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PROBLEMS OF PHYSIOLOGY OF THE PRESENT TIME

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Most of the masters in physiology have attempted in one way or another to lay before their fellow craftsmen their ideas concerning the right methods to be used in physiology, its natural boundaries, and its future development. We read these utterances sometimes with admiration, sometimes with doubt, but always with interest, and also, alas, with disappointment. For it has not been given to any of our saints or prophets to pierce very far into the uncertain future, and one seeks in vain for a fundamental thought or principle which shall illuminate the mystery of life. Our greatest men have, in fact, been wise enough to teach us by example rather than by precept; the chief lesson that one may learn from their lives and writings is that we must continue to investigate, to observe, and to experiment, and that in this way only can sure progress be made toward the goal of which we all dream. The time seems not yet ripe for the master-mind to gather the scattered data and mold them into great generalizations or laws such as have been achieved in other sciences. We must, perhaps, admit that the philosophical basis of physiology, its general principles and quantitative laws, have been borrowed in large part from other departments, and that the subject has not as yet fully repaid this indebtedness by contributions derived solely from its own resources. We have no names to which science as a whole owes as much as it does to Galileo, Lavoisier, Newton, Mayer and Joule, Darwin or Pasteur,[1] and since we may claim that our greatest physiologists rank with the first intellects of their age, their failure to penetrate farther into the causation of vital phenomena must be attributed to the intrinsic difficulties and complexity which the subject offers to the human mind. None of us can change this condition, and those who desire to forecast the future must be content, therefore, to view the subject from the standpoint of past experience and the

[1] While two of the names quoted have a right to be classed among physiologists (Lavoisier and Mayer), the contributions made by them which have been so fundamental to all sciences were in the departments of chemistry and physics.

history of other sciences whose field of work has presented apparently less formidable difficulties.

In what may be termed the golden period of physiology, that is, the latter two thirds of the nineteenth century, the period during which the subject became established definitively as an experimental science, the rich and abundant harvest of facts gathered by the first workers who adopted exclusively experimental methods awoke enthusiasm and brightest anticipations. The workers in physiology were animated by a confident belief that their science was on the highroad to a successful solution of the nature and properties of living matter. Now, however, at the beginning of the twentieth century, one hears frequently the voice of dissatisfaction and criticism. Although the workers are more numerous, and the methods and appliances are more complete, the harvest of facts is not so rich nor so significant. Therefore to many it would seem that the methods used are at fault; there is need at least for a new point of view. It requires but little reflection to become convinced that some of the implied or expressed criticism directed toward recent work in physiology is unjust and is founded upon a misconception of its true nature and development. I refer particularly to the belief so frequently expressed that much of the current investigation in physiology is sterile as regards its immediate applicability to practical medicine, and the further statement that the subject itself has become isolated in a measure from the other biological sciences.[1] I do not contest the accuracy of these statements, but both results must be regarded as a necessary outcome of the normal and healthy development of the science of physiology. The general history of physiology is known to us all; it is not necessary to enter into details. It arose out of medicine and developed in intimate relations with the study of anatomy. But even in its earliest history its most significant results were obtained by the use of the experimental method, and in the nineteenth century its separation from the purely observational sciences was clearly recognized. The establishment of physiology as an experimental science is usually attributed to Johannes Müller and his pupils or their contemporaries who fell under his influence. But as I read its history, its modern characteristics, whether for good or for evil, owe their origin as much to the French as to the German school. Johannes Müller himself was not preëminent as an experimenter, — he made use of anatomical rather than physiological methods; but his contemporary Magendie was a typical modern physiologist, and whatever may have been the extent of his personal influence during life, there can be no question that his methods of work and his points of view are the ones that were subsequently

[1] Meltzer, *Vitalism and Mechanism in Biology and Medicine*, *Science*, vol. XIX, p. 18, 1904. Verworn, *Einleitung*, *Zeitschrift für Allgemeine Physiologie*, I, p. 1, 1902.

