Ludwig and modern physiology / [Sir J. Burdon-Sanderson].

LUDWIG AND MODERN PHYSIOLOGY.

BY

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By J. Burdon-Sanderson.

I. INTRODUCTION.

The death of any discoverer—of anyone who has added largely to the sum of human knowledge—affords a reason for inquiring what his work was and how he accomplished it. This inquiry has interest even when the work has been completed in a few years, and has been limited to a single line of investigation—much more when the life has been associated with the origin and development of a new science and has extended over half a century.

The science of physiology, as we know it, came into existence fifty years ago, with the beginning of the active life of Ludwig, in the same sense that the other great branch of biology, the science of living beings (ontology), as we now know it, came into existence with the appearance of the "Origin of Species." In the order of time physiology had the advantage, for the new physiology was accepted some ten years before the Darwinian epoch. Notwithstanding, the content of the science is relatively so unfamiliar, that before entering on the discussion of the life and work of the man who, as I shall endeavor to show, had a larger share in founding it than any of his contemporaries, it is necessary to define its limits and its relations to other branches of knowledge.

The word physiology has in modern times changed its meaning. It once comprehended the whole knowledge of nature. Now it is the name for one of the two divisions of the science of life. In the progress of investigation the study of that science has inevitably divided itself into two: ontology, the science of living beings; physiology, the science of living processes, and thus, inasmuch as life consists in processes, of life itself. Both strive to understand the complicated relations and endless varieties which present themselves in living nature, but by different methods. Both refer to general principles, but they are of a different nature.

To the ontologist, the student of living beings, plants, or animals, the great fact of evolution, namely, that from the simplest beginning our own organism, no less than that of every animal and plant with its

[1] Founded upon a lecture delivered at the Royal Institution, January 24, 1896. Printed in Science Progress, Vol. V, No. 25, 1896, pages 1–21.

infinite complication of parts and powers, unfolds the plan of its existence—taken with the observation that that small beginning was, in all excepting the lowest forms, itself derived from two parents, equally from each—is the basis from which his study and knowledge of the world of living beings takes its departure. For on these two facts—evolution and descent—the explorer of the forms, distribution, and habits of animals and plants has, since the Darwinian epoch, relied with an ever-increasing certainty, and has found in them the explanation of every phenomenon, the solution of every problem relating to the subject of his inquiry. Nor could he wish for a more secure basis. Whatever doubts or misgivings exist in the minds of "nonbiologists" in relation to it may be attributed partly to the association with the doctrine of evolution of questions which the true naturalist regards as transcendental, partly to the perversion or weakening of meaning which the term has suffered in consequence of its introduction into the language of common life, and particularly to the habit of applying it to any kind of progress or improvement, anything which from small beginnings gradually increases. But, provided that we limit the term to its original sense—the evolution of a living being from its germ by a continuous, not a gradual process—there is no conception which is more free from doubt either as to its meaning or reality. It is inseparable from that of life itself, which is but the unfolding of a predestined harmony, of a prearranged consensus and synergy of parts.

The other branch of biology, that with which Ludwig's name is associated, deals with the same facts in a different way. While ontology regards animals and plants as individuals and in relation to other individuals, physiology considers the processes themselves of which life is a complex. This is the most obvious distinction, but it is subordinate to the fundamental one, namely, that while ontology has for its basis laws which are in force only in its own province, those of evolution, descent, and adaptation, we physiologists, while accepting these as true, found nothing upon them, using them only for euristic purposes, i. e., as guides to discovery, not for the purpose of explanation. Purposive adaptation, for example, serves as a clue, by which we are constantly guided in our exploration of the tangled labyrinth of vital processes. But when it becomes our business to explain these processes—to say how they are brought about—we refer them not to biological principles of any kind, but to the universal laws of nature. Hence it happens that with reference to each of these processes, our inquiry is rather how it occurs than why it occurs.

