value of the species or variety, and this more accurately than can be done by the ordinary descriptive terms. The discrimination of species has hitherto been dependent upon the experience and judgment of each systematist, and consequently the results have often been most conflicting and confusing. By the use of a precise mathematical criterion of species 'splitting' and 'lumping' is no longer possible and any hybrid or intergrade, which may have been described as a species or a variety, is clearly shown by its intermediate position and by the absence of isolation, while a sport is indicated by its relative fewness of individuals and its place at the extreme of variation.

The possibilities of statistical methods in the study of individual variation extends far beyond the applications here proposed. The gradual change of the specific type and of the variability of a species, the distinguishing of stable from plastic groups, the influence of environment upon specific form, and many other matters of importance to the philosophical naturalist and systematist, are in the future to be investigated quantitatively.*

* Those who desire further information on the quantitative study of species are referred to the excellent paper of Dr. F. Ludwig: 'Die Pflanzlichen Variationscurven und die Gauss'sche Wahrscheinlichkeitscurve,' in the Botanisches Centralblatt, 73: 241, 1898.

JULIUS SACHS (II).

IT was at Würzburg that Sachs first found fit opportunity to develop his talent for teaching. Too often it happens in lecture-rooms that '*man Viele sieht, die nicht da sind*,' but this did not apply to him. His fascinating, lucid expositions stimulated the students, whilst he knew well how to practically illustrate his subject. He worked incessantly at the materials for demonstrating, drew and painted a number of diagrams, and was constantly adding to his stock of dried plants, alcohol preparations, models and cultures. He considered that all should be in due relation to the subject-matter in a scientific lecture as in the acting of a play. In the winter he lectured on general botany (anatomy and physiology), and in the summer on the 'Natural History of the Plant World.' Besides this he often gave experimental demonstrations in the summer and this necessitated a great deal of work; occasionally he lectured on the history of botany and on the physiological basis of morphology. After 1874 he had a class every term for microscope work.

A great number of botanists worked at one time or another in his laboratory. The first were Dr. Kraus and Millardet (both formerly at Bonn and Freiburg). Among others attracted by him to Würzburg were Baranetzky, Brefeld, Francis Darwin, Detlefsen, Elfving, W. Gardiner, Godlewski, Goebel, Hansen, Hauptfleisch, Klebs, H. Müller-Thurgau, Moll, Noll, Pedersen, Pfeffer, Prantl, Reinke, D. H. Scott, Stahl, Vines, De Vries, Marshall Ward, Weber, Wortmann and Zimmermann. He insisted upon his pupils being in earnest about science, and he brooked no laziness. Weak natures naturally felt his influence most strongly, but he set a higher value on those from whom he could gain something.

With failing health he withdrew more and more into himself. "I am beginning to take private pupils again," he writes, "but there is little pleasure in it. When a professor reaches the age of sixty he ought *eo ipso* to be pensioned off with his full salary; it might be possible to arrange a university that would serve as an almshouse, but I would not go into it."

He urged his pupils to make comprehensive studies even as he was constantly striving after wide generalizations. He was a master in the art. We have only to think of his 'Experimental Physiology,' his 'Text-book' in four editions, his 'History of Botany' and his 'Lectures on the Physiology of Plants.' Although he wrote with ease, he bestowed great care upon composition, and usually made several rough sketches before the work was done to his satisfaction. In later years he generally dictated, and the 'Lectures' were written in this way. The great debt owed by modern botany to his 'Text-book' can scarcely be appreciated even yet by the younger generation of botanists.