adopted in physiology. I am not concerned at present, however, with the attempt to estimate justly the relative influence of these great men and their pupils; the simple point that I wish to insist upon is that they established physiology as an experimental science, and pointed out that its most intimate relationship must be with the other experimental sciences of physics and chemistry. Physiology, said Bernard, is not a natural but an experimental science, and most recent writers have defined the subject as consisting essentially of the physics and chemistry of living matter. The two results spoken of above have followed as an inevitable outcome of this course of development. As an independent science, with specific problems of its own, physiology has naturally loosened its connections with the art of medicine. Formerly one of the handmaids of the noble art, it has been freed in a measure from this servitude, and although its results must always be of the greatest importance to the scientific side of medicine, it can no longer be expected to devote itself mainly to the immediate needs of the physician. The practical problems of medicine that can be studied by physiological methods have been undertaken less and less frequently by the physiologist proper; they have fallen to the hands of the pathologist and the clinician. Physiology does its part in this work by giving to such men the needful technique and training which have been developed by the study of its own problems, and the results obtained redound no less to the credit of physiology because the investigator concerned happens to be classified as a pathologist or clinician. All of the sciences are characterized by this mutual helpfulness; the methods and standpoints developed in one frequently give essential aid to the workers in a related science; and the full outcome of the labors of the narrow specialist cannot be justly estimated by the immediate results in his own department. The physiologist proper, the specialist in physiology, must devote himself to the peculiar problems of his own subject. It cannot be otherwise, for who else is to attempt the solution of these problems? The practical interests of such work to medicine may seem to be remote, but it is hardly necessary to repeat the often-quoted injunction, founded upon past experience, that the solution of a special problem of a fundamental nature carries with it in the long run the most important practical results. The state of affairs in physiology is exactly similar to what has long been recognized as proper and natural in chemistry and physics. The chemical problems of practical medicine are not solved by the chemist, scarcely indeed by the physiological chemist. But those who undertake these problems avail themselves to the fullest of the knowledge and methods of chemistry, and without this aid their work would be impossible. In the same way physiology will continually aid in the immediate practical work of medicine, although those

who designate themselves as physiologists may less and less frequently give their own hands to such work. We who are physiologists should not be lukewarm nor too critical in our attitude toward the work of the specialist. Those who undertake the solution of the problems of medicine find a large and sympathetic audience; their work wins quick recognition, and oftentimes substantial rewards; while those who attempt the more special and peculiar work of the science of physiology are not likely to attract the attention or the interest of physicians; they must look to their colleagues for encouragement and recognition. What has happened to physiology in this matter of its relation to medicine will eventually be true of the other medical sciences. The tendency is already well developed in the subject of anatomy. The specialist in this subject is no longer interested chiefly in the surgical or medical bearing of his problems; he has questions of his own that look toward the understanding of the great laws of growth and development. Medicine should not wish to keep its children forever tied to its own apron-strings. In proportion as they develop normally and healthfully, they must look forward to an independent existence, and the great mother doubtless will find most honor and help from her offspring as they reach their maturity and contribute to her support otherwise than by immediate hand-service.

It has been inevitable also that the development of physiology as an experimental science should cause it to grow away from the other biological sciences. Anatomy and the morphological side of botany and zoölogy are observational sciences, and their methods vary widely from those employed in physiology. It is still true, of course, that purely anatomical work may furnish important data for physiological conclusions, for instance, in the physiology of the nervous system; yet the tendency of physiology is and has been to depart from such methods, and there has become apparent an increasing lack of sympathy, a lessening of mutual understanding of each other's work between the anatomist and the physiologist. We cannot expect the old relationship to be renewed by a return of physiology to its ancient methods. On the contrary, if there is to be a restoration of the former close union, the advance must come from the side of anatomy. Many of the problems of this latter science will eventually call for the test of experiment, and even now an increasing number of its workers are occupying, as it were, a middle ground between the two subjects, — deriving their problems from the side of anatomy and their methods from the side of physiology. Through the influence of this band of workers it is possible that the two sciences may be brought more closely into touch with each other than has been the case for the last few decades. But while the bond between physiologist and biologist has been less cordial than in former years physiology has found a compensation in the ever-increasing intimacy of its relationships with

physics and chemistry. The physiologist looks more and more to chemistry, physics, and physical chemistry for suggestions and methods. How can it be otherwise, if the current statement be true that physiology in the long run has to explain the physics and chemistry of living matter? The truth of this point of view will be apparent to any one who will trace the development of physiology, and it is brought forcibly to the mind of every teacher of the subject when he attempts to direct the training of one who looks forward to a career as a specialist in physiology. I believe that every physiologist feels that the chief preparatory training in his subject should consist in a thorough grounding in physics and in chemistry. If many of the results of recent physiological investigations have not been as decisive as we would wish, is it not probable, nay, almost certain, that the fault lies not in the nature of the problems investigated, nor altogether in the character of the experimental methods employed, but in the inadequate training of the workers? If our investigators were better equipped in the matter of technical training, there would perhaps be less cause for complaint on the score of results, for in physiology, as in the other experimental sciences, the number of problems that may be studied by known methods is very large, one might almost say indefinitely large. We need in physiology not only the great experimenters like Ludwig and Bernard, men with an inborn spirit of curiosity and a talent for experimental inquiry, but also a large number of productive investigators whose capacity may be of a lower order, but whose training shall be complete enough to insure the acquisition of exact and positive results.

