# THE 'INTRODUCTION' TO CARL LUDWIG'S *TEXTBOOK OF HUMAN PHYSIOLOGY**

*Translated by*

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## TRANSLATORS' NOTE

Carl Ludwig (1816–95) published the second edition of his *Lehrbuch der Physiologie* in 1858–61, at the onset of the political and industrial ascendency of Germany in Europe and the beginning of 'the greatest ferment of ideas and revolution in attitudes since the middle ages.'[1] In Ludwig's laboratories physiology, still only an 'embellishment' of anatomy, joined with the burgeoning physics and chemistry of the day to form a new, independent, science. The two volumes of the *Lehrbuch* presented the first fruits of that merger.

Even as Claude Bernard in Paris conducted his investigations in a damp basement, the physiological institutes of Germany multiplied and grew strong, so that by 1879 an unnamed observer was able to describe the 'development of physiology during the last quarter century in Germany' as 'by general acknowledgement unprecedented in the history of science.'[2]

'Ludwig's *Physiology*,' wrote Wilhelm His, 'appeared like a meteor on the scientific horizon. It attacked the scientific knowledge of the day, demolishing former theories and conceptions with critical severity.'[3] The physical movement in physiology was quantitative and objective in outlook, in contrast to the older trend, which was descriptive, impressionistic and vitalistic.

According to Burdon-Sanderson, the book exerted an 'extraordinary influence.'[4] It 'gave the *coup de grace* to vitalism in the old sense of the word.'[5] The treatise began with a 'discussion of the elementary endowments of the structure or framework of the living body, and of the processes in which these endowments manifest themselves; seeking to arrive at a clear conception of each vital function by regarding it as a complex of constituent processes severally definable in chemical or physical terms. The book set forth no 'biological principles,' and therefore had no interest for the general reader. It was for students and for students only, but for them it was a revelation, a forecasting of the physiology of the future for those who were about to make it.'[4] The Introduction to the *Lehrbuch* was especially influential and sums up the essential argument of that work.

Unlike that of his colleague Emil Du Bois-Reymond, the fame of Ludwig did not spread far beyond his field. He never became a major public figure. Nevertheless, his enormous capabilities and his versatility, both as an investigator and as a teacher, attracted students to his laboratories from all over the civilized world, with the end-result that the schools of physiology which arose during the latter half of the nineteenth century in Germany, England, America, Austria, Italy, Russia, and Scandinavia bore the stamp of his influence. At the turn of the century nearly every important physiologist then active had once been a student of Carl Ludwig.

Ludwig's disciples have not been entirely unanimous in regard to the outlook put forward in the *Lehrbuch*. According to Robert Tigerstedt, Ludwig wrote as a mechanist, that is, he tried to give a 'purely mechanical explanation of life.'[6] William Stirling wrote that Ludwig merely sought in the *Lehrbuch* 'to bring the phenomena manifested by living beings into line with those of physical science, and to apply to their elucidation the same methods as are applicable to the study of physical and chemical phenomena.'[7] According to Paul Heger, 'For Ludwig, the living being is characterized not by the special nature of the force which animates him, but by the complexity of the reactions from

* The *Einleitung* (pp. 1–15) in Carl Ludwig's *Lehrbuch der Physiologie des Menschen*, Erster Band, Zweite neu bearbeitete Auflage, Leipzig & Heidelberg, C. F. Winter'sche Verlagshandlung, 1858.

[1] LITTLEFIELD, HENRY W., *History of Europe since 1815*, New York, Barnes & Noble, 20th ed., 1959.

[2] The vivisection question in Germany. *The Nation* (*New York*), 1879, **28**, 417–418.

[3] HIS, WILHELM, 'Carl Ludwig and Carl Thiersch,' *Popular Science Monthly*, 1898, **52**, 338–353. Translation of *Karl Ludwig und Karl Thiersch*, Leipzig, F. C. W. Vogel, 1895.

[4] BURDON-SANDERSON, J. 'Carl Friedrich Wilhelm Ludwig,' *Proc. roy. Soc. London*, 1895–96, **59**, Part 2, i—viii.