No entirely satisfactory text-book had appeared since Schleiden's 'Outlines,' a book that contained much that was critically suggestive, but, on the other hand, was one-sided and tinged by the author's personal prejudices; nor had the later editions of it been brought up to date with the advance of science. Sachs' book was the first to make Nägeli's and Hofmeister's researches known to the world. It was written in an unusually clear, literary style, and contained all that was best according to 'the present state of science,' as the title page says, especially the author's important physiological researches. The letter-press was interspersed with numerous illustrations, chiefly Sachs' own work and not seldom the results of laborious, tedious experiments. These illustrations have been frequently reproduced and, contrary to Sachs' express wish, have become common property. Too often it has been considered quite unnecessary to obtain his consent to the use of the figures, and the appearance of a newer text-book decked out with his own illustrations elicited from him the somewhat bitter though just remark that a student, using this book, would surely think that he (Sachs) was employed by the author to illustrate his work. Towards the end of his life the frequent revisions needed for a text-book became a burden to him; he could not make up his mind to a fifth edition and he wrote his 'Lectures' in a freer style of exposition.

The book, however, that presents the best insight into Sachs' individuality is his 'History of Botany.' Nägeli had originally been commissioned to undertake this work, which was to form a part of 'The History of Science in Germany,' issued by the Royal Academy of Bavaria, but he had soon abandoned the task. It cost Sachs five years' continuous toil. As with all human work, it has many defects and omissions, but the lucidity, the profound philosophical bent of Sachs' mind, lend an incomparable charm to the whole. An English translation of this work appeared in 1890.

If I further attempt briefly to characterize Sachs' importance with respect to science it is with a due sense of the difficulties of the case. His activity was so comprehensive, the results of his researches have become, through his 'Text-book,' so largely common property that it is not easy briefly to set forth what he has done for science. One would have to write a history of botany from 1860 onwards to justly rate his services. But this is by no means the place for such a work, nor do I feel equal to the task. The extracts already given show that he was no one-sided physiologist, and he was fully aware of the fact. "It may surprise you," he writes, "that from my boyhood the mysteries of relationship (systematic botany) have interested me more than those of biology and physiology. I have apparently specialized in the last-named branch of science, because I have always been of the opinion that the ultimate problems of systematic botany can only be solved by physiological methods." His latest treatises most clearly reveal what he meant.

De Bary's remarks with respect to Mohl apply more or less to almost all distinguished investigators ('Bot. Zeitung,' 1872, p. 572): "As regards a number of discoveries for which we are indebted to Mohl, his claims to priority in them may justly be disputed if this expression be taken to denote the pretension to have first seen or spoken of a thing, * * * the lucid, confident recognition of it is, however, due to Mohl's observation." But in Sachs' case the remark applies not merely to the observation of facts, to which Mohl confined himself, but to bringing into prominence the importance of such facts in their relation to the common stock of our knowledge, and to the right ordering of observations in the general building of knowledge—work on which he laid great stress. He writes: "As I read your book I feel anew how much more merit there is in working out a comprehensive subject from reliable sources, and from a higher standpoint, than in constantly supplying fresh contributions, which, however meritorious in themselves, are yet as the scattered stones of the hillside compared to milestones pointing us on our way!"

Sachs is best known and most famous as the founder of the modern physiology of plants, and his physiological works may be next touched upon. "My earliest treatises," he once wrote, "were composed at a time when the physiology of plants was simply non-existent; I myself was entirely self-taught and consequently much of my work was imperfect, especially the manner of exposition." Nevertheless these earlier works are of great importance. Next to be named come his works upon chemical philosophy. The investigations of Ingenhouss, Th. de Saussure, Liebig, Boussingault and others had supplied the foundation upon which, in connection with the results of plant-anatomy, a more exact knowledge of the phenomena of metabolism was to be built up. It was Sachs who first pointed out "that the starch in chlorophyll is not merely a secondary deposit, but must be regarded as the product of the assimilating activity (produced by the action of light) of the granular, chlorophyll substance; that it is formed in the chlorophyll out of its original elements, and is conducted to the growing buds and to the tissues which store up the reserve material"*—a brilliant addition to our knowledge, the fundamental importance of which needs hardly to be demonstrated at the present day.

