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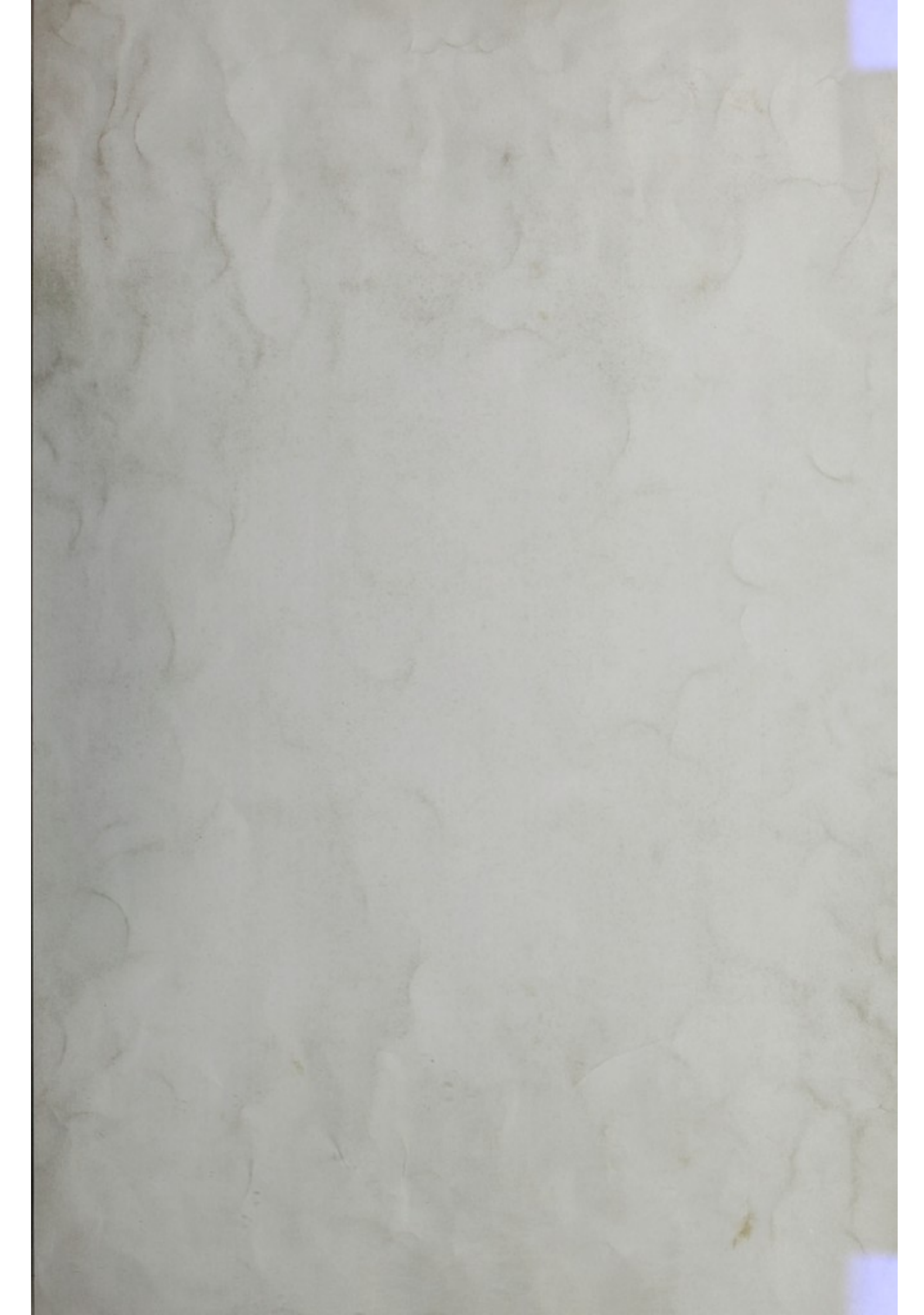
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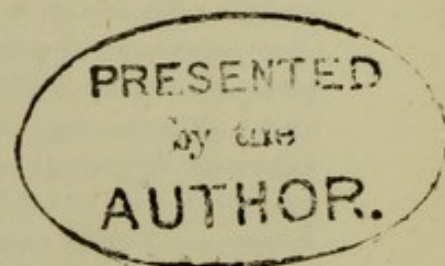
THE MUTUAL RELATIONS  
OF THE  
VITAL AND PHYSICAL FORCES.

BY  
WILLIAM B. CARPENTER, M.D., F.R.S., F.G.S.,  
Examiner in Physiology and Comparative Anatomy in the University of London.

*From the PHILOSOPHICAL TRANSACTIONS.—PART II. FOR 1850.*



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1850.

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VITAL AND PHYSICAL FORCES.

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XXXVI. *On the Mutual Relations of the Vital and Physical Forces* \*.

By WILLIAM B. CARPENTER, M.D., F.R.S., F.G.S.,

*Examiner in Physiology and Comparative Anatomy in the University of London.*

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I. *Introductory Remarks.*

THE degree to which the phenomena of Life are dependent upon Physical agencies, has been a subject of inquiry and speculation among scientific investigators of almost every school. That many of the actions taking place in the living body are conformable to the laws of mechanics, has been hastily assumed as justifying the conclusion that *all* its actions are mechanical; and hence arose the *iatro-mathematical* doctrines, which obtained considerable currency among the physicians and physiologists of the seventeenth century†. In like manner, the fact that many of the

\* The author thinks it due to himself to state, that the inquiry whose results are embodied in this paper has been occupying his attention for some years; in proof of which he may cite the following passage from a review of Prof. MATTEUCCI's "Lectures on the Physical Phenomena of Living Beings," contributed by him to the "British and Foreign Medico-Chirurgical Review" for Jan. 1848 (p. 235):—"There can be no doubt that the present tendency of scientific investigation is to show a much more intimate relation than has been commonly supposed to exist between *vital* and *physical* agencies; and to prove that, whilst the former are of a nature altogether peculiar, they are yet dependent upon conditions supplied by the latter. And the more closely these phenomena are investigated, the more intimate and uniform does that dependence appear; so that we seem to have the general conclusion almost forced upon us, that the *vital* forces of various kinds bear the same relation to the several *physical* forces of the inorganic world, that they bear to each other; the great and essential modification or transformation being effected by their passage, so to speak, through the germ of the organic structure, somewhat after the same fashion that heat becomes electricity when passed through certain mixtures of metals." Of the paper communicated by Dr. FOWLER to the British Association at its last meeting (September 1849) under the title—"If Vitality be a Force having Correlations with the Forces, Chemical Affinities, Motion, Heat, Light, Electricity, Magnetism, Gravity, so ably shown by Professor GROVE to be modifications of one and the same Force?"—he has no more knowledge than that which he has obtained from the short abstract of it in the Report of that meeting, published since the greater part of his own paper had been written; and whilst it is evident from that abstract that Dr. FOWLER has been pursuing the same line of investigation with himself, and with somewhat of the same results, he has not thought this a sufficient reason for keeping back his own communication from the Royal Society. For he thinks it will appear, from the extract he has cited, that he may fairly claim priority in the enunciation of the *idea*; and he ventures to believe that the systematic working out of that idea, which he has attempted in this paper, will give it a claim to the consideration of physicists and physiologists, such as it scarcely derives from the treatment which it has received from Dr. FOWLER—so far, at least, as the author can judge from the abstract referred to. (See the *Supplementary Note*, p. 757.)

† "The body," says Dr. BOSTOCK (History of Medicine, p. 165), "was regarded simply as a machine composed of a certain system of tubes; and calculations were made of their diameter, of the friction of the fluids in



changes of composition which take place within living bodies are analogous to those occurring externally to them, was assumed by another party as the foundation of the hypothesis that *all* the phenomena of life are of the nature of Chemical actions ; and of that hypothesis the *iatro-chemical* doctrines which superseded the system of GALEN, and which held their ground under various modifications for several centuries, were the natural expressions \*. The insufficiency of either of these hypotheses, or of both of them combined, to explain the phenomena of life, gave origin to a third, which was undoubtedly more correct in its fundamental conception than either of its predecessors had been ; the position assumed being, that the phenomena of each living body proceed from a *vital* agency, or *anima*, peculiar to each organized structure, and having nothing in common with chemical or mechanical principles †. The sect of the Vitalists, however, did not steer clear of the exclusiveness which had been the great fault of the chemists and physicists ; but, in looking at every action of the living body as the immediate result of vital agency, claimed for that agency much that is clearly attributable to the operation of chemical and physical forces.

Among modern Physiologists there is a distinct recognition of the fact, that many of the phenomena of living bodies may be placed in the same category with those of inanimate matter, and that such are not otherwise affected by vital agency than as this prepares or modifies the conditions under which they occur. But there is also a distinct recognition of the fact, that living bodies present a large class of phenomena which are altogether peculiar to them, and which can only be attributed to agencies of which the inorganic world is altogether independent ; and hence has arisen the notion of *vital agency* as the foundation of Physiological science, just as the notion of *affinity* is the foundation of Chemistry, and that of *mutual attraction* of General Physics. And putting aside all hypothetical considerations with regard to the abstract nature of that agency, Physiologists have been aiming to determine the laws

passing along them, of the size of the particles and the pores, the amount of retardation arising from friction and other mechanical causes, while the doctrines of derivation, revulsion, lentor, obstruction, and resolution, with others of an analogous kind, all founded upon mechanical principles, were the almost universal language of both physicians and physiologists towards the close of the seventeenth century."

\* "The leading principle of the chemists," says Dr. BOSTOCK (*op. cit.* p. 138), "was, that the living body is subject to the same chemical laws with inanimate matter, and that all the phenomena of vitality may be explained by the operation of these laws." The chemical physicians of the seventeenth century held "that the operations of the living body are all guided by chemical actions, of which one of the most important and the most universal is fermentation. The states of health and disease were supposed to be ultimately referable to certain fermentations, which took place in the blood or other fluids ; while these fluids themselves were the result of specific fermentations, by which they were elaborated from the elements of which the body is composed" (*op. cit.* p. 157).