[5] ————,'Ludwig and modern physiology,' *Science Progress*, 1896, **5**, 1–21.

[6] TIGERSTEDT, ROBERT, 'Karl Ludwig, Denkrede,' *Biographische Blätter*, 1895, **1**, part 3, 271–279.

[7] STIRLING, WILLIAM, 'Carl Ludwig, Professor of Physiology at the University of Leipzig,' *Science Progress*, 1895, **4**, 155–176.



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which are derived the manifestations of life.'[8] Finally, Ludwig's most severe critic, John Scott Haldane, considered the *Lehrbuch* as a mechanist textbook in whose 'general plan there is absolutely no place left for the living organism as such.'[9]

Owsei Temkin has recently suggested that the programme of the physical movement in German physiology was formulated in the preface of Du Bois-Reymond's *Untersuchungen über thierische Elektricität* and that this programme amounted to mechanistic materialism.[10] It is true that the preface is an example of that outlook in its most extreme form.[11] Nevertheless, in view of Du Bois-Reymond's own assertion that Ludwig was the 'standard bearer of the school' (*'Fahnenträger der Schule'*),[12] the Introduction to the *Lehrbuch* merits consideration as the theoretical *Fahnenträger* which opened the modern period in physiology.

In translating the Introduction, every effort has been made to carry over philosophical nuances into the English text. In rendering nineteenth century physical concepts from German into English, these have been expressed in the terminology of English language textbooks of physics and chemistry published at the time. Finally, the translators have drawn freely from the word choices of others, notably Lombard[13] and Cranefield,[11] who have previously published translations of passages from the Introduction.

## Carl Ludwig's Introduction

TASK. Scientific physiology has the task of determining the functions of the animal body and of deriving them consequentially from its elementary conditions.

All functions which depend on some sort of animal existence – however variously they manifest themselves in terms of their specific appearance, their spatial distribution, their absolute value and their time of occurrence–surely have in common the fact that a very great many conditions always interlace to produce them.

If, in fact, one subjects to investigation from this viewpoint some manifestation of life which is apparently quite simple, for example the flexion of the phalanx of a finger, one quickly discovers that the impulse to movement does not arise in the finger, but comes to it through a tendon connected to a muscle, while if one devotes one's attention to the muscle, one perceives that its function results from the effect of many like structures, the so-called muscular tubes. A precise analysis dissociates these further into the most varied constituents and succeeds therein in comprehending the muscular cylinder as a stable arrangement with readily variable constituents. In these latter [the analysis] discloses thereupon elements of finite but extraordinarily small magnitude through whose varying attractions the movements in the muscle are produced. However these very small elements are again divisible into chemical atoms, electrical fluid and luminiferous ether, substances which, in the end, offer unconquerable resistance to the means of analysis which science has at its disposal today. Since, however, we do not directly observe the movement in the muscular molecules, or even in the muscle sheath, the tendons, or the periosteum, but in the finger, only one side of our phenomenon is dismembered with the above consideration, namely that one which contains, in general, the cause of the movement. For since the movement is carried over [from the muscle] to its primary and secondary sheaths, and to tendons, bones and so forth, it encounters resistances which are dependent on the stiffness, elasticity, shape, etc. of these parts. All these phenomena, however, are themselves consequences of very intricate arrangements, which likewise must first be all divided into their elements, if the resolution of this manifestation of life is to be achieved.

[8] Heger, Paul, Ludwig (Carl Friedrich Wilhelm), *Dictionnaire de Physiologie par Charles Richet*, Paris, Librairie Félix Alcan, 1928, Tome X, pp. 267–276.

[9] Haldane, J. S., *Mechanism, Life, and Personality: An Examination of the Mechanistic Theory of Life and Mind*, London, John Murray, 1921.

[10] Temkin, Owsei, 'Materialism in French and German physiology of the early nineteenth century,' *Bull. Hist. Med.*, 1946, **20**, 322–327.