The formation of starch largely engaged his attention later on. He contrived a simple means of quantitatively estimating starch-assimilation, and by the application of the 'iodine test' to leaves or portions of leaves, respectively, supplied an extraordinarily simple and instructive method of demonstration.

His services in improving the culture of plants in nutrient solutions are well known. They drew down upon him a violent attack from Knop which deeply wounded him, and not without reason. It is now one of the most elementary experiments in the physiology of plants to rear a plant from germination to seed-bearing by the administration of nutrient salts, but at that time it was maintained that the seed-bearing plants of maize must have been placed in the solution of nutrient salts after they had attained a flourishing condition!

He incidentally discovered the interesting fact that polished marble slabs may be corroded by roots—a fact of some importance for the understanding of the functions of these organs. He began to work upon entirely virgin soil when, at the close of his fiftieth year, he set on foot investigations which brought to light by microscopical tests, and above all by microchemical methods, the movements, chemical changes, and final consumption of the reserve material during the growth of organs. These experiments have also proved of fundamental importance, and he lays stress upon the fact that they served first to lead him to think

* 'Collected Essays,' p. 335.

that the chlorophyll grains are the true organs of assimilation. A bare reference must suffice to the classical treatises on the germination of the date-palm, of grasses, or on inulin, etc.

In later years he ceased to contribute experimentally to our knowledge of metabolism. Other problems had meanwhile claimed his attention. His investigations—the first to be made—into the action of heat claim special notice. The phenomena of freezing had long been in need of investigation, and here also Sachs' work created a clear conception of the problem and went far towards clearing it up. Even more important were 'The Physiological Experiments upon the Dependence of Germination on the Temperature.' For by these the law of the 'drei Kardinalpunkte' (three cardinal points) was established, and the term 'Optimum' introduced for one of them—a name that has been adopted in other departments of science. These experiments were carried out with the simplest appliances not even in a botanical laboratory, but in his own rooms at Prague. His great manual dexterity and skill in devising simple, but extremely effective, instruments were most useful to him.

The discovery that with sensitive organs there are temporary conditions of rigor due to heat and cold has become an intrinsic part of physiology, whilst the establishment of the fact that not only light, but at the same time a sufficiently high temperature, is needed for the formation of cholorophyll in the higher plants was of great interest.

From amongst the series of researches grouped together in the *Gesammelten Abhandlungen* (*Collected Essays*) under the heading 'The Action of Light' I should like shortly to refer to the treatise 'Upon the Influence of Daylight on the Production and Development of Different Plant-organs.'

The fact that the formation of cells and organs is dependent upon light was submitted in this paper for the first time to a searching investigation; it was shown that the formation of roots was in many cases directly favored by light; the conclusion was drawn from Wigand's data that with fern prothallia light determines the dorsiventrality, and the phenomena of etiolation, which still present many enigmas, were more closely examined. The investigation into the action of light through the medium of the foliage-leaves upon the formation of flowers was especially important to Sachs, because it formed the starting-point for his later theory of 'Matter and Form.' It showed him that plants, such as *Tropaeolum*, *Brassica*, etc., continue to produce etiolated stem-parts and leaves in darkness "in sufficient quantity for the production of fresh blooms if this depended only upon the bulk of the material stored for the purpose and not also upon the particular quality of it," a fact that later led him to form his theory as to the specific matter out of which organs are formed. The formation of blossoms was proved to depend directly or indirectly upon light, inasmuch as by the assimilating activity of the leaves in light the materials destined to produce flowers are formed. Later research into 'The action of the ultra-violet rays upon the production of flowers' seeks to define this phenomenon more closely.

The action of colored light upon plants in respect to assimilation and to their heliotropic curves, etc., received soon after valuable confirmation. Sachs introduced the simple and convenient method of counting the bubbles given off by water plants in light, and came to the conclusion (which lately has again been questioned) that the so-called chemical rays have very little to do with the giving off of oxygen.

