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THE INSTRUMENTS OF PLANT BIOLOGY[1]

By Dr. H. A. SPOEHR

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RESEARCH and teaching are the warp and woof in the complex fabric of education. The necessity of adjustment to the new world which scientific thought is creating is the joint responsibility of the teacher and of the researcher. Institutions devoted to research, in order to remain virile, must from time to time reexamine their aims and objectives and effect a restatement of their program in conformity with the advancement produced by their own efforts and with that of modern thought. The dedication of this building marks another step in the progress of biological science in the Carnegie Institution of Washington.

Our institution has since the inception of its activities supported various research projects in the plant sciences. These have been devoted mainly to special problems, and from time to time new projects have been undertaken which were organized either independently or in conjunction with existing ones. In 1928 the Division of Plant Biology was formed to embrace all these projects operating in the western United States, with the view of facilitating cooperation between the workers in these groups and with other activities of the institution, for the unification of research programs and of administrative arrangements and to provide a basis for future development.

The Division of Plant Biology is thus composed of a number of sections constituting relatively small groups of workers who are devoting their attention to special projects. These sections are located according to the requirements of the particular scientific problems under investigation.

Portions of the western United States are of inestimable value for intensive study of the natural proc-

[1] Address at the dedication of the central laboratory of the Division of Plant Biology, Carnegie Institution of Washington. This building is located on the campus of Stanford University, and dedication exercises were held August 27, 1929, Dr. Henry S. Pritchett, vice-chairman of the board of trustees of the Carnegie Institution of Washington, presiding.

esses and successions of large plant communities, because here these still exist undisturbed by the direct and indirect influences of man. These virgin areas make possible the study of the factors and conditions which are determinative for the existence of specific biologic units.

The Desert Laboratory, at Tucson, Arizona; the Coastal Laboratory, at Carmel, California; the Alpine Laboratory, on Pike's Peak, Colorado, and a number of experimental bases at several places in the western United States offer unusual facilities for the investigation of problems in which particular organisms, the climatic complex or edaphic conditions play an important rôle. It is the aim of the division that the laboratory investigations at these stations supplement the field studies for which the locality offers special opportunity.

We now have a central laboratory for work on some of the more general problems which require more elaborate laboratory apparatus and equipment. This laboratory offers opportunity for the development of more effective correlation and unification of effort of the outlying stations. The site of the present developments includes five acres of land leased from Stanford University by the Carnegie Institution of Washington, and the provisions of the lease make it possible to increase this up to twenty acres as occasion requires. These developments embrace the laboratory building of reenforced concrete construction, the adjoining preparation house, the glass-house, with head-house and the transplant and culture gardens. In the basement of the laboratory are facilities for optical and photochemical work; here are also the shop, heating plant and ample space for storage. The first floor is equipped for biochemical investigation; on the second floor are the library, the laboratories for experimental taxonomy and cytological work in connection therewith, and two smaller laboratory rooms. The preparation house has been built for use in the isolation of physiologically important compounds. This work entails the handling of relatively large quantities of plant material, large amounts of highly inflammable solvents and the use of noisy machinery. Therefore, it was deemed best to locate this work in a separate building. The development of the transplant gardens and greenhouse has permitted the transfer here of practically all the perennial coastal transplants heretofore temporarily held at other stations. For investigations entailing the culture of plants, either in the open or under glass, the conditions on the Stanford campus are exceedingly favorable. The laboratory as well as these gardens are also offering the opportunity for undertaking here cooperative experimental studies on several basic problems in connection with members of other scientific institutions in different parts of the world.

As Millikan has stated, "A science, like a planet, grows, in the main, by a process of infinitesimal accretion . . . each new theory is built like a cathedral through the addition by many builders of many different elements." If this be true of the relatively simple and severe structure of physics, it is even more so of the tremendously intricate science of biology. The biologist is confronted with such a multiplicity of phenomena and with such a diversified aggregation of physicochemical systems that he can hope to build a sound and well-grounded structure only through the contributions of a variety of craftsmen.

The chemist and physicist have detected and studied the forces with which they are dealing by means of instruments of their own construction. The deflection of a galvanometer indicates the flow of an electric current and its use has taught us much of the nature of electricity. But such knowledge as we now have of the nature of electricity has been gained through the correlation of observations from various systems or instruments designed to manifest electrical phenomena. This knowledge would be very limited if the physicist and chemist had confined themselves to the movements exhibited by the galvanometer or to its construction and material composition, significant as these are.