[11] Cranefield, Paul F., 'The organic physics of 1847 and the biophysics of today,' *J. Hist. Med.*, 1957, **12**, 407–423. This paper contains numerous excerpts in translation from the Du Bois-Reymond preface.

[12] Du Bois-Reymond, Estelle, and Diepgen, P., *Zwei grosse Naturforscher des* 19. *Jahrhunderts; Ein Briefwechsel zwischen Emil Du Bois-Reymond und Carl Ludwig*, Leipzig. J. A. Barth, 1927. Cited on p. 119 of Rothschuh, K. E., *Geschichte der Physiologie*, Berlin, Springer-Verlag, 1953.

[13] Lombard, Warren P., 'The life and work of Carl Ludwig,' *Science*, 1916, **44**, 363–375.

ELEMENTARY CONDITIONS. Whenever the body of an animal is subdivided to its ultimate parts, one is always led finally to a limited number of chemical atoms and to phenomena which may be explained by the assumption of a luminiferous ether and electricity. One draws the conclusion, in harmony with this observation, that all forms of activity arising in the animal body must result from the simple attractions and repulsions which are observed upon the coming together of these elementary substances. This conclusion would be unassailable if it were possible to demonstrate with mathematical precision that the mentioned elementary conditions in the animal body are so arranged with respect to direction, time, and quantity, that all functions necessarily originate from their interactions, whether the organism be living or dead.

This conception, is, as is generally known, not the traditional. It is that one among the newer, which, as especially opposed to the *vital*, has been designated the *physical*. Aside from all details, this view, finds its justification in the irrefutable requirement of logic that a cause shall underlie each result and in addition in that well-tried principle of all experimental sciences that one brings into consideration only what is indispensably necessary as a basis of explanation. It disputes thus the justification of setting up new bases of explanation, as long as the inadequacy is unproved of bases which are more elementary. It does this all the more decisively if bases such as neural ether, vegetative spirit, and so forth, have been contrived expressly to explain some dark phenomenon or other, when there is no other evidence for the existence of these substances and when these especially contrived explanatory bases do not satisfy rigorous requirements, as does, for example, the luminiferous ether of physicists. If such an hypothesis should come to satisfy rigorous requirements, however, then our point of view would never resist it, even if the basis of explanation were still new and unheard of. For support of these principles see the consideration by Du Bois, Animal Electricity, First Volume, Preface,* which is both nobly conceived and fertile in ideas.

MULTIPLICITY OF THE FUNCTIONS WHICH DEPEND ON GIVEN ELEMENTARY CONDITIONS. Even though the above requirements, which alone suffice for the physical conception, cannot be realized, it is at least quite certain that its explanatory bases must be taken into account in any examination of each and every living process, since they exist empirically. It is probable, moreover, that these [bases] alone suffice for formulation of a theory of the phenomenon of life, since they, so manifold and active, are quite enough to cause the abundance of the phenomena of life.

1. **Functions of the formless elements.** By virtue of the attractions between similar and dissimilar weighable atoms, finished substances are built up. Depending on the fervour of the mutual adherence of the atoms in the latter, they form a building material of variable density, stability, resistance, strength, durability, and elasticity. Empirically, however, each substance is found to have a particular arrangement of its weighable parts, proper to luminiferous ether and electricity. These relations manifest themselves through specific electromotive forces and electric conductivity, through peculiarities of colour, refractive power, transparency, and heat conductivity, phenomena which, insofar as they permit any explanation at all, point to an altered density of luminiferous ether within the space enclosed by the substance, and partly to a varying mobility of its atoms under the influence of ether vibration. The attraction between the dissimilar atoms leads to chemical compounding. Even among a few

* Du Bois-Reymond, E., *Untersuchungen über thierische Elektricität*, Erster Band, Berlin, Verlag von G. Reimer, 1848 (Translator's note).

elements the number of various possible combinations can be very great, since it is permissible not only for an atom of one element to unite with the atom of another, but also for one atom of a kind to unite with a group of others (a complex atom) and groups with groups. Now the compounds of various atomic numbers vary naturally from one another in their properties, although compounds of similar atomic numbers are not similarly characterized; for at the formation of each is also the influence due to the direction of the attractions within the complex atoms. If one now recalls that the *amounts* present of bound heat and bound electricity (?) play an essential role in the determination of properties, then it follows that compounds of even the same elements, with unvarying atomic numbers may produce a multitude of extremely varied substances, and thus all the greater are the possible varieties attainable through the compounding of similar elements, of various atomic numbers, or even more through the compounding of differing elements with constantly varying atomic numbers.