A keen controversy was aroused by the opinions he formed in consequence of his researches into 'The movements of water in plants.' But even if his inbibition theory be rejected it must not be forgotten how many valuable facts are due to his activity in this field. The effects produced by the chemical and physical state of the soil upon transpiration, the checking action of salt solutions, low temperatures, etc., were well established; the 'Lithium Method' was used for measuring the rate of the transpiration current; and the profound and far-reaching importance of transpiration for the life of most plants was demonstrated.

A further laborious and protracted series of experiments dealt with the phenomena of growth and of movements produced by stimuli. Among the more notable of these are the construction of the first auxanometer, the graphic description of his observations, and the recognition of the grand period of growth. His investigations into the growth of the main and side roots first proved convincingly the factors which condition the regular extension of the root system in the ground, and established the distribution of growth in roots, as well as the correlation between main and side roots. A number of isolated observations are also to be found in this exhaustive treatise. Sachs' clear, perspicuous style renders it a pleasure to read any of his essays, even when he is compelled to enter minutely into detail.

The phenomenon of 'Hydrotropismus' (the name originated with Sachs) had already been occasionally investigated, but Sachs showed it to be due to irritability, demonstrated its importance and facilitated the examination of it by a simple apparatus. The 'Hängende Sieb' (hanging sieve) is now to be found, like the auxanometer and the klinostat, in every botanical laboratory.

The 'Tropisms' (Heliotropism, Geotropism, etc.) made large demands upon his time and attention. When under Hofmeister's influence, as regards experimental physiology, he inclined to an external, mechanical conception of these, but abandoned this later. His own words best denote his standpoint: "I, too, should have nothing to say against the term 'Lebenskraft' (vital force), and have indicated as much from time to time in my 'History of Botany,' but the word has been spoilt and rendered nugatory by misuse. I say, therefore, to denote my conception of the organic world, that the province of true physiology begins where that of mechanics, physics and chemistry of organisms ends. Indeed, I go farther and maintain that the time will come when in physiology will be found the ultimate basis (what Goethe speaks of as 'die Mütter') of all natural sciences." There is no need to say that this vitalistic view did not prevent him from working out with the deepest interest the phenomena of growth-curvatures. He also established the phenomenon known as 'after-effects,' and contributed many other valuable isolated experiments.

If he attached great importance to theories, he was fully conscious of their transitory nature; and I might mention, as an example of this, that in his later years he did not lay so much stress upon his theory of Heliotropism. There will be more to say about this when reference is made to his treatise on orthotropic and plagiotropic organs.

In the meanwhile attention must be directed to the essays upon the connection between cell-formation and growth, which in my opinion belong to his most brilliant achievements. As a result of Nägeli's researches on the apical cell, numerous botanical works had arisen dealing with the laws of cell-division. It was this tendency, exaggerated until it was justly dubbed 'Zellfängerei,' that led men to neglect plants and organs as a whole for the mere cells, and to take it as granted that growth is determined by the manner and method of cell-division, much as the shape of a building is determined by the way the building-stones are laid one upon another.

Hofmeister's brilliant, though hardly well-grounded, opposition had but little success; only a few botanists took any notice of it. It was Sachs who, in his usual clear manner and by the aid of simple contrivances, first explained the relations between cell-disposition and growth. In his opinion the latter is the determining factor, the arrangement of cells depending upon growth. This explained why, for instance, cross-sections through cylindrical masses of cells in plants belonging to widely separated groups may present the same appearance of cell-arrangement as a developing alga or a hair of a dicotyledon. The introduction of the terms 'anticlinal' and 'periclinal' made a brief, striking bird's-eye view of the matter possible, and facilitated further study of the changes in cell-disposition occurring during growth. A large group of facts was brought together under a common heading, and not only was the way made smooth for further investigations into the causes of the arrangement of cells, but an important point of departure was also made for experiments on the evolution of organs which do not possess an apical cell.