If, as I believe, every one will admit the correctness of the facts stated above regarding the tendency of modern physiology to imitate closely the methods used in physical and chemical investigations, the only point to be considered in this connection is whether or not this tendency is premature. Is physiology, in fact, in a sufficiently developed state to employ the methods of the exact sciences? After all, most of the criticism regarding current physiological investigation seems to carry with it the implication that in great part at least the subject as yet is not prepared for the quantitative methods of the other experimental sciences. In considering this point much depends necessarily upon the meaning one gives to the term physical and chemical methods. If we restrict this term to purely physical or chemical studies of living matter in the cell or in the organism, the contention of those who are dissatisfied with the results of recent work is more readily understood, although, in my opinion, far from being justified. Dealing with a substance whose composition is very complex and unstable, and whose structure is not known, it is apparent that rapid progress cannot be expected and exact results cannot often be obtained even by the

employment of accurate methods of research. Such work demands, as Ludwig expressed it, that we shall explain each phenomenon as a function of the conditions producing it, or, to use Mach's phraseology, as a function of those variables upon which it depends. It is necessary in such experiments that one condition or set of conditions be kept constant while another is varied in a known way. While this end is often attained in the study of the properties of dead matter, it seems entirely obvious that the complex and unstable living matter should offer much greater difficulty, and that the results obtained should be much less definite and conclusive. Hence the numerous investigations in physiology that lead to diverse and inconstant conclusions. Hence also the error into which falls the over-sanguine physiologist who imagines that he can borrow his method from physics or chemistry and apply it forthwith to the successful study of the properties of living matter. Every one must grant that this kind of work represents the highest ideal of physiological investigation, an ideal toward which the science should endeavor to develop; but judging solely by the results obtained hitherto, one may be forced to admit that the acquisition of positive knowledge by these methods has been slow and uncertain. Such relatively simple problems as the elasticity of the living tissues, the hydrodynamics of the blood-flow, the electrical phenomena of the functional nerve-fibre, the chemical changes of the foodstuffs during digestion and absorption, the chemical changes of respiration and secretion, are still the subjects of apparently endless controversies. Few of the problems of this character that occupied the attenton of our predecessors fifty years ago have been solved satisfactorily. In each generation certain conclusions are accepted and taught, but we are all aware how constantly our views are undergoing change, and how few are the facts that we may consider as definitively demonstrated. The writers of text-books are obliged to prepare frequent new editions not only for the purpose of adding new material, but of correcting the old. In fact, in respect to the exact methods of research, the state of physiology is not greatly different from that of physics or chemistry a century ago. Doubtless much of the work done by these methods is poorly done, or at least leads to no positive conclusions, owing to the intrinsic difficulties of the subject. But granting all this, it seems to me nevertheless that in this direction lies the path of greatest honor for those whose capacity and training mark them as leaders in the subject. We cannot seriously criticise this kind of work without surrendering all hope of the future of physiology. We can only justly criticise the lack of judgment in those who undertake it without sufficient preparatory training or knowledge of the subject.

If, on the other hand, by physical and chemical methods we under-

stand the experimental method, whatever may be the character of its technique, then the question suggested above becomes relatively simple. This, I believe, is the standpoint assumed by the founders of modern physiology, and this is the truth which they wished to emphasize when they claimed that physiology is essentially an experimental science which must develop along lines similar to those worked out in physics and chemistry. When Magendie completed the demonstration of the division of function between the anterior and the posterior roots of the spinal nerves, a distinction that had been assumed by Bell on anatomical grounds, he used the chemical and physical method; he stimulated each root, and thus arrived at a positive conclusion which could never have been reached except by the employment of the experimental method. And those observers like Langley, who in our own day are slowly unraveling the physiological mechanism of the so-called sympathetic or autonomic nervous system and are using experimental stimulation at every stage of the work, are also in this sense employing the physical and chemical method. From this point of view there is no room for criticism regarding the progress, past or future, of the science of physiology. Most of our advance in knowledge has been due to direct experimental inquiry, and the opportunities for further satisfactory work of the same character are lacking only to those who fail in the zeal or talent requisite to imagine and carry out experimental investigations. A recent writer[1] has said, "He who cannot discover and classify new facts in any branch of natural science after a few weeks, or at most a few months, of industrious work must indeed be ignorant or unskilled." As regards experimental physiology, I cannot agree with this author in the implied simplicity of the task of discovery of new facts. I fancy that the unpublished history of the subject contains records of many investigations which were carried out by observers neither ignorant nor unskilled, but which failed to unearth any new facts. But this much seems to me to be certain, that in physiology at present there is abundant opportunity for every grade of investigation. The subject is not so far advanced that new facts of even the simplest kind are without value. That purely anatomical studies may have a profound influence upon physiological theories is illustrated in the most striking way by the history of the so-called neurone doctrine and by the modified views upon this subject that are beginning to be felt in consequence of the anatomical work of Apáthy, Nissl, Bethe, and others. For physiology, however, it is all-important that the ideas suggested from the anatomical side shall be verified and expanded by the experimental method. Bethe's experimental

[1] Ostwald, *The Relations of Biology and the Neighboring Sciences*, University of California Publications, *Physiology*, I, p. 11, 1903.