The multiplicity of the forms of chemical combination, although endless, can for our purposes be divided into two categories, one of which includes all those complex atoms which under certain conditions lack affinities to other compounds or elements, while the second category includes those endowed with affinity.

In calling attention to this difference one must remain mindful of the fact that a compound of several elements as well as the chemical affinity of an element are by no means determined by the type or number of the weighable atoms. For it is known that individual elements (oxygen and phosphorus for example), as well as innumerable other compounds, display active affinities at one time, but not at another. Thus, if the property being described is not inherent in the atoms themselves, but results from several conditions appearing together, then one may also say that chemical affinity is the resultant of definite components, which enter a reaction with certain directions and strengths. This expression applies particularly and without exception to the affinity which results from atomic linkage, where, here as elsewhere, the same total effects result out of the most varied individual forces and conversely the most varied total effects result out of the same individual forces, each according to the arrangement in which the latter come together. According to this picture the neutral substances would be those whose resultant is perceived as an affinity of zero, while the resultant of those endowed with affinity would be a finite value.

We now turn our attention to the final substances. Here we immediately discover that, however manifold are the modifications of affinity, certain of its general characteristics nevertheless recur, which we comprehend by the designation acids, bases, etc., etc. According to the conception just advanced, it cannot be surprising that both acids and bases, etc., are producible through combination of the same elements, but it is surprising how extensively C, H and O, partly by themselves and partly in combination with nitrogen and some of the negative metals (arsenic, antimony, bismuth, etc.), succeed in forming entire series of compounds which are related to one of the mentioned groups so that these compounds alone form a rich chemical world. Science can as yet give no answer as to what peculiarity causes precisely these elements, so richly represented in the animal body, to support this capacity. Science tells equally little as to how the reciprocal attractions of the atoms come about so that the resulting combinations belong to one or another affinity-group or how it is that complex atoms are able to assume the role of [simple] atoms so that it is possible to replace the elements in a compound by these complexes and therefore by an ever higher complexity of substances representing elements, to produce bodies which are equivalent in their affinity. Thus, as Löwig has demonstrated in a masterly investigation, methyl- and ethyl- take over the role of H and form compounds at the 2, 3, and 4 atom as does H with antimony, bismuth, etc., which, analogous to similar compounds of H with N to form ammonium, become bases, and may no longer be distinguished in their manifestations of affinity from ammonium and potash. The same is found in the Wurz substances, followed up by Hoffmann in such a distinguished way, which produce the ethyl-, methyl- etc. compounds, corresponding to $NH$, $NH_2$, $NH_3$, $NH_4$. No matter what the affinities may be, possible and attained, their consequences for the processes in the animal body are of fundamental importance. For survey, we separate them into chemical and dynamic.

A. CHEMICAL CONSEQUENCES. The significance of these differs according to whether the forces of the affinity between substances in contact with each other are sufficient or insufficient to cause a change in the atomic grouping. In the latter case, we regard the transformation of adherence into solution as a particular expression of attraction. Depressing capillarity, precipitates, etc. are expressions of repulsion. If, on the other hand, the affinity does cause an alteration in the atomic constitution, then by the attractions which prevail during this process the two substances are either combined according to stoichiometric relations without preceding decomposition or all, or individual portions constituting them are united after a preceding decomposition of the complex compound. Or finally, substances endowed with affinity may break down to other groups without entering into new compounds with one another. If one surveys these manifold possibilities, it then becomes conceivable that in the animal body, which contains so many complex atoms, not only must the number of conversions, reaching almost into infinity, occur under circumstances which generally permit chemical change, to the point where a chemical equilibrium among all the substances is produced, but also that with quite simple variations, as for example in the quantitative relations of the substances present or depending on the temporal sequence in which the individual reactions occur, the steps from the beginning to the end of the possible disintegrations can be very diverse, quite different from one another.