It has been well said that the natural sciences are the children of necessity. Just as the other natural sciences owed their origin to the necessity of acquiring that control over the forces of nature without which life would scarcely be worth living, so physiology arose out of human suffering and the necessity of relieving it. It sprang, indeed, out of pathology. It was suffering that led us to know, as regards our

own bodies, that we had internal as well as external organs, and probably one of the first generalizations which arose out of this knowledge was, that "if one member suffer all the members suffer with it"—that all work together for the good of the whole. In earlier times the good which was thus indicated was associated in men's minds with human welfare exclusively. But it was eventually seen that nature has no less consideration for the welfare of those of her products which to us seem hideous or mischievous, than for those which we regard as most useful to man or most deserving of his admiration. It thus became apparent that the good in question could not be human exclusively, but as regards each animal its own good—and that in the organized world the existence and life of every species is brought into subordination to one purpose—its own success in the struggle for existence.[1]

From what has preceded it may be readily understood that in physiology adaptation takes a more prominent place than evolution or descent. In the prescientific period adaptation was everything. The observation that any structure or arrangement exhibited marks of adaptation to a useful purpose was accepted, not merely as a guide in research, but as a full and final explanation. Of an organism or organ which perfectly fulfilled in its structure and working the end of its existence nothing further is required to be said or known. Physiologists of the present day recognize as fully as their predecessors that perfection of contrivance which displays itself in all living structures the more exquisitely the more minutely they are examined. No one, for example, has written more emphatically upon this point than did Ludwig. In one of his discourses, after showing how nature exceeds the highest standard of human attainment—how she fashions, as it were, out of nothing and without tools instruments of a perfection which the human artificer can not reach, though provided with every suitable material—wood, brass, glass, india rubber—he gives the organ of sight as a signal example, referring among its other perfections to the rapidity with which the eye can be fixed on numerous objects in succession and the instantaneous and unconscious estimates which we are able to form of the distances of objects, each estimate involving a process of arithmetic which no calculating machine could effect in the time.[2] In another

[1] I am aware that in thus stating the relation between adaptation and the struggle for existence, I may seem to be reversing the order followed by Mr. Darwin, inasmuch as he regarded the survival of organisms which are fittest for their place in nature, and of parts which are fittest for their place in the organism, as the agency by which adaptedness is brought about. However this may be expressed it can not be doubted that fitness is an essential of organisms. Living beings are the only things in nature which by virtue of evolution and descent are able to adapt themselves to their surroundings. It is therefore only so far as organism (with all its attributes) is presupposed, that the dependence of adaptation on survival is intelligible.

[2] I summarize here from a very interesting lecture entitled "Leid und Freude in der Naturforschung," published in the Gartenlaube (Nos. 22 and 23) in 1870.

discourse—that given at Leipzig when he entered on his professorship in 1865—he remarks that when in our researches into the finer mechanism of an organ we at last come to understand it, we are humbled by the recognition "that the human inventor is but a blunderer as compared with the unknown Master of the animal creation."[1]

Some readers will perhaps remember how one of the most brilliant of philosophical writers, in a discourse to the British Association delivered a quarter of a century ago, averred on the authority of a great physiologist that the eye, regarded as an optical instrument, was so inferior a production that if it were the work of a mechanician it would be unsalable. Without criticising or endeavoring to explain this paradox, I may refer to it as having given the countenance of a distinguished name to a misconception which I know exists in the minds of many persons, to the effect that the scientific physiologist is more or less blind to the evidence of design in creation. On the contrary, the view taken by Ludwig, as expressed in the words I have quoted, is that of all physiologists. The disuse of the teleological expressions which were formerly current does not imply that the indications of contrivance are less appreciated, for, on the contrary, we regard them as more characteristic of organism as it presents itself to our observation than any other of its endowments. But, if I may be permitted to repeat what has been already said, we use the evidences of adaptation differently. We found no explanation on this or any other biological principle, but refer all the phenomena by which these manifest themselves to the simpler and more certain physical laws of the universe.

Why must we take this position? First, because it is a general rule in investigations of all kinds to explain the more complex by the more simple. The material universe is manifestly divided into two parts, the living and the nonliving. We may, if we like, take the living as our Norma, and say to the physicist: "You must come to us for laws; you must account for the play of energies in universal nature by referring them to evolution, descent, adaptation." Or we may take these words as true expressions of the mutual relations between the phenomena and processes peculiar to living beings, using for the explanation of the processes themselves the same methods which we should employ if we were engaged in the investigation of analogous processes going on independently of life. Between these two courses there seems to me to be no third alternative, unless we suppose that there are two material universes, one to which the material of our bodies belongs, the other comprising everything that is not either plant or animal.

