemistry to an ever-increasing extent in the solution of their respective problems. If chemists in the past few decades have lost the prominence which they once held in agricultural research it is because they have permitted others to lead in the work of scientific collaboration. Extreme specialization may perhaps have narrowed our vision to the point of overlooking the fact that chemistry in its relation to agriculture is not an end but a means, and thus of neglecting the opportunities in that fertile region where chemistry and the other sciences overlap. It is in the coordination of chemistry with other sciences that the agricultural chemist of the future must be trained. Such an attitude brings not a relinquishment but an enlarged conception of the relations of chemistry to agriculture.

The field is so vast that it is impossible to indicate in this brief address the nature and variety of the problems which await solution. The agricultural chemist is not concerned, as in the early days, with the mere chemical analysis of soils and crops and animals, but rather with the dynamic rôle which is played by the constituents in the soil solution and in the fluids of the living organism. He does not consider the question of fertilizing for the increased production of grain or seed alone, but also for the increased yield of oil or carbohydrate or protein. The old problems of the chemical composition and rôle of humus need to be reopened; old experiments with fertilizers and cattle feeds need to be reviewed and repeated in the light of newer knowledge. What are the effects of the lesser studied elements, such as boron, iodine, fluorine, manganese, aluminum, etc., upon the growth and function of plants and animals? What are the factors which control the acidity or alkalinity of soils and their influence upon the production of different crops? What are the chemical, physical and biological functions of the numerous bacteria, fungi, protozoa and other microorganisms that inhabit the soil? For the solution of these and the many other important problems which might be named, the agricultural scientist needs to equip himself with the latest methods of research and to summon to his aid the resources and appliances of every science, but of chemistry foremost among all. For, after all is said, the chemical elements in their various combinations are the basis for the material existence of soils and crops and animals; eliminate these and the whole fabric of agriculture dissolves, leaving "not a rack behind." No scientist is so competent as the chemist to understand the fundamental laws which underlie the processes of agriculture and no scientists have described so well as chemists the operations of these laws in the classic works upon husbandry.

This new laboratory, which is dedicated to the service and advancement of agriculture, is for the purpose of instruction as well as of research. However great may have been the increase in chemical knowledge during the past century, it is doubtful if the spirit or method of instruction is any better than that employed by Liebig in the laboratory which he established at Giessen just a century ago. It is fittingly described by one of his pupils, the late Professor Johnson, in an address before the Connecticut Board of Agriculture in 1873, when in speaking of the critical method of scientific inquiry, he said:

> It was in that spirit that Baron Liebig instructed the students who gathered in his laboratory from all quarters of the globe to learn the art of making discoveries in science. They were set to testing the truth of some idea, or the connection of some fact, or else to make new observations and discover new facts to lead to new ideas. It was not the novelty or the glory of discovery, but the genuineness of discovery that was regarded as of first importance. He listened patiently to their accounts of each day's progress, considered their plan of investigation, saw the apparatus or arrangements they devised, witnessed the observations they were led to, and heard the theories they imagined. He encouraged, but he criticized. He asked questions, suggested doubts, raised objections. His students were required not only to collect facts, or supposed facts, and to connect and complement them by comparison, analogies and theories but they were made to attack their theories in every weak point and to verify or disprove the supposed facts by scrutiny from every side.

The fruits of Liebig's teaching are a sufficient proof of the value of this method of instruction.

What lessons are so suggestive as the subject-matter of agricultural chemistry for arousing the interest and intelligence of youth! The basic principles of life and culture are here involved and the teacher has at his command a multitude of themes touching all the commonplace phenomena of our daily existence. Such themes have inspired the greatest thinkers, for they form the warp which holds together the fabric of our civilization. It was Emerson who once exclaimed:

> What would we really know the meaning of? The meal in the firkin, the milk in the pan—show me the

ultimate reason of these matters; show me the sublime presence of the highest spiritual cause lurking, as it does lurk, in these suburbs and extremities of nature; let me see every trifle bristling with the polarity that ranges it instantly on an eternal law;—and the world lies no longer a dull miscellany and lumber room but has form and order.