† "We are told," says Dr. BOSTOCK (*op. cit.* p. 175), "that the *anima* superintends and directs every part of the animal economy from its first formation ; that it prevents or repairs injuries, counteracts the effects of morbid causes, or tends to remove them when actually present, yet that we are unconscious of its existence ; and that, while it manifests every attribute of reason and design, it is devoid of these qualities, and is, in fact, a necessary and unintelligent agent."



of its operation ; following the same mode of inquiry for this purpose, as that which has been found successful in other departments of scientific investigation. In doing this, it has been necessary for them to *isolate*, as much as possible, those phenomena which may be regarded as Chemical or Physical, from those which must be distinguished as Vital ; in order that, by the collocation and comparison of the latter, their mutual relations may be discovered. Still, after making every possible allowance for the operation of chemical and physical agencies, in the *direct* production of the changes of composition, mechanical movements, &c. which connect living beings (so to speak) with the universe around them, it is impossible for the discriminating inquirer not to see, that the influence of these agencies is *indirectly* exerted, to a yet greater extent, in the production or modification of purely vital phenomena. Thus, to take a very simple case, it cannot be for a moment doubted that heat and light exert an influence upon the vegetable germ, which is essential to its growth and development into the perfect plant, and to the performance of all the actions of the latter, whether these have reference to the extension of its own fabric, to the formation of organic compounds from the materials supplied by the inorganic world, or to the production of the germs of new individuals which are in like manner to go through the same series of phases. Hence light and heat have been designated as “vital stimuli ;” the current idea being, that their agency upon the vegetable germ excites or awakens the forces which were dormant in it ; and that, by enabling it thus to assimilate the new materials supplied by the inorganic world, and to give to these the structure of organized bodies, they contribute to develop the latent powers of these materials, which in their turn exhibit vital properties as they are made to form part of organized structures. Such, at least, is the doctrine of those who have most clearly expressed themselves upon the relation of the “vital stimuli” to the “vital properties” of organized bodies ; and the author has not been able to find in physiological writings, any indication of a more intimate relationship between the physical forces and vital phenomena, than that just stated,—save on the part of those who have vaguely identified Heat or Electricity with the “vital principle,” with about the same amount of philosophical discrimination as that which was exercised by the iatro-chemists and iatro-mathematicians of the sixteenth and seventeenth centuries.

The views of physical philosophers have been directed of late almost exclusively to the *dynamical* aspect of the inorganic universe ; that is to say, its phenomena have been studied as the manifestations of certain *forces* ; and each department of science takes cognizance of one or more of these, its *general* laws being nothing else than expressions of the modes and conditions of their operation, so far as known to the scientific investigator. That among all these forces there are very intimate mutual relations, is a conviction which has been gradually increasing in strength in the minds of philosophical inquirers during the whole of the present century ; in consequence of the extraordinary development which the sciences of Chemistry, Electricity, Mag-



netism, Optics, and Thermotics, have undergone during that period, and of the accumulation of facts which more or less distinctly indicate the existence of such relations to those who know how to read them aright. Amongst those who have laboured most successfully in this line of inquiry, Prof. FARADAY stands pre-eminent; but the author is not aware that any other attempt has been made to *formularize* the entire series of these mutual relations, than that which has been put forth by Prof. GROVE in his short treatise 'On the Correlation of Physical Forces;' in which he seeks to establish "that the various imponderable agencies, or the affections of matter which constitute the main objects of experimental physics, viz. heat, light, electricity, magnetism, chemical affinity, and motion, are all correlative or have a reciprocal dependence:—that neither, taken abstractedly, can be said to be the essential or proximate cause of the others, but that either may, as a force, produce or be convertible into the other; thus heat may mediately or immediately produce electricity, electricity may produce heat, and so of the rest" (p. 8).

That the same view might be probably applied to the mutual relations of some of the Vital forces, did not escape Prof. GROVE's sagacity, as will appear from the following passage near the conclusion of his essay:—"I believe that the same principles and mode of reasoning might be applied to the organic, as well as the inorganic world, and that muscular force, animal and vegetable heat, &c., might, and at some time will, be shown to have similar definite correlations; but I have purposely avoided this subject, as pertaining to a department of science to which I have not devoted my attention" (p. 49). The forces here alluded to by Prof. GROVE, however,—those of muscular *motion* and *heat*,—are really *physical* in their manifestations, though generated in living bodies; the purely *vital* operations of growth, development, and reproduction are not even named by him; and not the slightest hint is given by him of the existence of any such relation between the Vital and Physical forces, as it is the chief object of this paper to establish.

Believing, as the author himself does, that all *force* which does not emanate from the will of created sentient beings, directly and immediately proceeds from the Will of the Omnipotent and Omnipresent Creator (which is evidently the idea entertained by LOCKE\*),—and looking therefore at what we are accustomed to call the physical forces, as so many *modi operandi* of one and the same agency, the creative and sustaining will of the Deity,—he does not feel the validity of the objections which have been raised by some to whose opinions on philosophical questions he attaches great weight, against the idea of the absolute metamorphosis or conversion of forces. In deference to those opinions, however, he would here say *in limine* that his present object is to show, that *the same relation* (in whatever way defined) exists among the several vital forces, whose operation may be traced in living bodies, as exists among the physical; and that the vital and physical forces are themselves connected by a similar relationship. And as a mode of expressing that relationship

\* Human Understanding, Book II. Chap. xxi. *On Power*, § 4.



without any hypothetical assumption, he would state his idea of the "correlation" of two forces, A and B, to be this;—that A, operating upon a certain form of matter, ceases to manifest itself, but that B is developed in its stead; and that, *vice versâ*, B, operating upon some other form of matter, ceases to manifest itself, but that A is reproduced in its stead. The idea of correlation also involves that of a *certain definite ratio* or equivalent between the two forces thus mutually interchangeable; so that the measure of force B, which is excited by a certain exertion of force A, shall, in its turn, give rise to the same measure of force A as that originally in operation. Thus, when an electric current is set in motion (to use the common phraseology) by galvanic action, the amount of chemical decomposition which it will effect bears a precise correspondence (*cæteris paribus*) with the amount of zinc which has undergone oxidation; chemical action thus exciting electricity, which in its turn reproduces the original equivalent of chemical action. In like manner, when water at  $212^{\circ}$  is converted into steam, the heat which it receives is no longer manifested *as* heat, but mechanical force is developed in its stead, and this in a certain definite ratio; as soon, however, as the steam, losing its elasticity by condensation, returns to the condition of water, the original equivalent of heat is again developed, its mechanical force being no longer manifested.

Whether we regard it as most consonant to our ideas of the nature of force, to consider the one force, in any such case, as itself becoming *latent*, whilst it excites an equivalent measure of a force of another kind which was previously *dormant*,—or whether we consider that the one force is actually *converted* into the other, and that there is really no such condition as dormant or latent force,—the fact of the mutual relationship, and the definite character of that relationship, remains the same; and it is upon this, rather than upon any hypothetical representation of it, that the author wishes chiefly to insist. Although, therefore, the terms "conversion" and "metamorphosis" will be occasionally employed in the present paper, as the most convenient modes of expressing the author's meaning, he is desirous that it should be understood that he does not desire to imply anything else than the existence of the relationship just defined.

One more preliminary remark is necessary, upon a point on which Prof. GROVE has not thought it requisite strongly to dwell; namely, the necessity for a certain *material substratum* as the medium of the change in question. Thus, to take a familiar case, the correlation of Electricity and Magnetism is indicated by the development of magnetic attractions and repulsions in iron, when a current of electricity is made to circulate around it. In like manner, the correlation between Heat and Electricity is shown in the disturbance of electric equilibrium, which ensues on the application of heat to bars of certain dissimilar metals (especially bismuth and antimony) in contact with each other. The iron, in the first case, is the necessary medium for the development of the magnetic force by electricity; as the bars of dissimilar metals are in the second, for the development of the electric force by heat. So, again, in the



(so-called) magnetization of light by Prof. FARADAY, it seems necessary that the magnetic force should act through some material substratum, in order to produce any effect upon the luminous ray; the intensity of the effect varying according to the medium employed.—This consideration will be found of great importance hereafter, when the mutual relations of the Physical and Vital forces are brought under discussion.

## II. *Mutual Relations of the Vital Forces.*

Our clearest idea of the agencies essentially concerned in the production of vital phenomena, is derived from the study of the history of the development of any single organism; and it will be convenient to take that of the Plant in the first instance, as presenting us with these phenomena in their least complex assemblage.

The germ of a Cryptogamic plant, when set free from its parent, is a minute particle, apparently homogeneous in its character, but probably *a cell* in the earliest stage of development.—I. The first change which we witness, is its *growth* or enlargement; and this, when analysed, is found to involve several distinct operations. 1. The germ, under the influence of light, decomposes carbonic acid, and unites its carbon with the elements of water; at the same time decomposing ammonia, and uniting its azote with oxygen, hydrogen and carbon derived from the sources just named; thus forming *organic compounds*, such as no operation of ordinary chemistry has yet been able to imitate. 2. These organic compounds, at first in the condition of crude amylaceous and albuminous substances, need to be rendered *plastic* or organizable, by the process of assimilation, before they are fit to be applied to the extension of the living structure. 3. The organization of this plastic material then takes place, by which its materials are withdrawn from the fluid, and incorporated with the solid texture; and in this process they become fully possessed of the properties of the fabric of which they form part. 4. At the same time, a further process of organic transformation may generate other compounds, which occupy the cavity of the cell, and which are not destined to undergo organization, but are *secreted* or set apart for some ulterior purpose. In these, as in the organic compounds first generated, it is probable that the elements are arranged according to the laws of chemical affinity, although no agency but that of a living organized body has yet been found capable of bringing about their combination in these modes.