The second reason is a practical one. We should have to go back to the time which I have ventured to call prescientific, when the world of

[1] The words translated in the above sentence are as follows: "Wenn uns endlich die Palme gereicht wird, wenn wir ein Organ in seinem Zuzammenhang begreifen, so wird unser stolzes Gattungsbewusstsein durch die Erkenntniss niedergedruckt, dass der menschlicher Erfinder ein Stümper gegen den unbekannten Meister der thierischen Schöpfung sei."

life and organization was supposed to be governed exclusively by its own laws. The work of the past fifty years has been done on the opposite principle, and has brought light and clearness where there was before obscurity and confusion. All this progress we should have to repudiate. But this would not be all. We should have to forego the prospect of future advance. Whereas by holding on our present course, gradually proceeding from the more simple to the more complex, from the physical to the vital, we may confidently look forward to extending our knowledge considerably beyond its present limits.

A no less brilliant writer than the one already referred to, who is also no longer with us, asserted that mind was a secretion of the brain in the same sense that bile is a secretion of the liver or urine that of the kidney; and many people have imagined this to be the necessary outcome of a too mechanical way of looking at vital phenomena, and that physiologists, by a habit of adhering strictly to their own method, have failed to see that the organism presents problems to which this method is not applicable, such, e. g., as the origin of the organism itself or the origin and development in it of the mental faculty. The answer to this suggestion is that these questions are approached by physiologists only in so far as they are approachable. We are well aware that our business is with the unknown knowable, not with the transcendental. During the last twenty years there has been a considerable forward movement in physiology in the psychological direction, partly dependent on discoveries as to the localization of the higher functions of the nervous system, partly on the application of methods of measurement to the concomitant phenomena of psychical processes; and these researches have brought us to the very edge of a region which can not be explored by our methods, where measurements of time or of space are no longer possible.

In approaching this limit the physiologist is liable to fall into two mistakes; on the one hand, that of passing into the transcendental without knowing it; on the other, that of assuming that what he does not know is not knowledge. The first of these risks seems to me of little moment; first, because the limits of natural knowledge in the psychological direction have been well defined by the best writers, as, e. g., by Du Bois-Reymond in his well-known essay "On the limits of natural knowledge," but chiefly because the investigator who knows what he is about is arrested in limine by the impossibility of applying the experimental method to questions beyond its scope. The other mistake is chiefly fallen into by careless thinkers, who, while they object to the employment of intuition even in regions where intuition is the only method by which anything can be learned, attempt to describe and define mental processes in mechanical terms, assigning to these terms meanings which science does not recognize, and thus slide into a kind of speculation which is as futile as it is unphilosophical.

II. LUDWIG AS INVESTIGATOR AND TEACHER.

The uneventful history of Ludwig's life—how early he began his investigation of the anatomy and function of the kidneys; how he became just fifty years ago titular professor at Marburg, in the small university of his native State, Hesse Cassel; how in 1849 he removed to Zürich as actual professor and thereupon married; how he was six years later promoted to Vienna—has already been admirably related in these pages by Dr. Stirling. In 1865, after twenty years of professorial experience, but still in the prime of life and, as it turned out, with thirty years of activity still before him, he accepted the chair of physiology at Leipzig. His invitation to that great university was by far the most important occurrence in his life, for the liberality of the Saxon Government, and particularly the energetic support which he received from the enlightened Minister Von Falkenstein, enabled him to accomplish for physiology what had never before been attempted on an adequate scale. No sooner had he been appointed than he set himself to create—what was essential to the progress of the science—a great observatory, arranged not as a museum, but much more like a physical and chemical laboratory, provided with all that was needed for the application of exact methods of research to the investigation of the processes of life. The idea which he had ever in view, and which he carried into effect during the last thirty years of his life with signal success, was to unite his life work as an investigator with the highest kind of teaching. Even at Marburg and at Zürich he had began to form a school; for already men nearly of his own age had rallied round him. Attracted in the first instance by his early discoveries, they were held by the force of his character, and became permanently associated with him in his work as his loyal friends and followers—in the highest sense his scholars. If, therefore, we speak of Ludwig as one of the greatest teachers of science the world has seen, we have in mind his relation to the men who ranged themselves under his leadership in the building up of the science of physiology, without reference to his function as an ordinary academical teacher.