researches upon the degeneration and regeneration of peripheral nerve-fibers have added greatly to the significance of his anatomical work, and will insure the recognition of the importance of the newer ideas concerning the physiological mechanisms of the nervous system. While I agree most heartily with Verworn [1] that physiology should claim "vollständige Freiheit in der Wahl des Objekts und in der Wahl der Methoden," I find it necessary to supplement this demand by the restriction that the methods, to be physiological, must be experimental. This peculiarity constitutes the shibboleth that serves to distinguish the physiologist from his biological comrades. So long as any physiologist answers to this designation, he should be recognized as a worthy member of our guild. The tendency sometimes exhibited by our most active and prominent workers, to magnify the importance of their own, perhaps newer, methods, by contemptuous or despairing criticism of the methods employed by other workers, seems to me not only ungenerous and unjustifiable, but even positively injurious to the advancement of our science. There is opportunity for important results from all good methods whether old or new, and he whose training or opportunities enable him to do his best work along well-established lines need not be discouraged or diverted in his labors because newer modes are the sensation of the hour. Our greatest teachers have been characterized always by a large-minded sympathy for work of all kinds so long as it is well conceived and well executed.

In all the biological sciences there is an opportunity for physiological work. Hypotheses based upon anatomical facts call for the test of experiment, and the methods that suffice in the beginning may be relatively simple, so that little or no technical training is required for the work so far as the experimental side is concerned. The experimental zoölogist has entered upon such a field. For no good reason he has selected this designation, which seems to suggest the formation of a new specialty. As a matter of fact, experimental work upon animals is necessarily physiological, and the experimental zoölogist must look for his methods and implements to the science of physiology. Work of this kind has all the fascinations of pioneer life; it holds out the possibility of rich discovery, of unexpected finds, and will doubtless attract from physiology and from anatomy the adventurous spirits with large ideas, together with many who are simply dissatisfied with conditions as they are. I cannot, however, sympathize with those who, stirred by the results already reported, seem to feel that all of the energy and ability of our subject should be diverted to this kind of work. On the contrary, however important and attractive this work may be, it is

[1] *Loc. cit.*

distinctly not the best field for the trained specialist in physiology. There is a large domain discovered by the pioneers of other times which needs development. Crude methods will not suffice for this work, and it constitutes the special field for the best-trained artisans in physiology. This most difficult and most fundamental work must be accomplished through the agency of the exact methods of physics and chemistry, and if those who have the requisite training are devoting themselves energetically to this duty, those of us who may lack the ability or special training for such complex undertakings should not be too critical of the results. In the nature of things the work of the pioneer is likely to bring greater glory and recognition to those who make a success of it, but the regions he opens must be subsequently explored and developed. Those who do this latter work are the ones who really determine the importance of each new discovery; they are the ones who ascertain for us whether it is a barren country that has been opened up, or one rich in the possibilities of wealth. This, as I see it, is the kind of work in which the great body of physiologists is actually engaged at present, and it is a kind of work in which the technical methods of physics and chemistry must be of increasing importance.

But whether physiological work is directed along purely physical or chemical lines, or is, to use a current designation, biological in character, so long as its experimental side is emphasized, it is pure physiology, and must, if pursued with energy and ability, contribute to the advancement of our science. This has been the line of development of modern physiology from the time when its founders first pointed out the inadequacy of observational methods and unsupported speculative reasoning. Those who were responsible for giving it this direction of growth felt that its future was thereby assured. "La physiologie," said Bernard,[1] "définitivement engagée dans la voie expérimentale, n'a plus qu'à poursuivre sa marche." For a long time we have been advancing along this path, and it is only necessary to look back to realize the great progress that has been made. When we look forward, however, difficulties present themselves that have made some physiologists doubt whether after all the experimental way will lead us to the end that the science has in mind. The apparently insuperable obstacles continually obtruding themselves always alarm unduly some of our leaders. Fifteen years ago a well-known physiologist, who has himself done much valuable experimental work, exclaimed that our present methods of investigation had reached their limit.[2] "The smallest cell exhibits all the mysteries of life, and our present methods of

[1] Bernard, *De la physiologie générale*, Preface, Paris, 1872.
[2] Bunge, *Physiological and Pathological Chemistry*, Introduction, English translation, London, 1890.

its investigation have reached their limit." But in the brief period that has elapsed since that complaint was made, many additions of striking importance have been made to our knowledge, "with the help of chemistry, physics, and anatomy alone." Since that time the discovery of internal secretions has opened a new field of experimental work; the methods of physical chemistry have found a fruitful application in the problems of secretion and absorption; physiological chemistry has steadily added to our knowledge of the composition of the body; our conceptions of the influence and extent of the action of enzymes has been greatly broadened, and the whole subject of so-called biological reactions, as illustrated by the acquisition of immunity toward foreign substances, has been added to our means of research.