B. DYNAMIC CONSEQUENCES. In this category we include those attractions and repulsions which result from the conversion and combination of chemical substances and act beyond the points of contact of weighable atoms. Substances attracted and repelled are put into motion through these effects exerted at a distance. This is a motion which can be transmitted to substances which initially are indifferent. Empirically, we regard heat and electricity in the animal body as the source of these attractions.

a. *Heat*. This word apparently signifies things which are very different. α *Free, transmissible heat*. This occurs either as *radiating* heat which, as is known, we are compelled to consider as a wave movement of so-called luminiferous ether; or as *conducted* heat which probably occurs only as a peculiar movement of a weighable substance, a movement transferred to it from the luminiferous ether. β. *Bound heat.* A great many specific states of matter (for example, the liquid and gaseous states of aggregation), the properties of metals, numerous combinations of atoms, etc., are manifested only with the assistance of heat. This occurs, to be sure, in such a way that, if a substance is transformed from one state (solid, oxidized, etc.) into another (liquid, metallic, etc.), a quite specific quantity of free heat disappears each time. If these substances are now led back into the first state, they again evolve the quantity of heat which has disappeared. Since these substances evolve and destroy heat according to circumstances, one might believe that this heat is present in them as a particular substance in a bound state. Since, however, there is evidence that free heat, either conducted or radiating, does not originate from a particular substance, this hypothesis is doubtful. Accordingly, only two ideas remain for explanation of the data included under the name of latent heat. According to one idea, the movement which we call heat acts to overcome the forces of affinity which bind certain atoms together. The heat-movement used up by these affinity-resistances would manifest itself again, however, if the dispersed particles succeed anew in their efforts at affinity, so that the act of combination of these atoms would be linked with some particular heat-movement. According to the other notion,* bound heat is interpreted as a movement between or within the atoms. This movement would be conveyed to the particles through heat which has been made to disappear. The particles would again enter into repose from this movement if they release their latent heat through entrance into a new combination. Whether either of these hypotheses is the correct one, or quite exclusively the correct one, has not yet been determined. No matter how these alternatives may be decided, this much is firm: Transformations which evolve heat can take place only as a result of transformations which destroy heat and more heat is never developed during the first transformation than was lost in the case of the second.†

The animal body is preeminently composed of heat-producing substances and the transformations which they undergo (mostly oxidations), evolve heat. The results of this evolution of heat could be very effective. Thus, among other things, heat which has become free could be used for the movement of weighable masses and thereby as a mechanical moving force. According to our present opinions, however, heat is not used this way in the animal body, at least not directly. Nevertheless, it may occur that a visible movement is converted into heat (through friction, etc.). Furthermore, the development of heat becomes significant as an affinity-producing circumstance, since under its influence oxygen combines and fermentations, etc. appear, which would not otherwise occur.

b. *Electricities.* Electrical manifestations may be deduced either from the existence of two separate weightless fluids or, more generally, from two separate states of matter. The electricities appear either as neutral (that is in such an internal interpenetration that their spatial separation cannot at all be demonstrated) or as separated (that is, in such an arrangement that the positive and negative states occur in spatially

* Ad. Fick. *Poggendorf's Ann.*, **91**, 287.

