SCIENCE

Vol. 74 — Friday, September 18, 1931 — No. 1916

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SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. McKeen Cattell and published every Friday by

THE SCIENCE PRESS
New York City: Grand Central Terminal

Lancaster, Pa. — Garrison, N. Y.
Annual Subscription, $6.00 — Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

PLANT SCIENCES IN THE SHEFFIELD SCIENTIFIC SCHOOL[1]

By Professor RUSSELL H. CHITTENDEN
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As a noted English scientist, Sir Walter Fletcher, has said recently, "In the field of research the whole body of knowledge has been advancing so fast that the individual workers, at their various points on its growing borders, are in danger of becoming so far separated one from another in the very course of their advance as to lose the fertility that comes from the easy exchange of ideas and methods." Hence, the value of such gatherings as this, by which workers in specialized fields can compare methods and results, gain perhaps added enthusiasm and encouragement, and go forth with renewed vigor in the prosecution of their own particular studies.

As a physiological chemist I like to think in broad terms of physiology as a study of the functions of living organisms, animal and vegetable; a study of the functions of living matter irrespective of its origin. Differentiation of these functions, as we all know, is determined largely by the character of the methods that have to be followed in their study. Thus, we emphasize chemical physiology and physical physiology mainly because the functions concerned are explainable by chemical laws or by physical laws, their study involving on the one hand the intricate methods of the chemist, while on the other the methods of the physicist are called for. Again, we stress the terms animal and plant physiology, recognizing thereby the innate differences in function characteristic of the two forms of life, understanding full well that in the higher forms individual functions can be studied successfully only by different technical methods applicable to each type. If we talk about physiological chemistry or biochemistry we are giving expression to the fact that owing to deepening knowl-

[1] An address delivered at the Conference for Investigators Interested in the Chemistry and Physiology of Plants, at New Haven, Connecticut, June 5, 1931.

edge there is a large accumulation of chemical data of the greatest physiological importance and significance which chemistry has been, and still is, making available. Such data have value largely as they throw light on, and help explain, physiological processes.

While to-day knowledge of plant physiology has progressed so far as to cover a wide field, with trained workers constantly contributing new facts and theories based on experimental work of diverse character, it may not be amiss to look back to the days of simple things, when in this country experimental work—laboratory work—was almost an unknown quantity. It is worth remembering that the first laboratory of physiology for the use of students in the United States was established in 1871 at the Harvard Medical School, while the first laboratory of physiological chemistry for instruction and research in this country was started here at Yale, in the Sheffield Scientific School, in 1874. In this same year, Sir Michael Foster, at that date a young instructor in University College, London, began the teaching of practical physiology and rudimentary physiological chemistry in England, his being the first laboratory course in these subjects offered in that country.

From these statements it is obvious that experimental work in physiology could have had few followers fifty years ago in the United States. Chemical laboratories, however, were much more numerous, and experimental work along chemical lines was gaining rapid headway at various educational centers, and consequently such work as had been attempted in plant physiology was essentially of a chemical character. Here at Yale the first appointment made in plant physiology was in 1846, at the time when what is now the Sheffield Scientific School was started. The incumbent of the professorship then established was John Pitkin Norton, and the appointment read "professor of agricultural chemistry and animal and plant physiology." It is apparent from the title that he was in reality professor of scientific agriculture, but his training in chemistry and in botany had been unusually broad and thorough for those days. For several years he had worked in chemistry at Yale with Silliman and he had spent one year at Harvard. After this preliminary training, he was two years with Professor Johnston in the laboratory of the Agricultural Chemical Association at Edinburgh and a year in the laboratory of Professor Mulder at Utrecht. Probably no American at that date had ever enjoyed such opportunities for scientific training in agriculture as he had experienced.

While abroad, he had made several contributions—the result of original work—to the British Association at Cambridge which had attracted much favorable comment. Most noteworthy was his study of the oat presented to the Highland Agricultural Society of Scotland, for which he received the prize of fifty sovereigns offered for the best piece of work on the subject. This paper was republished in the *American Journal of Science,* its scope being indicated by the following quotation: "Commencing with the young plant, he followed it through its successive stages of growth and development to its maturity, the many analyses giving the composition of the oat from the different parts of the plant separately, *viz.,* the leaf above and below, the stalk, the knots, the grain, etc., besides the organic constituents of the grain." This without doubt was the most thorough chemical investigation of the oat ever made up to that date.