The biologist is primarily interested in the forces of organic nature. Manifesting these forces are the multitudinous forms of plants and animals. These are the biologist's instruments, for they alone exhibit the phenomena which are the center of his interest. It is the initiation, correlation and succession of the changes manifested by his instruments which he is endeavoring to understand. It is our aim to approach the problem of interpreting the manifestation of life forces from various angles. The behavior of plants under natural and controlled conditions, their detailed description and orderly arrangement, their physical components, their chemical composition and the physical and chemical forces involved in their functioning all contribute, when correlated, to the same fundamental problem. The biologist is not unmindful of the fact that his conceptions of life processes are limited and that he is still using largely empirical methods. The discovery of the *mechanism* in any of the complex of functions of a living organism, even when described in terms of physics and chemistry, is not the real base of the problem, no more than the swing of a galvanometer reveals the nature of electricity. Yet the description of mechanisms must ultimately contribute to the solution in the same manner that the highly technical and involved experiments of the physical sciences have contributed to an understanding of the nature of electricity.

Obviously every phase of plant science can not be intensively and adequately pursued within a single organization. It is our aim to concentrate upon a few problems of fundamental significance and, with the careful recasting of research programs, to correlate aims and unify effort. On this basis the work of the division is to be conducted in relatively small and elastic units, the particular needs of the investigations determining the organization of personnel and equipment.

At the present time a number of fundamental problems are being approached in different localities and from different view-points. The series of investigations centering at the Alpine Laboratory and the field stations at Santa Barbara has resulted in an interpretation of the development of vegetation in which plant complexes are treated as organic units which have developed in response to environmental conditions. This method stresses the importance of dealing with the biotic community as a unit instead of treating plant communities as separate entities. From such a view-point it may be possible to gain a broader prospect of plant aggregates as the result of many involved and mutually interacting influences. Thus the complex of climatic and edaphic environment, regular and cyclic, over periods of time is expressed in the nature of the vegetation.

We can at best see but a very brief span in the life history of most of the existing plant societies. What they are to-day is to a large measure the reflection of past experiences. The studies in paleobotany which are being carried out within the division have helped to explain certain peculiarities of distribution which, for example, characterize the modern forests of western America. The fossil record of the redwood indicates that it was formerly distributed over most of the northern hemisphere, including Manchuria and Siberia. The influences which have brought about the greatly restricted range of this tree at the present time seem to be related to changes in climate. The physical history of the past and its influence on plant developments are thus being revealed by the study of fossils.

The arid regions of North America are characterized by certain extremes in climatic and edaphic conditions and consequently present many highly specialized and diversified forms of life. The relation of these conditions to the physiological behavior, distribution and evolutionary history of the flora has constituted most of the work that has been pursued at the Desert Laboratory. Very marked differences in the relations to the environment are exhibited by different species of desert plants, indicating divergent adjustment to external conditions and frequently diverse physiological behavior. This has been followed more particularly in the water economy of desert plants through both laboratory and field investigation. Observations on the establishment of new individuals, on the course of their developments and on the precise changes in the composition of vegetation have been carried on continuously over a period of many years. Correlated with laboratory experiments and anatomical studies, measurements of growth have been made on a variety of plant forms. These measurements, especially on trees, in different habitats, have now been made over extended periods of time.

With the object of contributing to the portrayal of the natural methods or processes which in the past have been operative in organic evolution, an elaborate series of experiments is in progress extending through the great range of natural conditions from the Pacific Coast line over the Sierra Nevada. Taxonomic questions, raised by herbarium studies and involving the characters commonly used in classification in prominent groups of our larger western American plant families, are subjected to experimental and statistical test wherever practicable. The methods are of the transplant type and, briefly, consist in moving diverse but closely related forms into a uniform environment and of moving a single form into diverse environments. These experiments, centered at this station and pursued at five field stations of decidedly different climatic complex, are arranged to give information regarding the stability or flexibility of different plant characters, particularly those which are the criteria used in plant classification. Experimental methods are also being developed to distinguish between fixed characters and temporary modifications resulting directly from environmental influences.