Of this relation we can best judge by the careful perusal of the numerous biographical memoirs which have appeared since his death, more particularly those of Professor His[1] (Leipzig), of Professor Kronecker[2] (Bern), who was for many years his coadjutor in the institute, of Professor Von Fick[3] (Würzburg), of Professor Von Kries[4] (Freiburg), of Professor Mosso[5] (Turin), of Professor Fano[6] (Florence), of Professo

[1] His. Karl Ludwig und Karl Thiersch. Akademische Gedächtnissrede, Leipzig 1895.

[2] Kronecker. Carl Friederich Wilhelm Ludwig. Berliner klin. Wochensch., 189 No. 21.

[3] A. Fick. Karl Ludwig. Nachruf. Biographische Blätter, Berlin, Vol. I, pt. 3.

[4] Von Kries. Carl Ludwig. Freiburg, Bd. I., 1895.

[5] Mosso. Karl Ludwig. Die Nation, Berlin, Nos. 38, 39.

[6] Fano. Per Carlo Ludwig Commemorazione. Clinica Moderna, Florence, I, No.

Tigerstedt[1] (Upsala), of Professor Stirling[2] in England. With the exception of Fick, whose relations with Ludwig were of an earlier date, and of his colleague in the chair of anatomy, all of these distinguished teachers were at one time workers in the Leipzig Institute. All testify their love and veneration for the master, and each contributes some striking touches to the picture of his character.

All Ludwig's investigations were carried out with his scholars. He possessed a wonderful faculty of setting each man to work at a problem suited to his talent and previous training, and this he carried into effect by associating him with himself in some research which he had either in progress or in view. During the early years of the Leipzig period all the work done under his direction was published in the well-known volumes of the Arbeiten, and subsequently in the Archiv für Anatomie und Physiologie of Du Bois-Reymond. Each "Arbeit" of the laboratory appeared in print under the name of the scholar who operated with his master in its production, but the scholar's part in the work done varied according to its nature and his ability. Sometimes, as Von Kries says, he sat on the window sill, while Ludwig, with the efficient help of his laboratory assistant, Salvenmoser, did the whole of the work. In all cases Ludwig not only formulated the problem, but indicated the course to be followed in each step of the investigation, calling the worker of course into counsel. In the final working up of the results he always took a principal part, and often wrote the whole paper. But whether he did little or much, he handed over the whole credit of the performance to his coadjutor. This method of publication has no doubt the disadvantage that it leaves it uncertain what part each had taken; but it is to be remembered that this drawback is unavoidable whenever master and scholar work together, and is outweighed by the many advantages which arise from this mode of cooperation. The instances in which any uncertainty can exist in relation to the real authorship of the Leipzig work are exceptional. The well-informed reader does not need to be told that Mosso or Schmidt, Brunton or Gaskell, Stirling or Wooldridge were the authors of their papers in a sense very different from that in which the term could be applied to some others of Ludwig's pupils. On the whole, the plan must be judged of by the results. It was by working with his scholars that Ludwig trained them to work afterwards by themselves, and thereby accomplish so much more than other great teachers have done.

I do not think that any of Ludwig's contemporaries could be compared to him in respect of the wide range of his researches. In a science distinguished from others by the variety of its aims, he was equally at home in all branches, and was equally master of all methods, for he recognized that the most profound biological question can only be solved by combining anatomical, physical, and chemical inquiries. It was this consideration which led him in planning the Leipzig Insti-

[1] Tigerstedt. Karl Ludwig. Denkrede. Biographische Blätter, Berlin, Vol. I, pt. 3.
[2] Stirling. Science Progress, Vol. IV, No. 21.

tute to divide it into three parts, experimental (in the more restricted sense), chemical, and histological. Well aware that it was impossible for a man who is otherwise occupied to maintain his familiarity with the technical details of histology and physiological chemistry, he placed these departments under the charge of younger men capable of keeping them up to the rapidly advancing standard of the time, his relations with his coadjutors being such that he had no difficulty in retaining his hold of the threads of the investigation to which these special lines of inquiry were contributory.

It is scarcely necessary to say that as an experimenter Ludwig was unapproachable. The skill with which he carried out difficult and complicated operations, the care with which he worked, his quickness of eye and certainty of hand were qualities which he had in common with great surgeons. In employing animals for experiment he strongly objected to rough and ready methods, comparing them to "firing a pistol into a clock to see how it works." Every experiment ought, he said, to be carefully planned and meditated on beforehand, so as to accomplish its scientific purpose and avoid the infliction of pain. To insure this he performed all operations himself, only rarely committing the work to a skilled coadjutor.