Thus we have in operation, in the simple *growth* of a vegetable cell, a force closely allied to chemical affinity, but so far different that it can only be exerted through a living organism; a force of assimilation or vital transformation; and a force of organization and complete vitalization. In speaking of them as distinct forces, it is only meant to affirm that their manifestations are diverse; for it cannot but be observed that they are all mutually dependent, and that they form part of a continuous series of phenomena which have but one ostensible cause,—the action of light and heat upon a living cell,—and but one destiny, the growth of that cell.



II. The *multiplication* of the cell, by spontaneous division or fission, is a process intimately connected with its growth, and takes place under precisely the same influences. It is by this kind of multiplication, that the simpler forms of vegetation are chiefly extended; and that the "germinal mass" is produced in the higher, the component cells of which, resembling each other in all their ostensible characters, seem to be nothing else than repetitions of that in which they all originated.

III. But from this homogeneous germinal mass, a complex and heterogeneous fabric is gradually evolved, of which the several parts or organs present wide diversities in structure and endowments. In this process of evolution or *development* (which obviously differs essentially both from growth and multiplication) it is usual to regard two separate agencies as in operation; namely, *Morphological Transformation*, which is concerned in the evolution of the several organs of which the entire body is composed; and *Histological Transformation*, the operation of which is limited to the component tissues of which these several organs are made up. It appears to the author, however, that, strictly speaking, there is but one such force; the form as well as the composition of each organ being determined by the *development* of particular tissues, and by their *multiplication* in one direction rather than another; he would therefore consider that the transformation of the simple primordial cells into other forms of tissue is the only indication of a distinct force which is manifested in the development of the fabric. Its assumption of its complete and perfect structure, is the result of that perfect harmony and balancing of the several forces of *growth*, *multiplication*, and *transformation*, which indicates, in the most distinct and unmistakeable manner, the controlling and sustaining action of an intelligent mind, acting in accordance with a determinate plan\*.

In the life of the fully-developed organism, we have still to trace the persistence of the same phenomena; for this is entirely made up of the vital manifestations of its component parts; and these, in the plant, are either cells of various forms, or are tubes formed by the coalescence of cells, which minister simply to the conveyance of liquids. The vegetable physiologist has long been familiar with the fact, that all the operations of the most truly *vital* nature are performed in *cells*, which have not departed in any considerable degree from their primitive type. These operations do not essentially differ in the most elaborate vegetable structure, from those which are performed in the simplest plants, and in the earliest stage of development of the more complex; the chief difference being, that the products of the actions of individual cells

\* The term "*germ-force*" has been employed by Mr. PAGET (Lectures on Repair and Reproduction) to designate the power which each germ possesses "to develop itself into the perfection of an appropriate specific form." The author has elsewhere shown (Brit. and For. Med.-Chir. Review, Oct. 1849, p. 413) that this term cannot be logically understood as anything else than "a comprehensive expression of all the individual forces which are separately concerned in the evolution, maintenance, and reparation of a living being." And so far from regarding the whole force which produces the evolution as being possessed by, or as residing in, the germ, it will be the author's object to prove that it is of *external* origin.



are employed for other purposes in the economy, instead of being appropriated by the cells alone. Thus the cells of the spongioles absorb the water, and those of the green surfaces obtain the carbon (from the carbonic acid of the atmosphere), which are required for the nutrition of the entire fabric; and it is especially in the cells of the leaves that those assimilating processes are performed, whereby the plastic fluid is prepared, at the expense of which the organization of new tissue may take place elsewhere, or from which the cells in remote portions of the fabric may draw the materials of their peculiar secretion. So, again, we find that the process of multiplication of cells is limited to certain parts in which the actions of growth are most actively going on; and that a large proportion of the solid fabric is composed of structures which have ceased to take any active share in the performance of the vital functions, and which retain their integrity simply because they are not exposed to influences that would occasion their decomposition.

Everywhere it is to be noticed, that if the condition of the tissues is such as to cause it to be changed by the play of the ordinary chemical affinities, it can only retain its normal character so long as it is performing vital actions; and when these cease, it either undergoes decay (which is the case with the softer tissues), or it becomes transformed into a substance which resists decay, as is seen in the conversion of "sap-wood" into "heart-wood" by the filling-up of the woody tubes with sclerogen, resinous secretions, &c., which have little tendency to decomposition. And it will be observed, too, that the combined influence of warmth, air, and moisture, which favours the rapid decay of dead tissue, is that which most promotes the growth of the living plant. Further, the more rapid and energetic are the processes of growth, the sooner (generally speaking) are they succeeded by decomposing changes; this is seen especially in the Fungi, whose growth is more speedy, and whose degeneration is more immediately consequent upon the completion of their term of life, than that of any other tribe of plants; and it is seen also in cases in which the leaves have been forced into extraordinary activity by an excess of heat and light, their death and exuviation being thus induced at a comparatively early period. Conversely, if the vital operations be retarded by the withdrawal of the external agencies on which they are dependent, we find that the life of the structure is proportionally prolonged, and the decomposing changes are retarded accordingly; this is seen in the well-known fact, that a bouquet of flowers may be made to preserve its appearance of freshness for some time longer when kept in a dark room than it would do if exposed to light. These facts, and many others which might be cited, indicate that every integral part of the living fabric possesses within itself a capacity of being so acted on by external agencies, that the very forces which would tend to decompose and destroy it if it were dead, only excite it to vital activity if it be alive; but that this capacity lasts no longer than the completion of its own term of growth, every individual cell being destined to pass through a certain series of changes, the completion of which leaves it at the mercy of the physical and chemical agencies to which it may



happen to be subjected; and the duration of its life being inversely proportional to the rapidity with which these operations are performed.

In addition to the phenomena included under the general term of growth or development, we have to study those which constitute the proper *generative* process. This appears to consist, as the author has elsewhere shown\*, in the reunion of the contents of two of the cells which had been previously separated by the process of fission. In the simplest tribes of plants, it would seem as if *all* the cells thus springing from the same primordial source, were capable of performing the generative act by "conjugation;" but this capability, like other endowments, is limited in the higher plants to particular groups of cells, which are developed in organs distinct from those concerned in the acts of nutrition, and are obviously set apart from the first for the performance of the act of generation alone.

Various kinds of *motion*, again, are performed by the agency of the vegetable structure, although these are less remarkable than they are in animals. From the extended researches of Prof. SCHLEIDEN it appears probable that within *every* cell, at some stage of its formation, a circulation of fluid takes place†, which is sustained by agencies that cannot be regarded as mechanical, and that are intimately connected with the formative processes; varying in its rate with the general activity of those processes, and only ceasing with their cessation. Wherever a cytoblast exists, the currents radiate from it and return to it again; in other cases (as the *Chara*) they are observed to extend over the whole lining of the cell-wall; in both cases being connected with the part that shows the greatest vital activity. The *zoospores* of various inferior *Algæ* are covered with *cilia*, by the vibration of which these bodies are carried through the water, and deposited at a distance from their parent. These zoospores are minute cells, formed within certain cells of the parent fabric, and liberated by their rupture. So, again, the spiral filaments long since observed in the *Characeæ*, the *Hepaticæ*, and in Mosses, and more recently discovered in the *Fucaceæ* and in Ferns, have a peculiar independent movement, which seems obviously destined to diffuse them, and thus to bring them into contact with the germ-cells which they are to fertilize. Each of these spiral filaments is developed within a distinct cell. And lastly, in certain plants, both of high and low organization, sensible movements are occasionally to be witnessed, which are immediately due to changes of form in their component cells; these changes of form being sometimes spontaneous, that is, occurring as a part of the regular series of the vital operations of those cells, and not directly excited by any external influences, as we see in the rhythmical movements of the *Oscillatoria*; and being sometimes consequent upon mechanical or other irritations applied to the cells which exhibit them, as in the case of the closure of the fly-trap of the *Dionaea*, but not being at all the less dependent upon the vital endowments of those cells, which cease to exhibit them when their vital activity is diminished. The folding of the leaves of the *Mimosa pudica* appears to take place

\* Brit. and For. Med.-Chir. Review, Oct. 1849, p. 346.

† Principles of Scientific Botany, p. 95.



spontaneously in some cases, and to be an excited phenomenon in others, thus combining the characters of both classes of movement, and showing their dependence on similar properties of the contractile cells.

Further, in many of the higher plants, and also in animals, we witness movements of fluid through a capillary network, which must be wholly or in part due to the vital relations of the fluid and the tissues through which it is carried; no physical agency being capable of entirely accounting for these movements, and some of them taking place under circumstances, which, as in the case of the rotation within the cells of the *Chara*, &c., seem to exclude the idea of such agency. Thus the *cyclosis* of SCHULTZ (a recent observation upon which, apparently free from all fallacy, has been recorded by Prof. BALFOUR, 'Manual of Botany,' p. 128), whether or not an universal phenomenon, seems unquestionably to present the spectacle of a rapid capillary circulation, not maintained by any *vis a tergo*, but depending upon forces connected with the vital endowments of the parts through which it takes place. The movement of nutritive fluid in the canals excavated in the tissues of many of the lower Animals, in like manner, seems to be but little dependent on mechanical propulsion, and to be chiefly maintained by some power originating in the living tissues. And even the capillary circulation of the highest animals, in which the regular flow is sustained by the propulsive power of the heart, exhibits certain residual phenomena,—such as local accelerations and stagnations,—which cannot be attributed to changes in the rate or power of the heart's contractions, and indicate the existence of influences arising out of the vital relations of the nutritious fluids to the tissues through which its movement takes place;—this movement being most active when the formative actions of the part are being most energetically performed, and exhibiting a retardation as soon as any influence depresses them\*.

The forces concerned in the growth, development, and movements of Animals appear to be essentially the same with those whose existence has thus been traced in plants. The animal, however, deriving its nutriment from organic compounds previously elaborated, does not perform that preliminary operation, which is so remarkably intermediate between chemical and vital agency, viz. the production of ternary and quaternary compounds, of complex atomic constitution, by the union of their elements. But in animals we find an additional power, termed Nervous Agency, nothing analogous to which exists in plants; this power, related on the one hand to the conscious mind, to which it communicates impressions derived from the external world, is also related, in a very remarkable manner, to the vital endowments of the organism in general, as will be presently seen, and particularly to the contractile tissues; the most perfect form of which (the striated muscular fibre) is usually called into action through its instrumentality, in obedience to mental impulses.