Norton came to New Haven with the expectation that he would be able to devote much of his time and energy to original investigation, for which he was so admirably fitted, but on returning to America he found himself obliged to play the part of a pioneer if he would help forward the development of scientific agriculture in this country. Unfortunately after five years of arduous work his career was suddenly closed by death.

Norton's successor in the Scientific School was John Addison Porter, appointed in 1852. He was a graduate of Yale, and he had enjoyed a long training in chemistry and physiology under Liebig, so that he had a high appreciation of the importance of agricultural chemistry and its application in the cultivation of crops.

More significant in a way was the appointment in 1856 of Samuel W. Johnson, who had worked for a long period with Liebig, his title being professor of analytical and agricultural chemistry. For many years he gave an annual course of lectures to graduate and undergraduate students of the Sheffield Scientific School upon agricultural chemistry and the physiology of plants. This course of lectures attracted so much attention both here and abroad that he was invited to deliver a course of lectures on these subjects in Washington, at the Smithsonian Institution. Later, in 1868, much of this material was brought together in book form under the title "How Crops Grow," dealing particularly with the chemical composition, structure and life of the plant. This book was followed two years later, 1870, by "How Crops Feed," which likewise gained wide attention. As an illustration of the great value of these two books it is only necessary to add that they were translated into German, Swedish, Russian and Japanese, while the first was also translated into Italian.

Johnson was not preeminent as an investigator. His strength lay in his breadth of knowledge, critical judgment and keen analytical mind, which fitted him well for the service he felt called upon to perform, *viz.*, the development of truly scientific methods for the advancement of agriculture. He was, as you doubtless know, the father of the agricultural experiment stations in this country, and his influence in agriculture was dominant for many years. Such original work as he carried on in the field of plant physiology had to do mainly with the fixation of ammonia, nitrification and the assimilation of complex nitrogenous bodies by vegetation. I recall a paper published in 1866 which dealt with the nutrition of plants, where, by feeding, under suitable conditions, uric acid, hippuric acid and hydrochlorate of guanine, he found that such amides resulting from the disorganization of protein compounds, as well as ammonia salts and nitrates, are capable of direct passage into the plant and there serve for the reorganization of albumen, etc.

I must also refer to William H. Brewer, who like Johnson was an early graduate of the Sheffield Scientific School and who for nearly forty years (1864–1903) was professor of agriculture here. A student of botany at Heidelberg and of chemistry with Bunsen, later with Liebig at Munich, a student of both sciences at Paris, he was broadly trained in the sciences underlying agriculture. Further, from 1860 to 1864 he was associated with J. D. Whitney on the first scientific survey of California, making a special study of the flora of the state, the results of which were published at Cambridge in conjunction with Sereno Watson in 1876, under the title "The Polypetalae." Brewer was a connecting link between chemistry, botany and forestry for many years and while he did no original work in plant physiology he was one of the influences here that helped to arouse interest in the sciences upon which scientific agriculture depends.

Also connected with this earlier generation was Daniel C. Eaton, professor of botany in the Sheffield Scientific School from 1864 to 1895. An enthusiastic worker in his chosen field, he trained many men in botany who like their teacher were interested primarily in structure and classification rather than in plant physiology.

It may seem somewhat foreign to the interests of this group of workers to recall these men of earlier times, for they were not, strictly speaking, what we should call to-day students of plant physiology, yet they created an atmosphere here favorable for the growth of knowledge contributory to a clearer understanding of physiological problems in relation to plant life and growth. It was natural in this new country that plant physiology should develop gradually from studies related to scientific agriculture. Successful agriculture was dependent upon the growth of the crops. If the crops failed it meant disaster to the farmer and to the community, while increase in yield frequently meant prosperity. Naturally, therefore, attention was focused largely upon studies which promised help in securing a rich crop, and it was the work of the chemist that was called for mainly.

As time went on, however, there gradually developed a more scientific spirit, study for the sake of truth, the gaining of knowledge to broaden the understanding of nature's ways without regard to practical application. To-day, the study of plant life by chemical and physical methods is yielding a rich harvest, but in Germany, for example, we look back to such men as Liebig and Ritthausen, from whom in the earlier years came the inspiration and the stimulus upon which present-day progress is more or less dependent, and in this country we may well glance backward to the early workers in chemistry, botany and agriculture who were likewise helpful in preparing the way for the advances in knowledge witnessed in this generation.