Long ago Borelli and his followers, the iatro-physicists and iatro-chemists, had rightly conceived the method by means of which the problems of physiology should be approached, and if in the eighteenth century the workers in this subject became discouraged and forsook the narrow path of physio-chemical methods and explanations for the broad and easy road of "baseless and senseless hypotheses," [1] who can doubt that the progress of physiology was thereby delayed? Whatever may seem to be the difficulties ahead, however inadequate our methods may appear, the history of physiology, like that of the other experimental sciences, teaches us in the clearest possible way that if we follow steadfastly the advice of our greatest teachers and continue to experiment, to try, new methods will be developed continually which will prove adequate to the fruitful investigation of the seemingly impossible problems that confront us. We have many examples in our own subject of the unwisdom of crying *ignorabimus*. Take the instance of the velocity of the nerve impulse. The greatest living master of physiology, impressed by the idea that the action of the nerve must depend upon the movement of an imponderable material propagated with a velocity comparable to that of light, had declared that it was hopeless to think of arriving at an experimental determination of this velocity within the short distance offered by the animal body. Yet a few years afterward Du Bois Reymond discovered the electrical phenomena of the stimulated nerve, and reasoning from this fact, Helmholtz was led to his beautiful and simple experiments, by means of which the velocity of the nerve impulse was accurately measured. Müller's surrender of the problem was due to a false assumption, and without doubt we or our descendants will find that many of the questions that seem to us beyond the limit of experimental study will be made accessible to investigation by the discovery of new facts and methods. To judge from the past, the great-

[1] Reil, *Archiv für die Physiologie*, vol p. 4, 1796.

est danger and mistake lies always in that hopeless attitude of mind which assumes that what is impossible now to our methods and to our limited vision will remain so forever. I cannot myself see any reason why the physiologist should be despondent of the future, nor why he should depart in any way from the rule laid down by Harvey, "to search out and study the secrets of nature by way of experiment." [1] Those who criticise existing tendencies and methods, and speak vaguely of a better way, have nothing definite to offer, except a return to the barren and disastrous method of speculation by way of the "inner sense." [2]

There are certain large problems in biology which, by definition at least, belong to physiology, but which as a matter of fact do not at present form a subject of investigation by physiologists. Such, for instance, are the great questions of development and heredity, and the varied and important reactions between the organism and its environment included under the term ecology, or bionomics. The course of development in biology has been such that in recent years these questions have fallen mainly into the hands of the morphologists. But the methods employed by the morphologists in their investigations tend to become more and more experimental, and we may infer that the workers who devote themselves to these problems will be compelled to have recourse more and more to the technical methods of physiology. It is therefore a fair question as to whether or not it is desirable that the specialist in physiology should give his attention to work of this character. Burdon-Sanderson, in an address before the British Association for the Advancement of Science, 1893,[3] took the ground that the field of physiology proper, as determined by the course of development, lies altogether in the province of what he calls the internal relations of the organism, that is, "the action of the parts or organs in their relations to each other." This definition is at least an approximately accurate statement of the scope of physiology as it has existed during the past two or three generations. I say approximately accurate, because as a matter of fact some recognized physiological work has concerned itself with the reactions between the organism and its environment, such work, for instance, as the effect of external temperature upon heat production, or the effects of altitude upon the elements of the blood. Still the reaction to the environment has been studied by the physiologist only in so far as the adaptation can be detected at once or within a relatively short period of time. Those reactions that are detectible only or mainly in the progeny have been left very

[1] Quoted from Pye-Smith, Harveian Oration, *Nature*, vol. XIX, 1893.
[2] Bunge, *loc. cit.*
[3] *Nature*, vol. XIX, 1893.

properly to those sciences whose dominant method is that of observation and comparison. In this regard the history of physiology offers an analogy to that of physics. Most of the problems of astronomy and geology are in a wide sense physical problems, but in the division of labor made necessary by the extent of the field to be cultivated, the specialist in physics has limited himself to the study of the properties of inanimate matter so far as they can be approached by the methods of laboratory experiment. The wider relations of this matter to the cosmical processes throughout the visible universe, and its transformations during long periods of time, have formed the subject-matter for independent although related sciences. The astronomer or geologist makes much use of physical knowledge and physical methods, but his subject is large enough to form an independent department of science. A similar division of labor has been followed in the sciences that deal with animate nature, and the part that has fallen to the physiologist is mainly the experimental laboratory study of the properties of living matter. It seems proper, and indeed necessary, that the broader ecological problems should form an independent science which will need specialists of its own. Work of this kind cannot be regarded as lying within the province of the specialist in physiology, although without doubt the development of the physiological sides of the subject will be made largely through methods and technique borrowed or adapted from physiology, and on the other hand the results obtained from ecological work will doubtless exert a reflex influence upon the methods and especially the theories of physiology.