\* That such is the case, must be admitted, the author believes, by all Physiologists and Pathologists who study the phenomena of the capillary circulation, whether or not they be disposed to admit the validity of the hypothesis of "vital attractions and repulsions" which has been offered by Prof. ALISON as an explanation of this order of phenomena.



In order to meet the more varied requirements of the Animal organism, a much larger proportion of its tissues undergoes various transformations, so as to depart more or less widely from the original cellular type, than we find to be the case in the plant; still it is no less true in the animal than in the plant—as proved by the researches of SCHWANN, extended and confirmed as they have been in this particular by the researches of all subsequent histologists—that *all the tissues possessing distinctly vital endowments\*, originate, directly or indirectly, in the transformation of cells*. And further, it may be stated, that *all the most active vital operations, in the Animal as in the Vegetable organism, are performed by tissues which retain their original cellular constitution with little or no change†*.

The several modifications of vital force which have now been enumerated will be found, when closely examined, to have a very intimate mutual relationship, however dissimilar may be the phenomena they produce. In the first place they are all exerted, even in the most highly organized living being, through a common instrumentality, the simple cell. Secondly, the entire assemblage of cells making up the totality of any organism, have all a common parentage; being linearly descended from the single primordial cell in which the organism originated. Thirdly, they are manifested in connection with each other, in those single-celled organisms, which are the lowest members of the two kingdoms respectively, and in which there is no separation or specialization of function.—Hence we may express them collectively under the general term of *Cell-force*; and seem entitled to affirm that each is a particular *modus operandi* of the same force as that which is concerned in cell-formation‡.

\* It may now be considered as a well-established fact, that the *simple fibrous tissues* may originate in a structureless blastema, and may be produced by its fibrillation, without passing through the intermediate condition of cells. But these tissues cannot be regarded as possessing any truly *vital* endowments; their properties being simply physical, and their uses in the economy merely mechanical.

† This general proposition was first advanced by the author in regard to the operations in which organic life consists (and which are common, therefore, to plants and animals), in his "Report on the Origin and Functions of Cells" in the Brit. and For. Med. Review for January 1843. The subsequent discovery of the cellular composition of the ultimate fibrilla of striated muscular fibre, by himself and Prof. SHARPEY contemporaneously, and the accumulation of various facts relative to the existence of cells or cell-nuclei at the peripheral extremities of the afferent nerves, as well as in the central organs, seem to justify the assertion that unmetamorphosed cells are the active agents in the production of Muscular and Nervous force; in the former case effecting contraction by their change of form, and in the latter developing nerve-force, which is transmitted along the fibres as its conductors.

‡ The author is particularly desirous that he should be understood as implying by the term "*cell-force*," *not* that the force is produced or generated *by* the cell, but that the growth of the cell is the most general objective manifestation of that force, and that the cell affords the ordinary instrumental condition for its exertion, though there can be no doubt that the force may be exerted in many cases in which cell-development does not take place. The use which he would make of the term is just that which is commonly made of the term "*Engine-power*;" every one knowing that the steam-engine possesses no power itself, but that it is simply the instrument most commonly employed, because the most convenient and advantageous yet devised, for the application of the expansive force of steam, generated by the application of heat, to the production of mechanical motion.



This inference derives a remarkable confirmation from a series of facts, which indicate that when that *specialization* of function takes place, which has been mentioned as a characteristic of the higher organisms, the cells which become the instruments of some one particular kind of operation seem to lose their other endowments,—as if the expenditure of the vital force of each cell upon any one purpose, unfitted it for any other agency. Thus the *assimilating* cells (whether floating in the nutrient fluids, or included in the absorbent glandulæ), whose function it is to convert the raw material supplied by the food into organizable *plasma*, exercise little or no purely chemical transformation; they do not undergo change of form; they do not exert any mechanical or nervous power; and they do not reproduce their kind. So, again, the cells which are specially endowed with the power of *multiplication*, seem to possess no other special vital endowment; simply receiving the nutriment which has been prepared for them by other agencies, and applying it to the production of new cells, which, if themselves possessed of more special endowments, do not reproduce themselves. Of this we see an example in the first development of the embryonic structure, the cells of which rapidly multiply by the process of fission, up to the time at which histological transformations commence, and then this multiplication almost or entirely ceases; so that (as in the case of the insect, whose larva is an embryonic mass of very rapid production, composed almost entirely of cells destined to undergo histological change during the metamorphosis) the perfect structure *may* be even smaller than that from which it is developed. In the formation of new parts which make their appearance at a subsequent time, the same rule generally holds good, viz. that their foundation is laid in a mass of cells which rapidly multiply up to a certain point without histological transformation, and then undergo histological transformation with little further multiplication. But the most striking illustrations of this principle are perhaps to be derived from those cases, in which a continual production of cells possessed of some special endowment goes on during adult life. Thus it is necessary for every act of *secretion*, that a new formation of secreting cells should take place within the ultimate follicles of glands. These ultimate follicles are really to be regarded (as shown by Prof. GOODSIR\*) in the light of parent-cells, which produce the true secreting cells in proportion as the materials of their growth are supplied by the blood. Now *these parent-cells themselves possess no secreting power, their vital force being entirely expended in the production of the true secreting cells*. On the other hand, *the true secreting cells possess no reproductive power, but die and are cast off when they have reached their maturity; as if their whole vital force were expended in the secreting process*, which is itself nothing else than a portion of the act of growth. This will be found, the author believes, to be the type of a large order of facts, of which some others will be presently noticed. Again, the cells which are endowed with the special *reproductive* power, exercised in the true act of generation, seem to possess no other endowment; they do not exercise chemical transformation, nor do they undergo

\* Anatomical and Pathological Observations, No. V.



histological change, nor do they multiply after the ordinary fashion. But here, again, we find that these cells are produced within others, whose whole endowment seems that of multiplication; the *sperm-cells* being generated in vast numbers within follicles or parent-cells, which have themselves no power of producing spermatie filaments; and each *germ-cell*, also, being a secondary product of the parent-cell of the ovule,—the other cells to which it gives origin (those which fill the embryo-sac in the vegetable ovule, and which form the vitellus of the animal unimpregnated ovum) being of very inferior character and transient duration. That a relation of reciprocity exists between the forces concerned in the growth, development, and maintenance of the individual organism, and those which are employed in the generative act,—so that an excessive expenditure of either diminishes the amount of vital force which is applicable to the other,—is an idea so familiar to physiologists, that the author need not here dwell upon it, further than to point out how completely it coincides with, and illustrates, the view for which he is contending.

When we look, moreover, at the tissues which have been developed from the original cells by histological transformation, we find that in proportion as they lose the cellular character, they for the most part cease to perform any strictly vital operation; as if the act of transformation had expended their vital power. We seem to see this in the development of tubes from cells, alike in the plant and in the animal, the tubes thenceforth serving merely for the conveyance of liquids; and in the development of the simple fibrous tissues of animals, the endowments of these fibres being purely physical, and what vital force they may retain serving merely to enable them to resist chemical change. When we look at the cells concerned in the production of *mechanical movement*, we find the same principle holding good in a most remarkable manner, these cells being apparently incapable of performing any other function. Thus the cells which constitute the fibrillæ of striated muscular fibre exercise no power of chemical transformation, they undergo no histological change, and they appear to be entirely destitute of the power of multiplication; the expenditure of their vital force in the act of muscular contraction involves their death and disintegration; and their renewal appears to be accomplished by a production of new cells by the continued agency of the parent-cell (or sarcolemma), which, itself possessing no contractile power, seems to hold the same relation to the contractile cells of the fibrillæ, that the parent-cells or follicles of glands hold to the true secreting cells occupying their interior. Again, the ciliary action, when the special endowment of a particular set of cells—as those lining the excretory ducts of the glands, respiratory organs, &c. of higher animals—appears to be in like manner incompatible with any other action, but to be the sole manifestation of the vital force of these cells. For the *ciliated epithelium is never a secreting epithelium*; so that in tracing the one form into the other, there seems to be such a marked transition in function (the mode of production and the general conditions of development being essentially the same) as clearly indicates that the ciliary action and the secreting agency, although very



dissimilar in themselves, are both to be looked upon as modes of operation of the same vital force as that which is exerted in the production of the cell. And this view derives remarkable confirmation from the fact, that in the history of the "zoospores" of the Algæ we have two distinct periods, one of ciliary action, and the other of growth and multiplication; *so long as the ciliary action continues, which is provided for their dispersion, no further vital change seems to take place in them; but so soon as this ceases and they become stationary, they begin to exercise chemico-vital transformations, and to grow and multiply as cells.*

These views in regard to the mutual relationship of the different kinds of vital force, are strikingly confirmed by the phenomena of *Nervous Agency*. There can be no reasonable doubt that the production of nerve-force in the central organs is dependent upon the development of the peculiar cells constituting the ganglionic or vesicular substance; and, as already remarked, the progress of physiological inquiry seems to justify the belief (long since entertained and expressed by the author) that either cells or cell-nuclei are the agents in the origination of nerve-force at the peripheral extremities of the nerve-fibres\*. The nerve-force thus generated is not merely expended in arousing mental activity on the one hand, or in exciting muscular contraction on the other, but has an intimate relationship (there can be no doubt) with all the other manifestations of vital force which the animal organism exhibits. So intimate is this relationship, so obvious is the controlling and regulating action of the nervous system over the operations of nutrition, secretion, &c., especially in the higher animals, that many physiologists have regarded these actions as necessarily *dependent* upon the exertion of nervous force. On the other hand, it has been urged with great plausibility by Prof. ALISON and others, that since the functions of organic life in Animals are performed under the same essential conditions as those of Plants, and since the acts of formation, secretion, &c. are effected by the very same agency in animals as in plants,—namely, by cell-growth,—there is no valid reason for regarding them as dependent upon nervous agency; although it must be freely admitted that they are greatly affected by that agency, being not merely accelerated and retarded through its influence, but also altered in kind. The view here advocated will, it is believed, afford a definite scientific expression for all the phenomena which bear upon this question. For, just as electricity developed by chemical change may operate (by its correlation with chemical affinity) in producing other chemical changes