No better illustration of the scientific value of study and research for the sake of increasing knowledge can be found than in the work of Thomas B. Osborne, during the years 1886–1928, as research chemist at the Connecticut Agricultural Experiment Station. His life, as you know, was devoted almost entirely to studies in protein chemistry, especially proteins of vegetable origin, his interest in this subject having been stimulated in part by Professor S. W. Johnson. To Osborne and his coworkers we owe much of our present-day knowledge regarding the chemical character and composition of the proteins of different plants, the partition of nitrogen and more specifically the proportion of the various amino-acids present in different vegetable proteins. Especially noteworthy was his work carried on with H. Gideon Wells, on the anaphylaxis reaction as a means of establishing chemical identity, resulting among other things in the conclusion "that each seed contains several chemically distinct proteins, and that no two seeds, unless very closely related botanically, contain chemically identical proteins."

Equally interesting was the conclusion that there must be an almost infinite variety of vegetable proteins, the anaphylactogenic property of a protein being determined by its chemical structure and not by its biological origin. Again, the researches of Osborne and Mendel on the nutritive value of the vegetable proteins have contributed largely toward establishing the close relationship between the chemical constitution of the proteins and their biological value. We have come to see that growth in the animal body is dependent upon the presence in the food of certain amino-acids, such as lysine, cystine and tryptophane, these being imperatively needed for the building of tissue and for making good the losses of cellular material. Hence, proteins which are lacking in these indispensable amino-acids, or contain them only in small amounts are physiologically inferior proteins, not fitted to meet the needs for proper growth.

But I must not continue longer. To cultivate research and thus promote the advancement of knowledge, to bring to light a new truth, in whatever the field of endeavor, is to the true scientist one of the great joys of life. As a recent writer (A. V. Hill) has expressed it: "In scientific research we work and work, sometimes for months and years, in digging a tunnel with no apparent results; then suddenly comes the supreme joy of life—daylight begins to glimmer at the end, and in a few minutes we see that nature, after all, has not played us false."

THE NEED OF COOPERATION IN BIO-CHEMICAL RESEARCH[1]

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A CONTINUOUS teaching and research contact with scientific workers in an academic atmosphere, such as has prevailed at Yale for the last thirty years, is an experience not to be enjoyed by many teachers. An active man could hardly fail to have been influenced by what has happened within this period of time, and also benefited by the many associations that such a professional career offers. It has been the writer's good fortune to have enjoyed such an experience, and he is not able to properly express his appreciation for the satisfaction and pleasures which he has enjoyed in many ways during the past thirty-one years through his associations with graduate students and cooperative undertakings, in the promotion of Yale's activities and productions in chemical research. Although it is nearly one third of a century, it has all happened so quickly that it is difficult to realize the significance of the advances that have been made in our knowledge of the field of chemical science and to comprehend the possibilities of discovery in the newer fields of research which have been opened up to the organic chemist within this period of time. There is no doubt that the younger men who have in their control the destinies of the next thirty years of scientific service have before them opportunities for successful accomplishments which are just as promising as the future held out to young investigators at the beginning of this century. We older men do not begrudge these new recruits to our ranks their rich opportunities, but we wish them the best of success, and with the hope that our accomplishments of the past thirty years will have made their course less difficult to follow, their problems easier to understand, and their methods of attack and conclusions more exact and definite.

[1] An address delivered at the Conference for Investigators Interested in the Chemistry and Physiology of Plants, at New Haven, Connecticut, June 5, 1931.

The last half century has seen a great advance, not only in the development of every branch of the natural sciences, but also in the number of these branches. It has been a growth which has necessarily led to much specialization, but not without great benefit to all the major divisions of the natural sciences.

The names of the new sciences, for example, such as geochemistry, biophysics, biochemistry, astrophysics, psychophysics, and many others, which we have not time to mention here, show that these new subdivisions are merely the overlapping of two or more of the older branches of science. Their fields of operations are the border lines of different sciences where the phenomena of natural interest are dependent on fundamental laws characterizing the special sciences involved. What has been the result of this overlapping?

(1) One result has been a breaking down of the old boundaries of science and a more general recognition of the scope and application of the theories and principles of the science of chemistry. To-day there is no definite boundary between chemistry and physics, between chemistry and crystallography, between chemistry and metallurgy, or between chemistry and technology.

(2) It has meant also that we have developed a highly specialized knowledge which now requires a much broader basis of scientific training than it did thirty years ago. As a result we have been called upon to give more thoughtful consideration to the preliminary training of those who desire to prepare themselves for professional careers and to pay more attention to the proper coordination of fundamental course subjects and to emphasize the dual nature of the major scientific projects now calling for investigation and solution.

(3) And, finally, it has caused to be evolved a new