† Woods, Giesser Jahresbericht über 1851, p. 23.

separated points). In this latter disposition, the electricities occur either at rest (tensed) or in motion, and in this latter state they are quite capable of conveying movement to weighable substances. In order for electricity at rest to initiate movement, it must be accumulated in some electrically isolated weighable substance, and an identical or oppositely-set electricity must, under the same conditions, be brought near to it, to a certain distance. Then, as the tensed electricities attract or repel each other, they draw their material habitat with them. The conditions for this type of effect are found so seldom in the animal body and also only in locations of such subordinate importance (for example, dry hairs), that we can exclude it from our attention without further consideration. On the other hand, of quite another significance for physiologists are the states of separated electricity occurring in transmission, or the so-called currents. In terms of their origins, as is known, currents

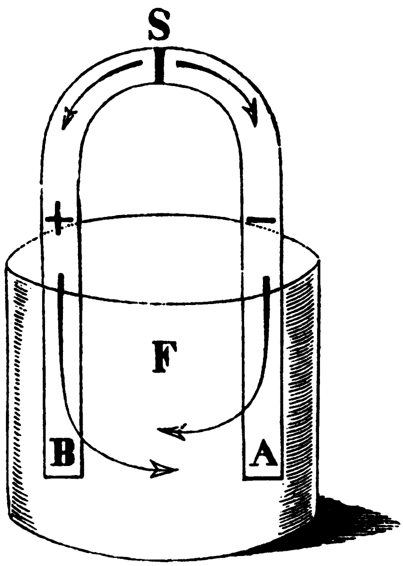


Fig. 1.

are thermal, inductive, and aqueous. For our purpose, only the first and the last of these, the galvanic and thermal, are significant. As is known, galvanic currents occur in an arrangement such as that presented schematically in Fig. 1, in which two electromotively active substances, A and B, are in contact at one of their terminations, at S, while their other terminations are immersed in an adhering liquid, which is chemically decomposable under the influence of electricity. The origin of the current circling in such an arrangement may be understood in various ways. The powerful electrical contact is explained in the following manner: At the contact of two electromotive substances a portion of the electricities existing neutrally within them is decomposed. This decomposition occurs at the contact points of the electromotive substances. From this point, the so-called electromotive barrier, the free electricities now flow over the conducting electromotive substances in such a way that one of the latter becomes coated with positive and the other with negative electricity. From these electromotive substances the electricities enter the liquid, and cross through it to the free terminations of the dispersers of electricity standing opposite (A,B), where they mutually neutralize each other and then anew are to be broken down at the source of electromotive decomposition. The significance of the electrical contact in relation to the fluid rests therefore in the fact that the latter conducts electricity, without at the same time decomposing it at its places of contact with the electromotive substances in the same arrangement in which it was disintegrated at S. For, if it were the case that the fluid reacted negatively toward B and positively toward A*, then the entering + and — electricities would be thrown back at the liquid contact points, but if the liquid, on the other hand, reacts indifferently or positively toward B and negatively toward A, then current becomes possible, since from the liquid boundary out, A is coated with positive and B with negative electricity. This hypothesis explains perfectly how it is possible for a current to arise and it also corresponds with the data, but it is nevertheless insufficient. First of all, it completely neglects the fact that a current is observed only if a chemical decomposition takes place within the fluid conductor. In addition, it depends on the principal of eternal rotation, since it does not suggest the source of the extraordinary motive powers which are peculiar to electrical currents and give rise to them. The consideration that the motive forces characteristic of the electric current could not be formed without destruction of other motion producing forces leads to the assumption that one or another of the chemical conversions accompanied by a galvanic current could serve as the origin of the force, so that, in agreement with experience, no current could exist without decomposition.** It follows next to consider how chemical transformations are able to initiate a flow of current. The nature of this effect can be no other than that which under other circumstances produces heat. The factual evidence for chemical conversion as a means of initiating or maintaining an electrical current consists in this: 1. The electricities and heat bear such a relationship to each other that they may be activated reciprocally. In other words, the movement of electricity can be produced through heat vibration, and conversely, heat vibrations can be produced through an electric current. Experience, as is known, decides for this supposition. 2. Only those chemical conversions produce an electric current which under other conditions are able to cause heat to pass from the latent into the free state. 3. The maximum heat producible by a flow of electric current in a liquid must be equal to that which can be made free directly through the decompositions occurring in it without production of a current.† 4. If an electric current evolves heat, then, assuming the validity of our hypotheses, it must finally be converted into movement, with the loss proportional to the quantity of heat formed, an assumption which is in accord with the data. The conditions which impede a current (line-resistance) are those which cause it to evolve heat. (*Becquerel*, *Lenz*, *Joule*.)