\* There can be little doubt that such is the function of the cells of the retina, which are shown, by the history of the development of the eye, actually to originate in the optic ganglion. The same appears to be the fact in regard to the cells in relation with the peripheric expansion of the auditory nerve, which originate in the auditory ganglion. (See Mr. H. GRAY's paper "On the Development of the Retina and Optic Nerve, and of the Membranous Labyrinth and Auditory Nerve," at p. 189 of the present volume of the *Philosophical Transactions*.) And it seems probable from the researches of KÖLLIKER (*Annales des Sciences Naturelles*, Ser. III. Zool. tom. vi. p. 102), that the plexuses which appear to constitute the ultimate distribution of the sensory nerves in the skin, are really composed of nerve-cells, which have sent out very slender prolongations to inosculate with each other.



elsewhere,—so may nerve-force, which has its origin in cell-formation, excite or modify the process of cell-formation in other parts, and thus influence all the vital manifestations of the several tissues, whatever may be their own individual characters. And this expression will also be found available for the well-known influence of mental conditions upon the properties of the various tissues and secretions, since this influence can only be exerted through the medium of nervous agency. Further, it not only appears that a simple withdrawal or disturbance of the nervous force supplied to particular organs occasions a retardation or perversion of their vital operations; but there also seems evidence that an influence of *an opposite kind* may be transmitted through the nervous system, which is positively and directly antagonistic to the vital powers of the several tissues and organs;—such, at least, appears to be the only mode of accounting for the extraordinary effect of a *shock*, mechanical or mental, in at once and completely destroying the contractility of the heart, and in immediately bringing to a stand the vital operations of other parts; and it harmonizes well with the fact that, in hemiplegia, the “palsy-stroke” transmitted from the brain along the spinal cord almost invariably affects the leg less injuriously than the arm, and for a shorter duration, recovery first taking place in the leg, even when it has been at first paralysed as completely as the arm. If the nervous force be regarded as a *polar* force (as suggested by Messrs. TODD and BOWMAN, ‘Physiological Anatomy,’ vol. i. p. 237 *et seq.*), analogous in its mode of transmission to electricity or galvanism, it is not difficult to understand that the *reversal* of the usual direction of its action may produce the effects in question, regard being had to the opposite effects shown by Prof. MATTEUCCI to be produced upon nervous excitability by the *direct* and the *inverse* electric currents\*.

It is hoped that the foregoing considerations (in support of which many others might be adduced†) will have served to establish the general proposition, that so close a mutual relation exists between all the vital forces, that they may be legitimately regarded as *modes* of one and the same force. The most general and characteristic of the manifestations of this force, which serves to unite and connect all the rest, is that which is concerned in *cell-formation*; and to this act, many of the other agencies appear to be essentially related. Thus the tissue of a muscle is constructed solely with a view to its manifestation of contractile power; whilst the development of nervous matter has reference entirely to the peculiar operations in which it is to be concerned. We find only one kind of tissue serving for the generation and transmission of nervous power; this alone affording the *material substratum* through which the vital force can manifest itself as nervous agency. And so, in like manner, it can scarcely be doubted that the contractile tissues, the assimilating cells,

\* Lectures on the Physical Phenomena of Living Beings, translated by Dr. PEREIRA, p. 262.

† The dynamical relations of the nerve-force to mental agency, on the one hand, and to the several vital forces on the other, constitute a field of inquiry of vast extent and profound interest. To this inquiry the author purposes to apply himself, should the views enunciated in this paper be accepted as true, or even probable, by those most competent to judge of their merits.



the secreting cells, &c., have their own respective peculiarities of structure or composition, whereby they are severally enabled to serve as the material substrata, through which the vital force is exerted in the production of the various phenomena of life.

### III. *Relations of the Vital and Physical Forces.*

Having thus endeavoured to develop the fundamental relations which subsist between all strictly Vital phenomena, by showing that a "correlation" may be traced among the several forces to whose agency they are attributable, it is the author's purpose to inquire, whether any similar relation can be shown to exist between the *vital* and the *physical* forces.

In the conduct of this inquiry, it will be advantageous to take, as our starting-point, a case in which the existence of such a correlation appears particularly obvious; that, namely, of Nervous Force, the strong *analogy* of which to *Electricity* is admitted by all who do not believe in the *identity* of these two agents. The disproof of their identity will be found, the author believes, in the numerous experiments of Prof. MATTEUCCI and others, who have failed to procure any manifestations of a change in the electric state of nerves, through whose agency muscular contractions were being most vigorously excited; and in the well-known fact, that the conduction of nervous force is prevented by pressure on the nerve-trunk, or by other disorganizing changes, which do not impair its power of conducting electricity. All the facts which have been adduced in support of the *identity* of these two forces will be found readily explicable on the idea of their "correlation" or mutual convertibility;—electricity, when acting through nerve-fibres, developing nervous force; and nerve-force, when operating upon a certain special form of apparatus, developing electricity. This view the author purposes now to unfold in more detail; adducing in support of it facts which are so well known to physiologists and electricians, that there can be no occasion to do more than cite them.

1. If an electric current be made to traverse the trunk of a *motor* nerve for a short distance only, it will produce contraction of the muscles which are supplied from its branches. It was formerly supposed that the contraction was excited by the immediate action of the electricity upon the muscles; but it has been clearly proved that the electric current need not proceed to them, its passage along the trunk for a very short distance being sufficient to develop the nervous force in its branches.

2. In like manner, if the electric current be passed for a short distance only along a *sensory* nerve, it will excite in the sensorium the peculiar sensations ordinarily produced by impressions conveyed through that nerve; that is to say, the ordinary tactile sensations, if the current be transmitted along a nerve of common sensation; or those of sight, hearing, smell, or taste, if the current be transmitted along the optic, auditory, olfactory, or gustative nerves. And thus, as remarked by MÜLLER, we may, by proper management, be made conscious at one and the same time of pricking sensations, of flashes of light, of a phosphoric odour, and of a peculiar taste;



all excited by a peculiar cause, the transmission of an electric current along the sensory nerves, through which these modes of consciousness are respectively excited.

This production of muscular contraction on the one hand, and of various forms of sensation on the other, by the transmission of an electric current through a nerve-trunk, along a short distance only, appear to indicate that it is to the nervous force called into activity by the electric, and not to the electric force itself, that the phenomena are immediately due; and so strong an analogy presents itself between this development of nerve-force in a nerve, and the development of the magnetic force in a piece of iron, as the immediate and direct result of a certain application of the electric current, that, whatever may be the view taken of the relation of the magnetic force to the electric, the relation of the nervous force to the electric can scarcely but be placed in the same category. It is no objection to this view to say, that the nervous force can only be excited in the nerve of a living animal, or in that of an animal recently killed. In all instances of conversion of force, as already noticed, some form of matter is required as the medium of the metamorphosis; and a slight change in the condition of that matter may have a very considerable effect in modifying the process of conversion. Thus, it is by causing an electric current to circulate around a bar of iron, that we most readily develop the magnetic force; but the molecular condition of that iron, whether hard or soft, crystalline or fibrous, has an important influence upon the result. Now we know that the normal condition of the nerve-fibre can only be kept up by the continual performance of the changes which constitute nutrition; so that if these changes be interrupted, its molecular condition speedily undergoes alteration. Hence, the fact that the electric force can no longer call forth the manifestations of nervous force, when a short time has elapsed after the suspension of the nutritive processes by the stoppage of the circulation, is in no way inconsistent with the idea here advocated of the intimate relation between the two.

In order to complete the idea of "correlation," however, it must be shown that the nervous force may be the means of developing electricity; and it seems the only feasible method of accounting for the results of the experiments of DAVY, FARADAY, MATTEUCCI, and others, upon the Electric Fishes, to look upon the development of electricity as the result of the action of their nervous force upon the peculiar organic apparatus to which its production is attributed. For the electric power has been ascertained to be entirely dependent upon the connection of that apparatus with the nervous centres, by nerve-trunks of large size, whose branches are distributed with extraordinary minuteness through the ultimate subdivisions of the electric organs; if these nerves be wholly divided, the electric discharge can no longer be called forth in the usual mode; if they be partially divided, the electric power is proportionably weakened; if the "electric lobe" of the encephalon be destroyed, removed, or injured, the electric power is annihilated or weakened, in precise accordance with the degree of damage inflicted; whilst, on the other hand, if the "electric lobe" be



mechanically irritated, or if the nerves proceeding from it be excited to action, even after their separation from the central organ, electric manifestations are obtained, the intensity of which is proportional to the excitement of nervous power thus effected. Various other phenomena recorded by MATTEUCCI make it evident, that the amount of electric force generated by the electrical apparatus is in precise accordance with the amount of nervous force which is transmitted to it\*.

Thus it appears that whilst electricity excites nervous force through the instrumentality of the nervous structure, nervous force excites electricity through the instrumentality of the electrical apparatus; and the case seems to be one which points directly to the existence of the *same kind of relation* between nervous force and electricity, as exists between electricity and magnetism, heat, chemical affinity, &c., whatever may be the form in which we think it best to express our notion of that relation. No one, the author believes, who has once adopted the idea of "correlation" as subsisting among the physical forces, can look at the peculiar connections to which he has adverted, as existing between the nervous and electrical forces, without perceiving how completely it is applicable to them. And he cannot but think that some such idea must have been present to the mind of Prof. MATTEUCCI, although he has not met with any distinct expression of it in his writings†.

But Electricity is not the only physical force possessing this peculiar relation to the nervous force.