The matter stands otherwise, however, in regard to the deeply interesting and important facts of embryological development. The laws of growth and senescence, the secrets of fertilization and heredity, must be studied in the long run by the physiologist; they are intrinsically physiological problems and must yield at last to the experimental methods of the laboratory. These questions have been studied heretofore chiefly by anatomical methods; but this is the natural order of development. The anatomical side is the simpler; it precedes and serves as a basis for physiological investigation, as the renaissance of anatomy in the sixteenth century formed the logical precursor of a similar awakening in physiology in the seventeenth century. The anatomist has been forced, so to speak, to take up first the problems of development, but of necessity the need for experimental work has soon made itself felt. The results that have been obtained by the use of the simple but ingenious experiments so far employed have been most suggestive, and indicate clearly that a promising future awaits the further extension of this method. If for a time longer such work

shall be done mainly by those whose training has been received in the observational sciences, it seems inevitable that the specialist in physiology must also enter the field. Chemical and physical methods are clearly adapted to the study of these problems, for in the end we expect to find the scientific explanation of growth and development in the physical and chemical properties of living matter. The subject is as truly a part of physiology as the processes of secretion and nutrition. In the current literature upon the subject there is at present a freedom in the formation of hypotheses and a reliance upon the virtues of the syllogism which tend to bring it into sympathetic relations with philosophy rather than with physiology. But as the store of observed and demonstrable data is increased, the boundary-line between the probable and the improbable will be more sharply drawn, and more objective methods and less ambiguous theories will mark the development of the subject along experimental lines.

In the strictly physiological literature of the past century, a characteristic feature has been the absence of philosophical speculation. Although the physiologists have been concerned most directly with the problems of life, they, of all the biological family, have been least productive in the philosophical discussions that have prevailed during this period. Those who were most conspicuous in laying the foundation of our exact knowledge followed upon an age of free speculation, and therefore, as it were by protest against this tendency, devoted themselves to an empirical study of the subject, following the admonition of Harvey mentioned above; of Hunter, whose advice was, "Don't think, try;" and of Magendie, whose guiding principle of work was similarly expressed.

At the present time there are indications that the workers in physiology are dissatisfied with this cautious attitude. There seems to be a reaction against the purely empirical procedure, and a demand for the discussion of the underlying philosophical principles. This tendency, in fact, has seemed to affect all of the experimental sciences. "All sciences," says Ostwald,[1] "are tending to be philosophical;" and he and others see in this fact an indication of the approach of an era of synthesis in science, a beginning of the unification of all the widely separated specialties toward a common end. Others will perhaps view this tendency with alarm, and imagine that history is repeating itself; that after a century of objective experimentation the restless mind of man is reverting to the speculative methods of the eighteenth century and attempting after the manner of other days to reach by a shorter path the final goal of an understanding of the mysteries of the universe. Truly, when one examines the results of this recent tendency, he

[1] *Loc. cit.*

finds in them but little to encourage his hopes of a more rapid advance in knowledge. While many protest against the inadequacy of our present methods, the progress that is actually being made is accomplished, as formerly, by those who adhere to the tried method of experimenting continually in every direction. So far as I can see, it is still the duty of the physiologist to insist upon the necessity and value of empirical work. What we need is not so much philosophical theories as new experimental methods, and these will be discovered only by those who, trained in the technique of the subject, are continually attempting to modify and improve existing methods. Physiology needs a Pasteur rather than a Descartes. It is possible that the sciences of physics and chemistry, being so much farther advanced than that of physiology, may feel acutely the need of reconstructing their philosophical basis in order that their working hypotheses may better adapt themselves to future experimental work, but in physiology the guiding principles which we have received from these sciences still hold out richest possibilities of results, and we have not within the limits of our own subject reached that degree of development which calls for a fundamental change in methods or theory. While deprecating, therefore, in the strongest possible way any effort to minimize the importance of the experimental work as now carried on in physiology, it seems to me, nevertheless, quite evident that some value must be given also to the character of the general philosophical idea upon which this work is based. The purely agnostic point of view is suited, perhaps, to individual minds; and where our ignorance is so great the empirical attitude is doubtless the most modest, and theoretically the most justifiable. But human nature is such that an entirely neutral and judicial standpoint fails to arouse in it much enthusiasm or strenuous endeavor. In science we need enthusiasm, for much work is to be done, and scientists as a body, like their fellow mortals, are not content to hold themselves aloof from speculations regarding the final object and significance of their labors. The nature of the underlying philosophical belief has always had an important influence upon the extent and character of scientific work, and we must take this factor into our reckoning in any attempt to estimate the conditions that contribute to the advance or to the retrogression of science.