His skill in anatomical work was equally remarkable. It had been acquired in early days, and appeared throughout his life to have given him very great pleasure, for Mosso tells how, when occupying the room adjoining that in which Ludwig was working, as he usually did, by himself, he heard the outbursts of glee which accompanied each successful step in some difficult anatomical investigation.

Let us now examine more fully the part which Ludwig played in the revolution of ideas as to the nature of vital processes which, as we have seen, took place in the middle of the present century.

Although, as we shall see afterwards, there were many men who before Ludwig's time investigated the phenomena of life from the physical side, it was he and the contemporaries who were associated with him who first clearly recognized the importance of the principle that vital phenomena can only be understood by comparison with their physical counterparts, and foresaw that in this principle the future of physiology was contained as in a nutshell. Feeling strongly the fruitlessness and unscientific character of the doctrines which were then current, they were eager to discover chemical and physical relations in the processes of life. In Ludwig's intellectual character this eagerness expressed his dominant motive. Notwithstanding that his own researches had in many instances proved that there are important functions and processes in the animal organism which have no physical or chemical analogues, he never swerved either from the principle or from the method founded upon it.

Although Ludwig was strongly influenced by the rapid progress which was being made in scientific discovery at the time that

entered on his career, he derived little from his immediate predecessors in his own science. He is sometimes placed among the pupils of the great comparative anatomist and physiologist, J. Müller. This, however, is a manifest mistake, for Ludwig did not visit Berlin until 1847, when Müller was nearly at the end of his career. At that time he had already published researches of the highest value (those on the mechanism of the circulation and on the physiology of the kidney), and had set forth the line in which he intended to direct his investigations. The only earlier physiologist with whose work that of Ludwig can be said to be in real continuity was E. H. Weber, whom he succeeded at Leipzig, and strikingly resembled in his way of working. For Weber Ludwig expressed his veneration more unreservedly than for any other man excepting, perhaps, Helmholtz, regarding his researches as the foundation on which he himself desired to build. Of his colleagues at Marburg he was indebted in the first place to the anatomist, Prof. Ludwig Fick, in whose department he began his career as prosector, and to whom he owed facilities without which he could not have carried out his earlier researches; and in an even higher degree to the great chemist, R. W. Bunsen, from whom he derived that training in the exact sciences which was to be of such inestimable value to him afterwards.

There is reason, however, to believe that, as so often happens, Ludwig's scientific progress was much more influenced by his contemporaries than by his seniors. In 1847, as we learn on the one hand from Du Bois-Reymond, on the other from Ludwig himself, he visited Berlin for the first time. This visit was an important one both for himself and for the future of science, for he there met three men of his own age, Helmholtz, Du Bois-Reymond and Brücke, who were destined to become his life friends, all of whom lived nearly as long as Ludwig himself, and attained to the highest distinction. They all were full of the same enthusiasm. As Ludwig said when speaking of this visit: "We four imagined that we should constitute physiology on a chemico-physical foundation, and give it equal scientific rank with physics, but the task turned out to be much more difficult than we anticipated." These three young men, who were devoted disciples of the great anatomist, had the advantage over their master in the better insight which their training had given them into the fundamental principles of scientific research. They had already gathered around themselves a so-called "physical" school of physiology, and welcomed Ludwig on his arrival from Marburg, as one who had of his own initiative undertaken in his own university das Befreiungswerk aus dem Nitalismus.

The determination to refer all vital phenomena to their physical or chemical counterparts or analogues, which, as I have said, was the dominant motive in Ludwig's character, was combined with another quality of mind, which, if not equally influential, was even more obviously displayed in his mode of thinking and working. His first aim,

even before he sought for any explanation of a structure or of a process, was to possess himself, by all means of observation at his disposal, of a complete objective conception of all its relations. He regarded the faculty of vivid, sensual realization (lebendige sinnliche Anschauung) as of special value to the investigator of natural phenomena, and did his best to cultivate it in those who worked with him in the laboratory. In himself this objective tendency (if I may be permitted the use of a word which, if not correct, seems to express what I mean) might be regarded as almost a defect, for it made him indisposed to appreciate any sort of knowledge which deals with the abstract. He had a disinclination to philosophical speculation which almost amounted to aversion, and, perhaps for a similar reason, avoided the use of mathematical methods even in the discussion of scientific questions which admitted of being treated mathematically—contrasting in this respect with his friend, Du Bois-Reymond—resembling Brücke. But as a teacher the quality was of immense use to him. His power of vivid realization was the substratum of that many-sidedness which made him, irrespectively of his scientific attainments, so attractive a personality.