There has been a wide-spread and constantly growing movement in biology to attempt to resolve the complex phenomena of organic nature into simpler systems and mechanisms which permit of exact treatment. This movement has its roots in a deep-seated, though often not frankly recognized, faith; a faith that biologic phenomena are amenable to the same rigorous treatment of experiment and reason that has yielded such marvelous results in physics and chemistry. As Whitehead has stated: "Faith in reason is that trust that the ultimate natures of things lie together in a harmony which excludes mere arbitrariness. It is the faith that at the base of things we shall not find mere arbitrary mystery." Historically considered, we are only at the beginning of this movement in biology. It is only within the past half century that the sum total of knowledge in chemistry, which is essential before applications can be made, has grown to sufficient proportions to make such an undertaking promising. And there are still enormous gaps in the systematic knowledge as well as in the broader conceptions which must be filled before chemistry and physics can serve as a language to express the phenomena occurring in living things. This is the highest function which these sciences can serve. To undertake the reduction of the great heaps of biologic observations and classification to some rational system is a task which the orthodox physicist and chemist have apparently deftly avoided.

The science of organic chemistry had its origin in the study of the chemical compounds constituting living organisms. This led to problems of the constitution of highly complex carbon compounds and thence to the fruitful era of synthesis of organic compounds, resulting in the artificial production of many substances previously obtainable only from some living organism. During this period plant chemistry pursued mainly those courses which led to substances useful as food, as drugs or in the arts. Recently there has been a marked reorganization in the realm of organic chemistry. On the one hand, problems of chemical kinetics, of structure and of valence have clearly resolved into physical chemistry, and on the other, backed by a century of experience in carbon compounds, the organic chemist is again turning to the chemistry of the living organism. He is now concerned not only with the substances which may be derived from living organisms, but primarily with those substances which play a rôle in the manifold *processes* of the organism and with these processes and reactions themselves. To those who lay emphasis on nomenclature and the artificial demarkations of science he may have become a biochemist, but his modes of attacking a problem remain those of the chemist. He has retained and fostered his valuable alliances with the exact sciences of physics and mathematics. This fruitful, unifying and correlating tendency so noticeable in physics and chemistry is gradually also permeating biology. It forms the basis of a newer faith, the understanding of which grows through application.

Synthetic organic chemistry has just celebrated its hundredth anniversary. Among its achievements is the production of many substances which formerly could be obtained only from a living organism. While this was unquestionably a great advance in knowledge, it is not improbable that it will some day be regarded as a detour on the highway of organic chemistry. Incidentally, the business of the farmer and forester may be materially influenced by the fact that a not inconsiderable portion of their products will take the form of raw materials for further transformation by chemical processes rather than by simply raising the field crops or trees as at present. But thus far organic chemistry has contributed relatively little to the really fundamental problem. The interconversion of the multitudinous organic compounds has familiarized us with their properties and certain general principles of carbon compounds. *Yet the basic problem remains.* This is not the synthesis of cane sugar, proteids or fats from other organic or even inorganic materials through the drastic methods of organic chemistry, but rather *how* these substances, and ultimately also coal and petroleum, are formed in nature from carbon dioxide, water and ammonia.

These steps are far more difficult and progress is apt to be much slower than in the past era. One of the first requirements is more precise knowledge of the physical and chemical composition of our apparatus, the plant; that is, the minute physical structure and chemical nature of the systems with which we are dealing. Is it not idle to speculate regarding the processes taking place in plant cells when we have but the most rudimentary knowledge concerning the materials of which the cells are constituted? The masterly researches to which Thomas B. Osborne devoted the entire scientific activity of a long life have resulted in our knowing but a small fraction of the nitrogenous components of plant cells. Yet this knowledge constitutes one of the very few sound foundation stones of plant physiology. Until we are more thoroughly familiar with the structure and composition of the instruments which manifest the forces the nature of which we are striving to reveal our quest must needs be empirical and fragmentary.

In order finally to understand the functioning of plants and their behavior in the great complex of natural environmental influences these functions must be resolved into processes the kinetics of which can be interpreted in terms of physics and chemistry. But this task constitutes a great deal more than applying existing techniques and conceptions of physics and chemistry. Supported by the latter, the biochemist must analyze systems and interpret reactions for which no exact counterpart has as yet been found in inorganic nature. We need but refer to certain enzymatic reactions, those of amorphous "mass molecules" and to photosynthesis.

Probably no one who has spent years in an active struggle with these problems would venture the opinion that in such a method or attitude of mind we have an open sesame which will throw wide the portals of life. Experimental biology has never been favored with methods or means of approach to its problems, which permit of apodeictical statements. Yet in the vast majority of biological phenomena we are sooner or later brought squarely to face problems dealing with changes of state and transformation of materials which are clearly of a physical or chemical nature and for the solutions of which only physical and chemical conceptions apply. Even though the application of physical and chemical methods may not at once reveal the ultimate nature of life processes it constitutes an essential step in an interpretation of the dynamics of biological phenomena.