Toward the middle of the nineteenth century magnificent work in physiology was being done in Germany and in France. The methods that were employed by Flourens, Magendie, and Bernard were as productive and as modern as those used by their contemporaries in Germany, but the influence of the latter school was seemingly more widespread, if we may judge this influence by the effect upon the entire body of investigators in physiology. Recent

historians,[1] outside of France, trace the modern revival chiefly to the German school, to the work and the influence of Du Bois Reymond, Ludwig, Helmholtz, Brücke, *et al.* It has seemed to me that one reason for the seeming neglect of the equally important work of the French school lies in the fact that the leaders in the German school were animated by a philosophical principle whose influence not only guided their own work, as it did, indeed, that of the French physiologists, but which was so emphasized and displayed before the eyes of men that it kindled enthusiasm and attracted recruits from all lands to the army of investigators in physiology. The flag under which they marched bore the motto of mechanism, and its followers were animated by the hope that physico-chemical and anatomical methods applied to the experimental study of the properties of living matter would soon bring these mysteries under the control of science. So rapidly indeed were results accumulated in the beginning that the over-sanguine believed the end nearly in sight, and the hope was entertained by not a few that we should soon understand the structure of living matter, and perhaps be able to manufacture it with our own hands. We realize now that this hope was premature. We know much more than our predecessors at the beginning of the nineteenth century; the science has marched onward at a rapid rate; but what seemed to be the end of the forest is only a small clearing, an open space, and in front of us still lies an apparently pathless wilderness. Naturally, therefore, the question has arisen as to whether or not we are following the right route; there has been a more or less general revival of the old discussions regarding mechanism and vitalism. On the basis of the knowledge and experience obtained by a century of work, there is a disposition to orient the subject anew regarding these guiding principles of investigation.

Recent writers have recognized various degrees or kinds of vitalism, the mechanical and psychical, the natural and transcendental, and the neo-vitalist, as distinguished from the vitalist of the eighteenth century. Leaving aside ultimate views as to idealism or materialism which can scarcely be supposed to exert any direct influence on scientific work, it seems to me that the vitalist in physiology now is what he has always been, one who believes that there is a something peculiar, a *quid proprium*, to use Bernard's expression, inherent in or indissolubly connected with living matter, a something that is different from matter and energy as understood in physics and chemistry, a something, therefore, that does not necessarily manifest itself in accordance with so-called physico-chemical laws. The name that we may give to this something matters but

[1] Tigerstedt, *Zur Psychologie der naturwissenschaftlichen Forschung*, Helsingfors, 1902; Burdon-Sanderson, *loc. cit.*

little; we may call it soul, animal spirits, vital principle or force ether, nervous fluid, inner sense, consciousness or psyche, but *plus c'est changé, plus c'est la même chose.* We may differ as to whether this something is connected with living matter in all its forms or whether its manifestations are limited to the nervous tissues, but if we admit its existence as a causal factor in any of the phenomena of life, then it seems to me that we adopt the standpoint of vitalism, and the nature of our work as well as our theories will be influenced thereby. The standpoint of the mechanist is simple. He believes that all the properties of living matter are of a chemico-physical nature, that is, properties that are dependent upon the structure and arrangement of the molecules and the eternal characteristics of their constituent parts. The C, H, O, N, S, P, etc., that enter into its composition carry with them their individual properties, and if nothing else is present in living matter, the phenomena exhibited by it must be a resultant of these properties, as the phenomena exhibited by sodium chloride depend upon the combination of the properties of the constituent sodium and chlorine. From this standpoint we may assume that if there is in living matter any recognizable form of energy not hitherto classified, it is intrinsically present in dead matter also, and we may hope to discover its existence by purely physico-chemical methods of investigation, with the probability, indeed, that it will be recognized first by the chemist or the physicist with his more exact methods and more favorable conditions for quantitative analysis. If we are unwilling to adopt this standpoint, then it seems to me that, unless we deem it wiser to assume an entirely agnostic attitude, we are logically forced to take one of two positions. With the older physiologists we may boldly assume the existence in living organisms of a finer stuff intermingled with the so-called matter, a substance that is not matter as we understand that term in science, but which, in combination with matter, gives to living things their distinctive characteristics; or we may assume the existence in the universe of a reality other than matter, with the belief that it is influenced by and exerts an influence upon matter only in the living form, in some such way as the earlier physicists postulated an ether that can be affected by matter only when in a certain state of vibration. If I read them correctly, most modern scientific authorities adopt substantially this latter point of view. The so-called psychical phenomena of life are differentiated from the physical, but at the same time it is admitted that the subjective or psychical manifestations are dependent upon physico-chemical changes in the material substratum. Huxley states the matter with his usual candor and clearness: "It seems to me pretty plain that there is a third thing in the universe, to wit, consciousness, which in the hardness of my head or