The changes which had gradually taken place in the cell theory have led to an entire alteration in its original meaning. This prompted Sachs, who always felt the need of clear and consequently historically correct conceptions, to introduce the definition '*Energid*.' In my opinion he thereby rendered good service to science. It was a great satisfaction to him that his achievements found favor with the most eminent histologists (Kupffer, for instance), and this consoled him for the fact that the botanists, now as on other occasions, instead of testing the innovation in its general application, sought only too zealously for instances in which it did not apply. But the time will surely come when it will be deemed absurd to describe a *Caulerpa*, for instance, as a 'unicellular' plant, and it fell to Sachs to fit scientific nomenclature to recent advances in knowledge. It was self-evident to him that definitions are only a means towards generalization and that they have absolutely no validity in themselves.

The essay upon orthotropic and plagiotropic plant-parts takes us into a region that lay nearest to Sachs' heart during the last years of his life, namely, that of physiological or causative morphology. In this treatise he deals with the connection between the structure (in the widest sense of the word) and the direction of the organs. The definitions 'orthotropic' and 'plagiotropic' were introduced, and referred more particularly to the dorsiventral structures that had long been neglected under the supremacy of the 'spiral theory.' He does not merely treat of the purely structural conditions, but of the causative relations between orthotropic growth and dorsiventral structure. Sachs would, I believe, have altered later his theoretical conclusions upon plagiotropism; they are based upon ideas which he no longer held, as we may see in the text, to be as thoroughly warranted as formerly. But putting aside these points, about which opinions still differ, we find ideas in this essay that are still working with considerable effect in morphology.

As a morphologist Sachs' activity displayed itself in one direction by some special studies that date from his earlier years, in another by his text-books, and again by his final general essays.

His two treatises, on Collema* and Crucibulum, show him at work in the region of cryptogams. It was he who in his 'Text-book' defended Schwendener's Lichen

*In this essay he approached very closely to the later lichen theory when he said that it looked as if a parasitical fungus had established itself in the nostoc; he believed that the nostoc-heterocysts might develop into a mycellium.

theory at a time when the cautious De Bary (in his criticisms of the second editions of the 'Text-book') looked askance at it. The Archegoniates are treated in the 'Text-book' with special interest, forming part, as they had done, of his own researches. His grouping of thallophytes (in the fourth edition of the 'Text-book'), which met with such adverse criticism, has at any rate attained the satisfactory position of being approached again in our own days by many writers.

Throughout his life he cared little for those details that often fill men's lives, and preferred to view matters from a wide and general standpoint. In the first edition of his 'Text-book' he had set his face against 'idealistic morphology' at a time when it was dominant, and in a paragraph of his 'History' that promises to become classical he laid bare the foundations upon which this tendency rested.

Darwinism was another bugbear to him and he intended to attack it vigorously in the 'Principles.' "As far as it goes I am delighted to be free from 'the immutability of species' and to be able on good grounds to accept evolution. But it is absolutely uncertain *how* we are to conceive of this latter. Therefore, I say that the natural system of classification is only to be explained by descent, but how *this* is to be explained no one knows. I regard descent as a fact, like gravitation, about which also we are absolutely in the dark." His whole conception of the world rebelled against 'the crude materialism' which he thought he found in Darwinism. "If my 'Principles' do not meet with the response I had expected, they have done me good service in showing me that Darwinism as a whole is entirely superfluous for any scheme of the final causes of nature. A superfluous theory has received its sentence."

He sought, however, to obtain some similar conception of causes by his theory of 'organ-forming matter,' which caused the external diversity of organs to appear dependent upon their material differences of substance, a view which had its origin in the researches alluded to above on the dependence of bud-formation upon the assimilation activity of the leaves. By this a theoretical basis was gained for experimental morphology; deformities, galls, etc., could be referred to definite changes of substance; and the assumption that stem-forming substances find their way to the point of stem-growth, root-forming to that of the root-system, explained to him most naturally the facts to be seen in reproduction. It is evident that in such a difficult subject one must look for sketches, or general views, rather than theories worked out in detail. But at any rate Sachs' views are more fruitful than Nägeli's 'Idio-plasma,' and he made a number of experimental morphological studies on their bases.