I am not sure that it can be generally stated that a keen scientific observer is able to appreciate the artistic aspects of nature. In Ludwig's case, however, there is reason to think that æsthetic faculty was as developed as the power of scientific insight. He was a skillful draftsman but not a musician; both arts were, however, a source of enjoyment to him. He was a regular frequenter of the Gewandhaus concerts, and it was his greatest pleasure to bring together gifted musicians in his house, where he played the part of an intelligent and appreciative listener. Of painting he knew more than of music, and was a connoisseur whose opinion carried weight. It is related that he was so worried by what he considered bad art, that after the redecoration of the Gewandhaus concert room he was for some time deprived of his accustomed pleasure in listening to music.

Ludwig's social characteristics can only be touched on here in so far as they serve to make intelligible his wonderful influence as a teacher. Many of his pupils at Leipzig have referred to the schöne gemeinsamkeit which characterized the life there. The harmonious relation which, as a rule, subsisted between men of different education and different nationalities could not have been maintained had not Ludwig possessed side by side with that inflexible earnestness which he showed in all matters of work or duty a certain youthfulness of disposition which made it possible for men much younger than himself to accept his friendship. This sympathetic geniality was, however, not the only or even the chief reason why Ludwig's pupils were the better for having known him. There were not a few of them who for the first time in their lives came into personal relation with a man who was utterly free from selfish aims and vain ambitions, who was scrupulously conscientious in all that he said and did, who was what he seemed and

seemed what he was, and who had no other aim than the advancement of his science, and in that advancement saw no other end than the increase of human happiness. These qualities displayed themselves in Ludwig's daily active life in the laboratory, where he was to be found whenever work of special interest was going on; but still more when, as happened on Sunday mornings, he was "at home" in the library of the institute—the corner room in which he ordinarily worked. Many of his "scholars" have put on record their recollections of these occasions, the cordiality of the master's welcome, the wide range and varied interest of his conversation, and the ready appreciation with which he seized on anything that was new or original in the suggestions of those present. Few men live as he did, "im Gaznen, Guten, Schönen," and of those still fewer know how to communicate out of their fullness to others.

III. THE OLD AND THE NEW VITALISM.

Since the middle of the century the progress of physiology has been continuous. Each year has had its record, and has brought with it new accessions to knowledge. In one respect the rate of progress was more rapid at first than it is now, for in an unexplored country discovery is relatively easy. In another sense it was slower, for there are now scores of investigators for every one that could be counted in 1840 or 1850. Until recently there has been throughout this period no tendency to revert to the old methods—no new departure—no divergence from the principles which Ludwig did so much to enforce and exemplify.

The wonderful revolution which the appearance of the Origin of Species produced in the other branch of biology promoted the progress of physiology, by the new interest which it gave to the study, not only of structure and development, but of all other vital phenomena. It did not, however, in any sensible degree affect our method or alter the direction in which physiologists had been working for two decades. Its most obvious effect was to sever the two subjects from each other. To the Darwinian epoch comparative anatomy and physiology were united, but as the new ontology grew it became evident that each had its own problems and its own methods of dealing with them.

The old vitalism of the first half of the century is easily explained. It was generally believed that, on the whole, things went on in the living body as they do outside of it, but when a difficulty arose in so explaining them the physiologist was ready at once to call in the aid of a "vital force." It must not, however, be forgotten that, as I have already indicated, there were great teachers (such, for example, as Sharpey and Allen Thomson in England, Magendie in France, Weber in Germany) who discarded all vitalistic theories, and concerned themselves only with the study of the time and place relations of phenomena; men who were before their time in insight, and were only hindered in their application of chemical and physical principles to

the interpretation of the processes of life by the circumstance that chemical and physical knowledge was in itself too little advanced. Comparison was impossible, for the standards were not forthcoming.