In conclusion, I wish to express, on the part of my colleagues and myself, the sincere appreciation of the thought and painstaking interest which President Merriam has given to the development of the organization and plans of this division, of the liberal support of the trustees of the Carnegie Institution and of the opportunity and splendid cooperation given by Stanford University.

SURFACE STRUCTURE AND ATOM BUILDING. II

By Professor W. D. HARKINS

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(5) *Graphical representation of the new periodic system.* A complete atom contains as many electrons as protons. If the weight of one proton (p) plus one electron (e) is taken as unity, then the atomic weight (W)[9] is supposed to give the number of protons and of electrons in the atom. That is, the symbol $(pe)_W$ represents the composition of any complete atom of atomic weight W. If P is the number of protons in the atom, then $P = W$. Let N represent, not the total number of electrons in the atom, but the number in the nucleus, then $P - N = Z$ is the *atomic number,* and $2N - P$ is the *isotopic number,* for any known or unknown atomic species.

An entirely new periodic system was revealed when two of the above variables were plotted on a two-dimensional diagram, but by far the simplest form of this system was found to be given with the isotopic number on one (Y) axis, and the atomic number on the other (X) axis. If even numbers are represented by heavy lines, and odd numbers of these variables by light lines, an extremely remarkable pattern is found to emerge (Fig. 8).

The isotopic number for any atomic species other than hydrogen gives the number of the isotope according to a system in which the lowest possible isotope of any element is given the number *zero.* For example the isotopic numbers for the known species of a few elements are: He, 0; Li, 0 and 1; Be, 1; B, 0 and 1; C, 0; Mg, 0, 1 and 2; Al, 1; Si, 0, 1 and 2; Fe, 2 and 4. If the empirical formula of any nucleus is written $(p_2e)_z\ (pe)_n$, then the subscript n gives the *isotopic number,* just as the subscript Z gives the atomic number.

The isotopic number is as important to distinguish the species as the atomic number to distinguish the element.

[9] Actually W is very close to, but in general is not exactly, a whole number. P is this whole number.

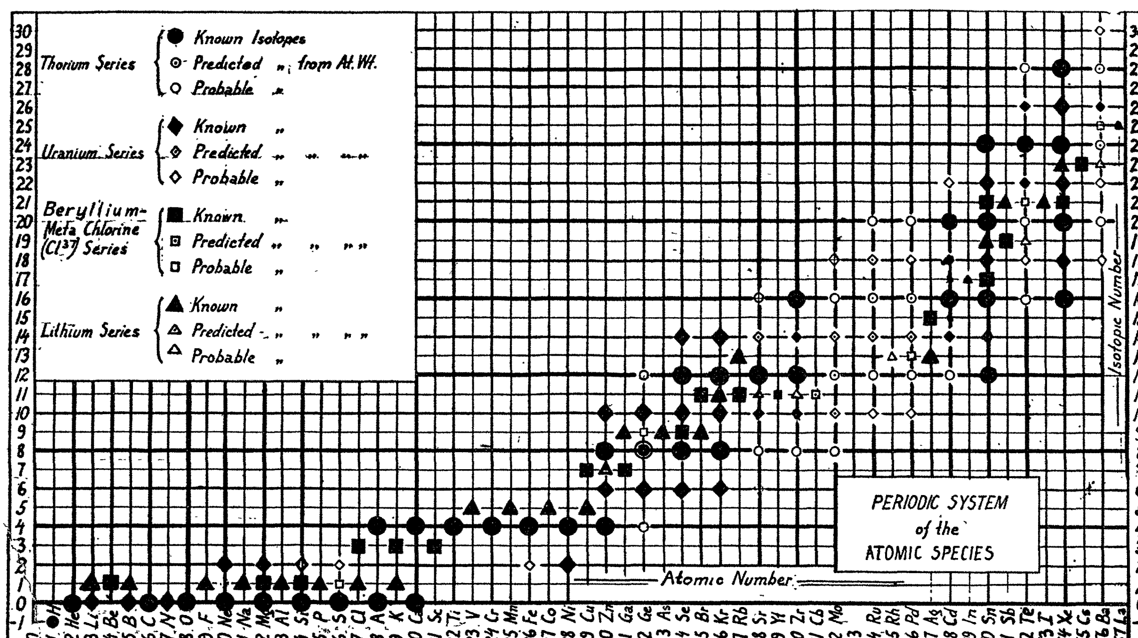

FIG. 8