Our sensations of heat and cold are entirely dependent upon the power which *Heat* possesses of exciting nerve-force in the sensory nerves. Further, if heat be applied to a motor nerve in its course, it will call forth muscular contractions; and if applied to a sensory nerve, it will occasion sensations, both common and special; precisely after the manner of electricity. Conversely, there are phenomena well known to physiologists, which have not yet been explained upon the purely chemical doctrine of calorification, and for which it does not seem possible that any such explanation can account. Several of these phenomena appear to point to the nervous force as a direct agent in the production of heat; the amount of caloric thus generated being

\* The question whether a disturbance of electric equilibrium occurs during the contraction of a muscle, and whether this is to be looked upon as the direct result of the operation of the nervous force, or is consequent upon the molecular changes taking place in the muscle under the influence of that force, must be regarded as at present *sub judice*. If the former prove to be the case, we have another instance of the direct production of electricity by nervous force; if the latter, the same metamorphosis would seem to take place through the intermediate condition of muscular force.

† [Since this paper was written, the author has had the satisfaction of learning, from the perusal of Prof. MATTEUCCI's Eighth Series of "Electro-Physiological Researches," that he has formally adopted the doctrine of the correlation between the nervous and electrical forces, which the author had himself put forth, nearly two years before, in a review of Prof. MATTEUCCI's "Lectures." (See Brit. and For. Med.-Chir. Review, Jan. 1848, p. 232.) In addition to the proofs adduced above, Prof. MATTEUCCI has furnished a new series, arising out of the action of an electric current transmitted through a *muscle*, on the *nerves* which ramify through it. (See p. 296 of the present volume of the Philosophical Transactions.)—Nov. 20th, 1850.]



proportional to the expenditure of that force.—Thus a “correlation” is distinctly indicated between Nervous force and Heat.

Precisely the same may be said of *Chemical Affinity*; for the application of various reagents to the nerve-trunks may be made to call into action their peculiar endowments, whether these be motor or sensory; whilst, on the other hand, there is ample evidence that the chemical properties of secretions may be greatly changed under the direct influence of nervous force.

The power of *Light* to excite the nervous force is clearly indicated by the influence of this agent upon the optic nerve, whose peculiar force is excited by the impression of light upon its peripheral extremities; conversely, there are certain phenomena of animal luminosity, especially among the *Annelida*, which do not appear to be directly referable to chemical change, but which seem to be rather dependent upon a direct exertion of nervous power; vivid scintillations (resembling the luminous effects of an electric discharge through a glass tube spotted with tin-foil) being excited by any irritation applied to the nervous system of these animals\*.

The relation of *Motion* to the nervous force is too striking to be passed by. The peculiar vital endowments of a nerve may be called into active exercise, as well by pinching or pricking it, as by electrical or chemical stimuli; thus by pressure on a nerve of common sensation, pain is excited; by pressure on a motor nerve, muscular contraction; by pressure upon the eyeball, sensations of light and colours may be produced in complete darkness; pressure applied to the meatus of the ear, so as to affect the auditory nerve, will give rise to a ringing sound; and by quickly but lightly striking the surface of the tongue, near its tip, with the finger, a distinct taste, sometimes acid, sometimes saline, is produced†. Conversely, the nervous force appears convertible into motion through the medium of the Muscular apparatus, just as it excites electricity through the instrumentality of the electric organs of Fishes. That the motor force thus generated is always proportional, *cæteris paribus*, to the

\* This is the conclusion at which the author arrived some years since, from observations which he made at Tenby on a small Annelide (probably a species of *Syllis*), in which the luminous discharges are seen with extraordinary brilliancy, when the animal is subjected to irritation, as by slightly pinching or pricking it, or by the movement of the water around it. The same conclusion was contemporaneously arrived at by M. DE QUATREFAGES, from observations made on the Annelida of the coast of France. “En étudiant, à l'aide du microscope, de petites Annélides transparents, M. DE QUATREFAGES est arrivé à découvrir un rapport curieux entre certains phénomènes de phosphorescence animale, et l'influence de l'agent qui détermine la contraction musculaire, et qui, à plusieurs égards, semble tant d'analogie avec l'électricité. Il est probable que la lumière plus ou moins vive, que répandent un grand nombre d'animaux inférieurs, ne dépend pas toujours de la même cause; que tantôt c'est un phénomène qui accompagne la décomposition des matières organiques, et que d'autres fois c'est le résultat de la sécrétion d'un liquide particulier; mais il est probable que, dans un grand nombre de cas, la cause de la phosphorescence est entièrement physique, et se lie, comme la contraction musculaire, à l'influence nerveuse.”—Rapport sur une Série de Mémoires de M. A. DE QUATREFAGES, relatifs à l'organisation des Animaux sans Vertèbres des Côtes de la Manche, par M. MILNE-EDWARDS (Annales des Sciences Naturelles, Troisième Série, tom. i. p. 23).

† See Dr. BALY's Translation of MÜLLER's Physiology, p. 1062.



degree of nervous power exerted, will be (the author believes) disputed by no physiologist; it is most remarkably illustrated in the extraordinary force developed under the influence of emotional excitement, which often calls forth a much greater measure of muscular power than the will can command.

Of the relations between *Magnetism* and the nervous force, the author thinks it preferable to say nothing more at present, than that various indications appear to him to be afforded, by recent investigations, of the existence of a direct and influential connection\*.

The relation thus pointed out between Nervous agency and the various Physical forces, is the more remarkable, when it is considered that the nervous power must be regarded as the *highest* of all the forms of vital force, both in its relations to mental action, and in its dominant power over organic processes of every kind. Considering how closely, as already pointed out, it is correlated to the forces concerned in muscular and ciliary movement†, in nutrition and secretion, in development and reproduction, it cannot be thought improbable that what is true of it should be true of them also; and that a relation of mutual convertibility should exist between these and one or more of the physical forces. Such relations the author believes to exist; and he now proceeds to adduce facts which appear to him adequate to support that belief.

The *muscular* force may be called forth, as is well known, by electricity directly applied to the muscle itself; by heat, cold, and chemical agents; and by mechanical irritation. These agencies, however, do not appear so directly concerned in the production of the motor power, as in occasioning that metamorphosis of living organized tissue into chemical compounds, whereon the development of the muscular force seems to be immediately dependent. It is now universally admitted that the disintegration of a certain amount of muscular tissue, and the new arrangement of its components in combination with oxygen supplied by the blood, is necessary for the development of its contractile force; and the considerations adduced by Prof. LIEBIG render it highly probable, that the muscular contraction may be regarded as proceeding from the expenditure or metamorphosis of the cell-force, which ceases to exist as a *vital* power, in giving rise to *mechanical* agency. The amount of muscular force developed appears to bear an exact correspondence with the amount of urea formed by the metamorphosis of the muscular tissue; and this metamorphosis involves the cessation of its existence as a living structure, and consequently the annihilation of the vital

\* Whatever scientific value we might have otherwise been disposed to attach to the researches of Baron von REICHENBACH on "Magnetism, Crystallization, &c. in their relations to Vital Force," they seem to derive some additional claims on our attention from the discoveries of Prof. FARADAY in regard to the universal operation of the magnetic force, and its relations to light and to the polar force of crystals,—discoveries which, be it observed, had not been made when the phenomena observed by Baron von REICHENBACH were first made public.

† In man and the higher animals, the ciliary movement does not appear to be in any degree controllable by nervous agency; but there can scarcely be a doubt that in the *Rotifera* it is thus governed.



forces which that structure possessed. We are, then, to regard the nervous, electrical, and other stimuli, under whose influence the muscular force is called forth, less as the immediate sources of that force, than as furnishing the conditions under which the vital force acting through the muscle is converted into the mechanical force developed in its contraction.

We do not yet know enough of the conditions under which *ciliary movement* takes place, to enable us to affirm that the production of mechanical motion through its means is in like manner the result of an expenditure of vital force; but the considerations formerly adduced in regard to the relation of ciliary action to other vital manifestations, together with the remarkable similarity between the influence of strychnia, opium, electric discharges, &c. upon the ciliary movement and upon muscular contractility, leave little room for doubt that what is true of the muscular force is true also of ciliary motion, and that it, too, is to be regarded as directly depending upon a conversion of vital force into mechanical motion. The continuance of motion in the cilia appears to be intimately related to changes taking place in the cells on which they are borne; and its persistence after the detachment of these cells from the remainder of the body, like the persistence in the contractility of muscular fibre which has been completely isolated from all its connections, proves that we must look to forces existing in them, and not to influences derived from any other source, for the maintenance of this curious operation.

Passing from these particular manifestations of vital force, which so remarkably indicate its relations to physical agencies, to those which, being concerned in the development and growth of organized structures, seem to have less in common with them, we shall fix our attention on the fundamental fact, that these Organizing forces (as we may conveniently designate them) are so completely dependent upon the continual agency of *Heat* (and in some cases of *Light* also), that they may be considered as the manifestations of the action of heat upon organized fabrics.

The necessity for this agency may be seen at every period of the life of organized beings of all kinds. In the lower tribes of animals, and in the entire vegetable kingdom, we trace this dependence in *the precise relation between the vital activity of each individual, and the amount of heat which it receives from external sources*. Every species is adapted to flourish within a certain range of temperature; and that amount of heat which is most effective in sustaining the life of one species, may be injurious or even fatal to another. But within the range which is compatible with the manifestation of its vital powers, we find that the relation is most constant between the temperature and the organizing force exhibited by each species. It is scarcely necessary to accumulate facts in support of a position so generally admitted; but the author particularly wishes to direct attention to the definiteness and exactness of this relation, and may instance the following facts as examples.

1. According to BOUSSINGAULT, the same annual plant, in arriving at its full development, and going through all the processes of flowering and maturation of its



seed, *everywhere receives the same amount of solar light and heat*, whether it be grown at the equator or in the temperate zone ; its *rate of growth being in a precisely inverse ratio to the amount it receives in any given time*. Hence it appears that the organizing force of Plants bears a relation of equivalence to the Heat and Light which act upon them.

2. This has been separately demonstrated with regard to the special influence of Light, in producing the decomposition of carbonic acid and the formation of chlorophyll, &c. ; the amount of carbon fixed by plants being *cæteris paribus* in accordance with the amount of illumination they receive. The influence of Light, it may be remarked, seems to be exerted only in this peculiar process of vital chemistry ; whilst that of Heat is exercised in *all* the other operations in which growth consists ; and hence it is that Animals are comparatively little dependent upon light, their food being prepared for them by the agency of the vegetable kingdom.