Vitalism in its original form gave way to the rapid advance of knowledge as to the correlation of the physical sciences which took place in the forties. Of the many writers and thinkers who contributed to that result, J. R. Mayer and Helmholtz did so most directly, for the contribution of the former to the establishment of the doctrine of the conservation of energy had physiological considerations for its point of departure; and Helmholtz, at the time he wrote the Erhaltung der Kraft, was still a physiologist. Consequently when Ludwig's celebrated Lehrbuch came out in 1852, the book which gave the coup de grâce to vitalism in the old sense of the word, his method of setting forth the relations of vital phenomena by comparison with their physical or chemical counterparts, and his assertion that it was the task of physiology to make out their necessary dependence on elementary conditions, although in violent contrast with current doctrine, were in no way surprising to those who were acquainted with the then recent progress of research. Ludwig's teaching was indeed no more than a general application of principles which had already been applied in particular instances.

The proof of the nonexistence of a special "vital force" lies in the demonstration of the adequacy of the known sources of energy in the organism to account for the actual day by day expenditure of heat and work; in other words, on the possibility of setting forth an energy balance sheet in which the quantity of food which enters the body in a given period (hour or day) is balanced by an exactly corresponding amount of heat produced or external work done. It is interesting to remember that the work necessary for preparing such a balance sheet (which Mayer had attempted, but from want of sufficient data failed in) was begun thirty years ago in the laboratory of the Royal Institution by the foreign secretary of the royal society. But the determinations made by Dr. Frankland related to one side of the balance sheet, that of income. By his researches in 1866 he gave physiologists for the first time reliable information as to the heat value (i. e., the amount of heat yielded by the combustion) of different constituents of food. It still remained to apply methods of exact measurement to the expenditure side of the account. Helmholtz had estimated this, as regards man, as best he might, but the technical difficulties of measuring the expenditure of heat of the animal body appeared until lately to be almost insuperable. Now that it has been at last successfully accomplished, we have the experimental proof that in the process of life there is no production or disappearance of energy. It may be said that it was unnecessary to prove what no scientifically sane man doubted. There are, however, reasons why it is of importance to have objective evidence that food is the sole and adequate source of the energy which

we day by day or hour by hour disengage, whether in the form of heat or external work.

In the opening paragraph of this section it was observed that *until recently* there had been no tendency to revive the vitalistic notion of two generations ago. In introducing the words in italics I referred to the existence at the present time in Germany of a sort of reaction, which under the term "Neovitalismus" has attracted some attention—so much indeed that at the Versammlung Deutscher Naturforscher at Lübeck last September it was the subject of one of the general addresses. The author of this address, Professor Rindfleisch, was, I believe, the inventor of the word; but the origin of the movement is usually traced to a work on physiological chemistry which an excellent translation by the late Dr. Wooldridge has made familiar to English students. The author of this work owes it to the language he employs in the introduction on "Mechanism and vitalism" if his position has been misunderstood, for in that introduction he distinctly ranges himself on the vitalistic side. As, however, his vitalism is of such a kind as not to influence his method of dealing with actual problems, it is only in so far of consequence as it may affect the reader. For my own part I feel grateful to Professor Bange for having produced an interesting and readable book on a dry subject, even though that interest may be partly due to the introduction into the discussion of a question which, as he presents it, is more speculative than scientific.

As regards other physiological writers to whom vitalistic tendencies have been attributed, it is to be observed that none of them has even suggested that the doctrine of a "vital force" in its old sense should be revived. Their contention amounts to little more than this, that in certain recent instances improved methods of research appear to have shown that processes at first regarded as entirely physical or chemical do not conform so precisely as they were expected to do to chemical and physical laws. As these instances are all essentially analogous, reference to one will serve to explain the bearing of the rest.