The form and manner in which a current once evolved can initiate a movement of material parts are, as is known, extraordinarily varied. A current is capable of

* that is, if, as a result of the contact, B becomes coated with positive and the liquid with negative electricity, etc.

** Helmholtz, *Die Erhaltung der Kraft*, Berlin 1847, p. 37 and following.

† Holtzmann, *Poggendorf's Ann*, **91**, 260. Koosen, *ibid.*, 427 and 525. Fabre, *Ann. chim. phys.*, 1854.

imparting a locomotion to the liquids which it penetrates (electric diffusion). Two conductors, having had a current flow through them, can attract and repel. A current is also capable of initiating movements of material masses through dispersion of magnetism, through the evolution, in conductors through which the electricity has flowed, either of free heat or of kinds of gas with latent heat, etc.

2. **Functions of the forms into which the weighable and weightless substances are brought.** To the elements, presented thus far and determining the functions of the animal body, there comes as a further condition the form of its individual parts. The significance of the latter lies in determining the direction of a given moment, rather than in producing it. The universal validity of this proposition is at once clear if one considers that form is nothing other than the arrangement of parts within a substance resulting from some attractions. Form accordingly is important only because it changes the direction and the appearance in time of the movements which impinge on it or which are produced in the substance which it invests. The truth of this principle can be verified through a consideration of each function of the animal body, insofar as form is involved in its manifestation. We draw attention here only to the characteristic changes which are produced in the effects of muscular force by virtue of the bendings of the articular surfaces and the length of the bones; to the changes which light rays undergo in their path through the characteristic curves of the media of the eye, to the separate propagation of nerve forces within the nerve fibres, etc.

3. **Functions of external influences with regard to the processes occurring in the animal body.** The system of elements, which is locked into specific forms, which we call the animal body does not exist in isolation, but it is also subjected to attraction and repulsion acting at a distance, which arise from the many substances surrounding it. Accordingly, the attracting and repelling effects which the elementary conditions of the body exert on one another will not be the only factors from which derive the functions of the animal. As is evident, the heat of the atmosphere and the resistance of clothing to heat conduction, etc., will have an influence on the amount of heat in the animal body. The intensity of gravity where an animal body happens to be located will in part determine the density of its constituents, etc. Through this reciprocal interaction between the earthly and sidereal on the one hand and physiological conditions on the other, it is understandable that innumerable consequences are produced, and therefore a course of events within the animal body cannot be fully understood until it is specified which external influences assert themselves at any moment on the attractions existing spontaneously within the animal body.

CONCLUSIONS FROM THESE OBSERVATIONS FOR THE CIRCUMSTANCES WHICH CHARACTERIZE THE ANIMAL. As a consequence of the elementary functions mentioned thus far, it is clear that the individual animal must offer an extraordinary multiplicity in the phenomena which take origin in it; further, that the animal reveals itself as a system in which forces can develop in an apparently independent way, but that such evolution of force is possible only so long and to the extent that chemical conversions occur in it; further, that with the magnitude of the material transformations and the material substances introduced into and eliminated from the animal, its capability for evolution of force must decline (fatigue) and rise (recovery); further, that any new movement or attraction acting on the body from within or without produces not a simple, but a many-sided, complex variation of the animal organism; further, that the individual constituents of the animal body exist in a dependence on each other which is only conditional, etc.

These numerous agreements between the consequences of our premises and the actual phenomena of animal life, which could easily be increased even more, which are found without any auxiliary assumptions, rouse from the very onset a predilection for their correctness, all the more favourable inasmuch as it has not been possible in actuality to accomplish anything similar, even remotely, through any other of the methods of investigation used hitherto. This decides us then to put the physical outlook into practice, with full strictness.

THE GENERAL TASKS OF PHYSIOLOGICAL INVESTIGATION. Under the assumption of the validity of the above considerations, the following general tasks in the field of physiology may be declared as possible.