The field of service to which this laboratory is dedicated is fertile; the outlook is vast; the future is full of promise, for never have the opportunities of applying chemistry to agriculture been greater. The reward, moreover, is certain, provided its devotees preserve the spirit and breadth of vision which actuated the founders of our science.

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## PREPROFESSIONAL TRAINING AS REVEALED BY THE NEEDS OF THE PHYSICIAN[1]

THE need of premedical training, as a foundation for a medical education, is evident, and its importance is recognized. What is not so clear, however, and what is not so easily decided, is how broad and deep and firm a foundation is required for the medical superstructure. Just as any building must always be considered, as a whole, before the type of foundation can be determined, so, in the same way, the problem of medical education, in its entirety, must be thought of, the better to understand and appreciate the kind of premedical instruction necessary. It is, therefore, hoped that by calling your attention, on the one hand, to what the finished product of a medical school should be, and, on the other hand, to the deficient product that is produced, you will be helped to realize the urgent need there exists for certain modifications of the present-day premedical courses.

The ultimate aim of the science and art of medicine is (1) to preserve or restore health, (2) to prolong life or (3) to alleviate suffering. The most important object of medical education is to prepare young men and young women to carry out these aims, *i.e.*, to qualify them to practice medicine. Since there is such a misunderstanding as to what the practice of medicine implies, and since the premedical teacher should be familiar with what being a physician means, it might not be amiss, at this point, to define it. The practice of medicine implies (1) an ability to diagnose the patient's ailment, and (2) an ability to take care of the patient, *i.e.*, to treat him by any one or more of all the known and recognized preventive and remedial measures that the diagnosis might indicate and suggest. Ability to diagnose is, of course, dependent upon a thorough knowledge (1) of the fundamental sciences—normal and pathological physiology, chemistry and anatomy, and (2) of the exciting and predisposing causes of disease. Ability to treat implies first of all an ability to diagnose, because diagnosis indicates and suggests the kind of treatment necessary, and second it presupposes a knowledge of therapeutics which means the taking care of a patient by any one or more of the following measures: (1) preventive, (2) suggestive, (3) dietetic, (4) physical, (5) hydrotherapeutic, (6) medicinal, (7) mechanical, (8) operative, etc., etc. It further assumes a proper and sympathetic attitude towards the patient. In the building up of a medical education, therefore, therapeutics is the ultimate aim. All other subjects are important only in so far as they throw light on it. In other words, the young doctor, the product of the medical school, should be a humanized being, one qualified by education and training (1) to determine, by diagnosis, what measure or measures are indicated, and (2) to faithfully carry out such treatment, or, if he can not do so himself, he will arrange that another, qualified, shall do it for him.

One need not travel far nor search long for evidence that the product of the present-day medical school is being found wanting. While it is clear there is trouble, it is not easy to localize it and determine its cause. Undoubtedly, the public is to blame on the one hand, and, on the other hand, the schools are certainly at fault. Unlike the successful business corporation which is vitally interested in the turning out of its wares in the form of finished products, because that means satisfied consumers and continued success, the schools have been more or less indifferent to the needs of their graduates, their interest in these ceasing largely at commencement time. And so we find, among others, the graduate in medicine, handicapped by his training or lack of training, unable to do full justice to his patients and to himself.

Though irregular practitioners and patent medicine venders have always been with us, and probably always will be, it is a fact that they are thriving to-day as never before. The United States Bureau of Census, in its 1919 report, gives figures which indicate that the value of patent medicines and compounds increased from $83,771,154.00 in 1909 to $102,463,400.00 in 1914 and to $212,185,700.00 in 1919, a percentage increase in the ten-year period, 1909 to 1919, of approximately 250 per cent. B. C. Keller, in an article, "Laity's idea of physician," ap-

[1] Read before the Association of Urban Universities, November, 1923.