Those who have any acquaintance with the structure of the animal body will know that there exists in the higher animals, in addition to the system of veins by which the blood is brought back from all parts to the heart, another less considerable system of branched tubes, the lymphatics, by which, if one may so express it, the leakage of the blood vessels is collected. Now, without inquiring into the why of this system, Ludwig and his pupils made and continued for many years elaborate investigations which were for long the chief sources of our knowledge, their general result being that the efficient cause of the movement of the lymph, like that of the blood, was mechanical. At the Berlin Congress in 1890 new observations by Professor Heidenhain, of Breslau, made it appear that under certain conditions the process of lymph formation does not go on in strict accordance with the physical laws by which leakage through membranes is regulated, the experi-

mental results being of so unequivocal a kind that, even had they not been confirmed, they must have been received without hesitation. How is such a case as this to be met? The "Neovitalists" answer promptly by reminding us that there are cells, i. e., living individuals, placed at the inlets of the system of drainage without which it would not work, that these let in less or more liquid according to circumstances, and that in doing so they act in obedience, not to physical laws, but to vital ones—to internal laws which are special to themselves.

Now, it is perfectly true that living cells, like working bees, are both the architects of the hive and the sources of its activity, but if we ask how honey is made it is no answer to say that the bees make it. We do not require to be told that cells have to do with the making of lymph as with every process in the animal organism, but what we want to know is how they work, and to this we shall never get an answer so long as we content ourselves with merely explaining one unknown thing by another. The action of cells must be explained, if at all, by the same method of comparison with physical or chemical analogues that we employ in the investigation of organs.

Since 1890 the problem of lymph formation has been attacked by a number of able workers, among others here in London, by Dr. Starling, of Guy's Hospital, who, by sedulously studying the conditions under which the discrepancies between the actual and the expected have arisen, has succeeded in untying several knots. In reference to the whole subject, it is to be noticed that the process by which difficulties are brought into view is the same as that by which they are eliminated. It is one and the same method throughout, by which, step by step, knowledge perfects itself—at one time by discovering errors, at another by correcting them; and if at certain stages in this progress difficulties seem insuperable we can gain nothing by calling in even provisionally the aid of any sort of eidolon, whether "cell," "protoplasm," or internal principle.

It thus appears to be doubtful whether any of the biological writers who have recently professed vitalistic tendencies are in reality vitalists. The only exception that I know is to be found in the writings of a well-known morphologist, Dr. Hans Driesch,[1] who has been led by his researches on what is now called the mechanics of evolution to revert to the fundamental conception of vitalism that the laws which govern vital processes are not physical, but biological—that is, peculiar to the living organism and limited thereto in their operation. Dr. Driesch's researches as to the modifications which can be produced by mechanical interference in the early stages of the process of ontogenesis have enforced upon him considerations which he evidently regards as new, though they are familiar enough to physiologists. He recognizes that

[1] Driesch. Entwicklungsmechanische Studien. A series of ten papers, of which the first six appeared in the Zeitsch. f. w. Zoologie, Vols. LIII and LV; the rest in the Mittheilungen of the Naples Station.

although by the observation of the successive stages in the ontogenetic process one may arrive at a perfect knowledge of the relation of these stages to each other, this leaves the efficient causes of the development unexplained (führt nicht zu einem Erkenntniss ihrer bewirkenden Ursachen). It does not teach us why one form springs out of another. This brings him at once face to face with a momentous question. He has to encounter three possibilities. He may either join the camp of the biological agnostics and say with Du Bois-Reymond "ignoramus et ignorabimus," or be content to work on in the hope that the physical laws that underlie and explain organic evolution may sooner or later be discovered, or he may seek for some hitherto hidden law of organism of which the known facts of ontogenesis are the expression, and which, if accepted as a law of nature, would explain everything. Of the three alternatives Driesch prefers the last, which is equivalent to declaring himself an out-and-out vitalist. He trusts by means of his experimental investigations of the mechanics of evolution to arrive at "elementary conceptions" on which by "mathematical deduction"[1] a complete theory of evolution may be founded.

If this anticipation could be realized, if we could construct with the aid of those new principia the ontogeny of a single living being, the question whether such a result was or was not inconsistent with the uniformity of nature would sink into insignificance as compared with the splendor of such a discovery.

But will such a discovery ever be made? It seems to me even more improbable than that of a physical theory of organic evolution. It is satisfactory to reflect that the opinion we may be led to entertain on this theoretical question need not affect our estimate of the value of Dr. Driesch's fruitful experimental researches.

[1] "Elementarvorstellungen . . . die zwar mathematische Deduktion aller Erscheinungen aus sich gestatten möchten." Driesch. Beiträge zur theoretischen Morphologie. Biol. Centralblatt, Vol. XII, p. 539, 1892.