heart, I cannot see to be matter or force or any conceivable modification of either." It is perhaps a question of terms only as to whether this point of view is properly designated as vitalism. Inasmuch, however, as it assumes a something that can be influenced only by living matter, possibly only by special forms of living matter, and in turn can only act upon living matter, it draws a line between the properties of the animate and the inanimate which represents a real distinction, and those who hold to this point of view or any modification of it can scarcely escape, for want of a better term, the designation of vitalist, even though it is recognized that the reaction between the subjective and the objective world may be governed by laws that are, strictly speaking, as mechanical as those reactions of matter that have been generalized under the laws of physics and chemistry. In this sense I believe that the majority of physiologists belong to the school of vitalists. The methods that they employ and the nomenclature they use are, however, mechanical, because the science recognizes that its ultimate aim is to understand the mechanics of living matter, and that in this way only, if at all, shall we be able to arrive at a conception of the relations of this matter to a reality of a different order. The older physiologists, and some of recent times, have used the conception of vitalism as a convenient and easy means of accounting for many processes which further investigation has shown to be purely mechanical. Experiences of this kind tend to strengthen our belief that most of the unknowns confronting us at present will be analyzed eventually in terms of the conceptions of physics and chemistry; but there is always present in physiology the tendency to assume that what is not clearly or conceivably reducible to the laws of matter and energy must therefore belong to the "irreducible residuum." The nature of this residuum, the connotation of the term vitalism, varies somewhat with each generation.

Bernard, in his lucid and masterly discussion of the phenomena of life, came to the conclusion that the irreducible residuum, to which the laws of chemistry and physics are not and cannot be applicable, is the power of development of the egg. "Car il est clair que cette propriété évolutive de l'œuf, qui produira un mammifère, un oiseau, ou un poisson, n'est ni de la physique ni de la chimie. . . . La force évolutive de l'œuf et des cellules est donc le dernier rempart du vitalisme."[1] In our own day the study of the mechanics of development is actively pursued by many investigators, and I fancy that few modern physiologists are inclined to take a truly vitalistic view of the process. However much the facts of development are beyond the possibility of explanation in terms of our present chemico-physical knowledge, it is clearly conceivable that the

[1] Bernard, *Revue des Deux Mondes*, IX, p. 326, 1875.

observed processes may all be due solely to the material structure of the fertilized ovum acting in accordance with physico-chemical laws, and that, therefore, our present methods of investigation may eventually bring these phenomena within the limits of a scientific explanation. The irreducible residuum recognized to-day, and indeed admitted always by many of the physiologists who are reckoned among the mechanists, is the psychical reaction, the phenomenon of consciousness. However much we may come to know of the physico-chemical processes that give rise to this reaction, it has been asserted by most of the scientific authorities of our time that the psychical side itself is beyond the possible application of the methods of physics and chemistry, a conclusion that, as it seems to me, is tantamount to the admission of the existence of a non-material reality. The study of consciousness has therefore been eliminated from the subject of physiology on the ground that the methods of our science are inapplicable. I fully agree, however, with the timely and courageous statement of Minot [1] that "Consciousness ought to be regarded as a biological phenomenon, which the biologist ought to investigate in order to increase the number of verifiable data concerning it." If for the present this task is confided to the workers in the independent science of psychology, the only successful methods that they can employ are those of observation and experiment, and eventually the latter mode of investigation must become the more important, and the subject must be recognized as destined to come within the province of experimental physiology. To Minot the most important work at present is to be accomplished by an extension of the comparative method to the psychological study of all forms of life, but to the physiologist it would seem that a no less promising although technically more difficult field will be found in neuro-pathology, which holds out hopes that definite variations in the psychical reaction may be connected with distinct alterations in the structure and properties of the material substratum. One can scarcely doubt that the combined labors of the psychologist, biologist, physiologist, and pathologist will eventually accumulate many verifiable data concerning consciousness. We are not able at present, it is true, to form any conception of the nature of the relation between the subjective and the objective, but new facts may alter wonderfully our insight into this mystery, and it is the clear duty of physiology to participate in the work of accumulating all possible data bearing upon this relation. The introspective method alone is insufficient, and we have no alternative but to trust hopefully in the less pretentious method of scientific observation and experiment. We may believe that in this

[1] Minot, *Presidential Address*, American Association for the Advancement of Science, Pittsburgh Meeting, *Science*, XVI. p. 1, 1902.

way a basis will be obtained upon which philosophy may reason, more surely and more successfully than is possible now, concerning the psychical life and its relations to the mechanical phenomena of the universe.

If I may summarize briefly my point of view regarding the present problems of physiology, what I have wished to emphasize is this. The experimental method, physical, chemical, biological, or anatomical is the life and hope of the subject. Its future depends solely upon the steadfast recognition of the necessity and possibilities of this means of research. Every investigator who is anxious to add to the stock of physiological knowledge should experiment ceaselessly by those methods which he is most capable of using, while those who are looking forward to the highest work in physiology should fit themselves by a thorough training in physics or chemistry, since the most difficult and the most fundamental problems in the subject require the use of the methods and modes of thought of these sciences. There must be an outlying division of workers who will keep the subject in touch with practical medicine, and other divisions through which communications will be established with psychology and the morphological sciences; but the flower of the army, the imperial guard, will consist of those who have been disciplined in the methods of physics and chemistry, and who are able to apply this training to the study of the properties of living matter.