3. The rate of "rotation" of the fluid within the cells of *Chara*, &c., and the rate of "cyclosis" in the latex-vessels of *Ficus elastica*, &c., appear to be in precise relation (within certain definite limits) with the temperature to which these organisms are subjected ; the movement of the fluids being accelerated by warmth, and retarded or checked by cold\*.

4. In cold-blooded Animals, the same relation may be seen, between the activity of the organizing processes, and the amount of Heat to which they are subjected. The production of larvæ from the eggs of Insects, like the germination of the seeds of plants, may be accelerated or retarded at pleasure, simply by the regulation of the temperature ; and the time required for the last metamorphosis is precisely in the inverse ratio to the heat supplied ; so that, as in the maturation of the plant, each individual of the same species receives the same amount of heat, whether the intensity of its action be greater or less. Further, it has been remarked by Mr. PAGET†, that the processes of *development* seem to require a higher degree of Vital force than those of simple *growth* ; and it harmonizes admirably with the doctrine here contended for, that there appears to be a necessity for a higher temperature for developmental operations, than for those of simple increase. Thus in the economy of the Social Bees, as shown by Mr. NEWPORT, there is a special provision for generating heat during the last few hours of the metamorphosis, in which the tissues and organs of the imago are being completed ; and in the Viper and some other ovo-viviparous Reptiles, there seems to be an unusual calorifying power, for the purpose of promoting the development of the embryo. So, again, it has been found by Dr. EDWARDS and Mr. HIGGINBOTTOM that the metamorphosis of Batrachia requires a larger amount of light and heat than

\* It would almost seem as if some anti-vital influence, resembling that of "shock" in animals, could be exerted by mechanical injury on plants. When a portion of the leaf of *Vallisneria* is detached for the exhibition of the movement of "rotation" in its cells, the movement generally ceases for some little time ; the application of warmth will usually re-excite it ; and it may then continue for several hours or even days.

† Lectures on Repair and Reproduction.



suffices for their growth in the larva state, being retarded or even prevented by the want of a due amount of these agencies (see p. 753); and it has been also shown by Mr. HIGGINBOTTOM that the *development* of new limbs in the Triton, to replace those which have been lost, cannot take place at a lower temperature than about 60°, although the processes of *growth* go on under a much less degree of heat\*. The general propositions enunciated by Prof. MILNE-EDWARDS†, in regard to the geographical distribution of the Crustacea, indicate the existence of this relation in the most decided manner. They are, briefly, as follows:—I. The varieties of form and organization (which may be regarded as so many varied manifestations of the organizing force) increase as we pass from the Polar Seas towards the equator, the number of species thus augmenting greatly as we go southwards. II. The differences of form and organization are not only more numerous and more characteristic in the warm than in the cold regions of the globe; they are also more important. III. Not only are those Crustacea which are most elevated in the scale deficient in the polar regions, but their relative number decreases rapidly as we pass from the equator towards the pole. IV. The average size of the Crustacea of tropical regions is considerably greater than that of the tribes inhabiting temperate or frigid climes. V. It is where the temperature is most elevated, that the peculiarities of structure which characterize the several groups are most strongly manifested. And VI., there is a remarkable coincidence between the temperature of different regions, and the prevalence of certain forms of Crustacea.—It is interesting to observe, that the want of a high temperature is no obstacle to the growth and multiplication of individuals of a comparatively small size and low grade of organization; the Arctic and Antarctic seas being as numerously peopled with such, as the tropical ocean is with higher forms. But the preceding statements point to a direct and definite relation between Heat and the Organizing force, as manifested in this group of animals. A comparison of the facts relating to the geographical distribution of other classes of cold-blooded animals would probably justify the same conclusions. There can be no doubt of their general applicability to the Vegetable kingdom.

5. The influence of temperature upon the general vital activity of cold-blooded animals is no less remarkable. The facts determined by the experiments of Dr. W. F. EDWARDS‡ lead to this general conclusion;—that the *rate of life* of Batrachia and Fishes, of which the activity of their respiratory process is the exponent, varies directly (within certain limits) as the temperature of the surrounding medium; so that the *duration of life*, when these animals are deprived of air, either partially or completely, or are placed in any other circumstances unfavourable to its sustenance, varies inversely with the external temperature. Thus when frogs were confined in a limited quantity of water, and were not allowed to come to the surface to breathe, it

\* Proceedings of the Royal Society, March 18, 1847.

† Histoire des Crustacés, tom. iii. p. 555 *et seq.*

‡ On the Influence of Physical Agents on Life, *passim*



was found that they died in from 12 to 32 minutes, when its temperature was  $90^{\circ}$ ; in from 35 to 90 minutes, when its temperature was  $72^{\circ}$ ; in from 350 to 375 minutes, when its temperature was  $50^{\circ}$ ; and from 367 to 498 minutes, when it was cooled down to the freezing-point. The prolongation of life at the lower temperatures was not due to torpidity, for the animals performed the functions of voluntary motion and enjoyed the use of their senses; but it was occasioned by the diminished activity of *all* their functions, and their consequent less demand for air. On the other hand, the elevation of temperature increases the demand for air, and occasions speedier death when it is withheld, chiefly by producing a vast acceleration in the rate at which all the operations, both of animal and organic life, take place.

6. Although the warm-blooded animals are in great degree removed, by the independent calorifying power which they possess, from the influence of external temperature, yet it is very easily shown that their vital activity is no less under the direct and immediate influence of heat, than is that of cold-blooded animals. In fact, it would seem to be for the sake of keeping up their vital energy to a certain high and uniform rate, that they are endowed with the heat-generating power; and if this power be not exercised, and the body be cooled down, its vital activity is reduced, and at last extinguished. From the experiments of CHOSSAT\* it appears that Birds and Mammals cannot (except in the case of the hybernating species) be cooled down more than  $30^{\circ}$  below their natural standard, without the entire suspension of their animal and organic functions. This depression of temperature consequent upon prolonged starvation, was found to take place as soon as all the fat and other disposable materials in the body had been burned off. But so soon as animals thus reduced to a moribund condition were subjected to external heat, which artificially raised the temperature of their bodies, their sensibility and muscular power were renewed; they flew about the room, and took food when it was presented to them; and their secretions were restored. If this artificial assistance was prolonged, until the digested aliment was prepared in sufficient amount to maintain the combusive process, they recovered; but if it was withdrawn too soon, they died.—The hybernating species of Mammalia differ from the rest essentially in this, that the lowering of the temperature of their bodies does not destroy their vitality, but merely suspends their activity, so that they are reduced for a time to a condition in all respects comparable to that of cold-blooded animals but little removed above absolute torpidity; and in this condition, all that has been said respecting the influence of external temperature upon the rate of life of cold-blooded animals, applies to them also.

The vast mass of facts, of which the foregoing are examples, appears to the author to justify the conclusion, that Heat is something more than a *stimulus* capable of arousing a dormant vital force; but, on the other hand, they by no means justify the assumption that heat and the "vital principle" are identical. That Heat, acting upon or through an Organized structure, then manifests itself as Vital force,—or that heat

\* Expériences sur l'Inanition.



and vital force are "correlated,"—seems to be the expression of their mutual dependence, which is most in accordance with all our knowledge of the influence of heat upon organized beings; whilst conversely (as will be shown hereafter) it accords with the fact of the restoration to the inorganic world—under some form or other—of all the *force* thus withdrawn from it.

It may serve, however, to bring this idea into contrast with the notions usually entertained, and to illustrate its application more fully, if it be considered in its relation to the Development of any highly organized being from its primordial germ-cell. According to the doctrine current among some physiologists, the whole "organizing force," "*nisus formativus*," or "*bildungstrieb*," which is to be exerted in the development of the complete structure, *lies dormant in this single cell*, the germ (it has been affirmed) being "potentially" the entire organism. And thus all the organizing force required to build up an oak or a palm, an elephant or a whale, is concentrated in a minute particle only discernible by microscopic aid.

As a refuge from this doctrine, which seems almost too absurd ever to have gained believers, other physiologists (among whom the author formerly ranked himself) have affirmed that *vital force must exist in a dormant condition in all matter capable of becoming organized*; that the germ-cell, in drawing to itself organizable materials, and in incorporating these into the living structure, does nothing else than evoke into activity their latent powers; and thus that, with every act of growth and cell-multiplication, new vital force is called into operation, whereby the process is continually maintained. This proposition, it may be safely asserted, does not involve any manifest absurdity. It attributes to oxygen, hydrogen, carbon, and nitrogen, properties which they were not previously supposed to possess; but no one could logically deny to these elements the possession of dormant vital powers, whilst they held that a dormant magnetic power might be attributed to iron. In the one case, as in the other (it may be affirmed), a certain combination of conditions is needed to call the property into exercise; and the living cell, combining the elementary substances into the pabulum of its growth, and then applying this to its own nutrition, calls their latent vital properties into activity,—just as (it has been argued) an electric current, made to circulate around a piece of iron, develops the latent magnetic force of that metal.

The views of Prof. GROVE, however, strike at the root of the notion of *latent force* of any description whatever; all force once generated being, in his estimation, perpetually *active* under one form or other; and its supposed "latency" being a hypothetical condition, the idea of which is quite unnecessary when the force which has ceased to manifest itself is recognized under some other form. Thus, in his view, when iron is rendered magnetic by an electric current, the development of the magnetic force is rather to be looked on as the result of the conversion of the electric, by the instrumentality of the iron, than as a case of the excitation of one force previously



dormant, by another which is expended in thus evoking it. Such an analogy should rather lead the physiologist to look for some extraneous source of the organizing force; and to suspect that when organizable materials are applied to the extension of a living structure, and are caused to manifest vital forces, *some agency external to the organism is the moving spring of the whole series of operations*. And thus, according to the view here advocated, the vital force which causes the primordial cell of the germ first to multiply itself, and then to develop itself into a complex and extensive organism, was not either originally locked up in that single cell, nor was it latent in the materials which are progressively assimilated by itself and its descendants; but is directly and immediately supplied by the Heat which is constantly operating upon it, and which is transformed into vital force by its passage through the organized fabric that manifests it. The facts already cited, which show how completely dependent the process of germ-development, both in plants and animals, is upon the constant agency of heat, and how precisely its rate may be regulated by the measure of that force supplied to it, appear to the author to be so much better accounted for upon this view than upon either of the others, that he ventures to think that they demonstrate it almost as fully as the nature of physiological evidence will admit.