He had already arrived at the conception of the continuity of the embryonic substance before the appearance of Weismann's 'Germ-plasm.' "That which has maintained itself alive, and has continually reproduced itself since the beginning of organic life upon the earth, moving steadily onward in the eternal change of all structures, in the unvarying alternation of life and death, *that* is the embryonic matter of vegetation, and it is this which in certain cases differentiates itself into the two sexes in order again to unite."

He conceived of the multiplicity of plant forms as arising, on the one hand, from the phylogenetic morphological differentiation (this, however, he regarded as an 'absolute mystery'), and on the other from the reaction of the common vegetable substance in response to external stimuli (automorphosis and mechanomorphosis). 'Adaptation' in Darwin's sense of the expression he considered entirely superfluous, and herein he was in entire agreement with

Nägeli. He expressed his views in a powerful manner in his last writings—the physiological 'Notices'* published in 'Flora.' The manuscript found after his death, entitled 'The Principles of Vegetable Formation,' has been handed over to Professor Noll for publication.

This slight sketch can give but an inadequate idea of Sachs' life-work, with its abundant results as regards science; indeed, I can but liken what I have written to a man striking, one by one, a few strings of an instrument that has answered to the touch of some great musician.

One may well say with the Psalmist in speaking of his days:

"Yet is their strength but labor and sorrow."

Nevertheless his life has borne rich fruit; his name is forever bound up with the history of botany. He has enriched this science by the discovery of new and important facts and conceptions and by his unrivalled power of clear definition. In the nature of things it is impossible that all his theories should retain acceptance, but they have all profoundly influenced his contemporaries. There is no doubt that in any other calling Sachs would have risen to the first rank; eccentricities and narrow 'specializing' were alike repugnant to him. In the last years of his life he applied himself eagerly to paleontological and zoological studies. "I must be learning, always learning," he wrote in a letter. In spite of his incessant labors, he was one of the few men of the present day who possess the gift of letter-writing and withal a spirited style, clear and trenchant. And yet these letters, written during the last fifteen years of his life, form one long report of illness.

At last Death, who in the latter years had often drawn very near, took him gently by the hand and led him to his final rest.

K. Goebel.

* These will shortly appear as a separate publication.

THE BREEDING OF ANIMALS AT WOODS HOLL DURING THE MONTH OF APRIL, 1898.

The temperature of the water has remained above the average almost throughout the month. During the first week the thermometer registered 41 F. to 42 F.; during the last week, 45 F. to 46 F. The specific gravity has varied from 1.0231 to 1.0235. The weather has been generally cloudy and the temperature of the atmosphere low.

Vertebrates. — The winter flatfish, *P. americanus*, ceased spawning early in the month, and, though the height of the breeding season was in March, few of the young flatfish have been taken, even over the natural spawning grounds. Young sculpin (*A. æneus*) were very abundant in the tow, especially during the first of the month. On April 4th a very large number were captured, and many were taken on the 18th. On the 27th a few more were taken which apparently had just hatched. Small cod and pollock have been frequently captured, and the latter were more numerous than in March. The young of the sand-launce (*A. americanus*) have diminished in numbers but little since last month, though some have increased considerably in size. On the 17th an unusually large number were taken. The young of the fall herring (*A. harengus*), from three-fourths of an inch to three inches in length, have appeared in increasing numbers. A few specimens of *Ctenolabrus* were examined on April 19th, but the sexual glands, though quite large, were not nearly mature. *Petromyzon* has been taken in the fish traps, and may be seen frequently in the markets.

Crustacea.—The small species of *Gammarus*, abundant in the tow during March, are still breeding. Their appearance, from day to day, is uncertain. One day there may be only four or five in the net, and the next day hundreds may be captured. A