1. One strives to divide the animal body into its constituents, and attempts through some criterion, as rigorous as possible, to separate these latter from all others, divorced from their functions within the animal organism. This important and fundamental work is taken over by chemistry for substances and by anatomy for forms. The former employs atomic weights for reliable designation of its objects, as well as the most outstanding manifestations of the relationships for the usual reagents, crystal form and specific weight. Anatomy must according to these considerations designate its forms through specification of constant and, where possible, mathematically expressable relations. Unfortunately the greatest portion of anatomists content themselves with very slightly determined characteristics and partly with quite thoughtless measurements.

2. One strives to determine, for functions which arise in more or less complicated apparatuses, their absolute value, independent of the manner and method of how the given results are obtained from the processes which underlie them. These considerations apply, for example, to the determination of blood pressure, the rate of nerve conduction, the amount of respiratory air, etc. If the accomplishment of this effort in an individual case is rather difficult and if the measured function originates from the most important organs and is of a most important type, the value of the result will only be more statistical and less scientific, imparting to observers merely indications for a true physiological investigation.

3. One strives to comprehend one or another activity as a function of the conditions producing it. This task should be viewed as the highest form of physiological investigation. In general, one can use either of two methods to satisfy this necessary requirement. *a*. One combines either theoretically (through mathematical-physical calculation) or practically (through physical-chemical experimentation) a certain number of conditions of known characteristics, which approximate to the organic, and compares the effects they produce with those produced in nature. This direct method leads at once to the greatest disclosures, but it is only seldom usable. It has, however, already been used with success, as for example, artificial digestion, flow in elastic tubes, a particular electrical combination, etc., serving for illumination of the



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digestive process, blood flow, muscular activity, etc. *b.* If this path is not usable, another leads to the goal, usually with no less difficulty. It amounts to separating the factors involved in some process, no matter whether they are altogether known or not, into groups, some of which are held constant and the others varied in a measurable way, in which at times one excludes the functions arising from one or another process. Under the stated assumptions, this general method provides information on the share which a given condition (the variable) has in producing an over-all function, but (as the forementioned has taught us), without helping the variable to produce this over-all result through its characteristic effect on other conditions. This method immediately furnishes unlimited scope to the investigation and the explanations thereby acquired are always of value, with the assumption that one can meet the necessary requirements. However, one naturally cannot regard it as an application of the latter, if, as it only too frequently occurs, a condition is varied while the constancy of the residuum has not been assured. The proposition that each explanation gained through this means has some value does not necessarily exclude the other, that the value of the result may vary. With regard to this thesis, it may be stated that an investigation will provide fruitful clarifications, which will be all the more valid and true, the more it has been possible to vary the *elementary* conditions of a process.

PLAN OF EXPOSITION OF PHYSIOLOGY. It is known that the chemical elements entering the animal body join together for the most part to form the so-called combined atoms. These compounds of the first order combine into such second and higher orders that the vital functions produced by the chemical properties of the body constituents do not result from a direct interaction of the elements, but are determined through the end-results of their complex combinations. The chemical compounds of the body come together into solid and liquid states for the formation of microscopic forms. A number of these forms, similar or dissimilar, arrange themselves into groups more or less intimately placed together, separated from one another in space, the so-called secondary forms, or organs. Several such organs come into relation with each other, further, as organ groups, which are determined partly on a spatial and partly on a functional basis, and from whose mutual arrangement the so-called organism finally emerges.

These things that we know indicate the route that a presentation of physiological processes must follow in order to lead to their understanding. They require that one first present the relations which substances entering the body as chemical units have to one another, then the effects which result from their compounding, etc. In a word, our knowledge requires a presentation ascending from what is relatively simple, progressively to what is further developed.

The plan indicated here is followed throughout this work insofar as it does not lead, according to the facts of the science, to empty schematism and darkness. Accordingly, the physiology of atoms and physical states comprises the first part of the volume at hand. After this, the physiology is presented of nerve fibres and ganglia and the combinations preeminently arising from them. Then the teachings on muscle elements and on the organs formed through their working together are discussed.