Having thus contrasted the doctrine for which he is contending, with those which are current among physiologists, the author thinks it well to point out that he no more regards heat as the "vital principle," or as itself identical with the "vital force," than it is identical with electricity or with chemical affinity. Nor does he in the least recognize the possibility, that any action of heat upon the inorganic elements can of itself develop an organized structure of even the simplest kind. The pre-existence of a living organism, through which *alone* can heat be converted into vital force, is as necessary upon this theory, as it is upon any of those currently received amongst physiologists. And it is the *speciality* of the material substratum thus furnishing the medium or instrument of the metamorphosis, which in his opinion establishes, and must ever maintain, a well-marked boundary-line between the Physical and the Vital forces. Starting with the abstract notion of Force, as emanating at once from the Divine Will, we might say that this force, operating through inorganic matter, manifests itself in electricity, magnetism, light, heat, chemical affinity, and mechanical motion; but that, when directed through organized structures, it effects the operations of growth, development, chemico-vital transformation, and the like; and is further metamorphosed, through the instrumentality of the structures thus generated, into nervous agency and muscular power. If we *only* knew of heat as it acts upon the organized creation, the peculiarities of its operation upon inorganic matters would seem as strange to the physiologist, as the effects here attributed to it may appear to those who are only accustomed to contemplate the physical phenomena to which it gives rise.

The variety of organic forms called forth by the agency of heat, which may be regarded as the products of its operation upon living germs, does not present any



real obstacle to the reception of this doctrine; since in *any* hypothesis which assumes a common force as operative in the living kingdoms of nature, it is necessary to admit that this force is modified in its action by the properties of the germ, just as that the general force of chemical affinity manifests itself differently in the reactions of each elementary and composite substance. And just as the chemist seeks to determine the laws of chemical affinity by observation and experiment, so does the philosophic physiologist aim to discover the general plan on which the vital force is exerted, in the production of the wonderful series of organized structures which have successively presented themselves on this globe.

In speaking of Heat as the physical agent especially concerned in the development of living organisms, and in the maintenance of their activity, the author would by no means leave out of view the other physical forces, *all* of which, if correlated to each other, as well as to the vital forces, must be capable of exerting an important influence on these processes. He has merely selected Heat, as the one whose operation is most extensive and most easily demonstrated; and every fact which indicates that other physical agencies are also in operation, will (of course) only add weight to his argument. To the universally-admitted agency of *Light*, in directly exciting one (at least) of the most important processes of vegetable growth, reference has already been made. But there is evidence that light has an influence upon certain processes of *development*, which cannot be accounted for by its agency in the fixation of carbon from the atmosphere, and in the production of organic compounds. One of the most remarkable examples of this agency is furnished by the experiments of MIRBEL upon the *gemmae* of *Marchantia polymorpha*. He found, after repeated trials, that during the development of these little discs, stomata are formed on the side exposed to the light, whilst root-fibres grow from the lower surface; and that it is a matter of indifference *which* side of the disc is at first turned upwards, since each has the power of developing stomata, or roots, according to the influence it receives\*. The experiments of Dr. W. F. EDWARDS indicate that a decided influence is exerted by light upon the metamorphosis of the Batrachia; since, according to his statements, when tadpoles, *arrived at nearly their full growth*, were secluded from the influence of light, but were supplied with aerated water and food, *they continued to increase as tadpoles* (so as to attain an extraordinary size, doubling or even trebling their usual full weight) without undergoing any metamorphosis†. The influence of light upon the

\* Nouvelles Annales du Muséum, tom. i.

† On the Influence of Physical Agents on Life, p. 53.—The results of the recent experiments of Mr. HIGGINBOTTOM appear to negative those obtained by Dr. EDWARDS, and to show that metamorphosis is only retarded by privation of light, when accompanied by reduction of temperature. But the remarkable fact above quoted from Dr. EDWARDS's statements, to which Mr. HIGGINBOTTOM has recorded nothing parallel, shows that there was some difference in the conditions of the two sets of experiments, which should prevent us from setting aside those statements, made (as they are) by a most trustworthy observer, until they shall have been more fully disproved.



minute Entomostracous Crustacea is well known. Their development is greatly retarded by the want of it; and the exuviation of their shells, which normally takes place at short intervals when they have attained their complete form and size (apparently for the purpose of freeing them from the minute plants with which their surface becomes clothed), is much less frequently performed\*. With these facts before us, we can scarcely refrain from suspecting that the deprivation of light may be the cause of the atrophy of the visual organs in certain animals which pass their whole lives in complete seclusion from its influence. This condition, which has been long known to exist in the common Mole, and also in the *Proteus anguineus*, and which has also been discovered in the *Amblyopsis spelæus*, a fish inhabiting the waters of the Great Cave of Kentucky, has recently been detected in a considerable number of species of Insects discovered in the very caverns of the Tyrol whose waters afford a *habitat* to the *Proteus*†. It may be supposed that the non-development of eyes in all these animals is a part of their original constitution, and is to be looked upon as an example of the adaptation of their organisms to the peculiar conditions of their existence; and such a view cannot at present be positively disproved. But the actual dependence of the nutrition of the visual organs, or (at least) of the nervous apparatus which forms the essential part of them, upon the continued agency of light, appears from the well-known fact, that if, by the complete opacity of the cornea, light is entirely prevented from entering the eye, the retina and the optic nerve become atrophied, and in time altogether lose their characteristic structure; thus clearly indicating the direct influence of light in keeping up those nutritive actions, by which the integrity of that structure is normally maintained.

That *Electricity*, also, has an important influence on the operations concerned in the development and maintenance of organized structures, can scarcely be doubted by any one who duly considers the proofs of the disturbance of the electric equilibrium in those parts of vegetable as well as animal bodies which are in a state of greatest functional activity, afforded by the observations and experiments of Prof. MATTEUCCI and others. At present, however, it would be premature to make any positive statement as to its *modus operandi*; although it would certainly appear most probable that it is more directly related to the chemico-vital changes of composition which take place in the living body, than to the operations of cell-growth, multiplication, and development, properly so called.

If the views advocated in this communication be correct, it follows that not merely are the *materials*, withdrawn from the inorganic world by vital agencies, given back to it again by the disintegration of the living structures of which they have formed

\* See Dr. BAIRD'S "Natural History of the Entomostracous Crustacea" (published by the Ray Society), p. 192.

† Specimen *Faunæ Subterraneæ*, Bidrag til den underjordiske Fauna, ved J. C. SCHIÖDTE: Kjöbenhavn, 1849.



a part, but all the *forces*, which are operative in producing the phenomena of life, are in the first place derived from the inorganic universe, and are finally restored to it again. The author thinks it not difficult to show that such is actually the case; the very same antagonism existing, in respect to the relation of the Vegetable and Animal kingdoms respectively, to the *forces* of the universe, as exists in regard to their *material components*. Plants, it will be recollected, form those organic compounds at the expense of which animal life (as well as their own) is sustained, by the decomposition of carbonic acid, water, and ammonia; and the *light*, by whose agency alone these compounds can be generated, may be considered as metamorphosed into the *chemico-vital affinity* by which their components are held together. The *heat* which plants receive, acting through their organized structures as *vital force*, serves to augment these structures to an almost unlimited extent, and thus to supply new instruments for the agency of light and for the production of organic compounds. The whole *nisus* of vegetable life may be considered as manifested in this production; and in effecting it, each organism is not only drawing *material*, but *force*, from the universe around it. Supposing that no animals existed to consume these organic compounds, they would be all restored to the inorganic condition by spontaneous decay, which would reproduce carbonic acid, water, and ammonia, from which they were generated. In this decay, however slow, the same amount of Heat would be given off, as in more rapid processes of combustion; and the faint luminosity which has been perceived in some vegetable substances in a state of *eremacausis*, makes it probable that the same is true of Light. And though the process of decay may be prevented or modified, so that the whole or a part of the materials of vegetable structures are disposed of in other ways, yet whenever they return to the condition from which they were at first withdrawn, they not only give back to the inorganic world the materials out of which they were formed, but the light and heat to which their production was due. Thus in making use of the stores of Coal which have been prepared for his wants by the luxuriant flora of past ages, man is not only restoring to the atmosphere the carbonic acid, the water, and the ammonia which it must have contained in the carboniferous period, but is artificially reproducing the Light and Heat which were then expended in the operations of vegetable growth. That the relative proportion of the light and heat thus restored, should be the same as that which they originally bore to each other, is by no means necessary; since each (according to Prof. GROVE's views) is convertible into the other\*. In the few cases in which *motion* is affected by the vital force of plants, this may be considered as restoring to the inorganic universe a certain measure of the force which they have derived from it, in the form of light and heat.

But the organic compounds which the agency of Light and Heat upon the Vege-

\* [In the second edition of his Essay on the "Correlation of the Physical Forces," just published, Prof. GROVE advances the opinion (p. 59) that when Light is "absorbed" (to use the ordinary phraseology), that is, when it ceases to manifest itself as light, it is usually converted into Heat.—Nov. 20, 1850.]



table structures has produced, are destined for a much higher purpose than that of being merely given back to the inorganic universe by eremacausis or combustion. In serving as the food of Animals, they not merely become the materials of their structures, but are rendered subservient to the production of the nervous and muscular forces. The animal, like the plant, receives *heat* from external sources; and this is expended, in the form of vital force, not merely in the building-up of the organism from its germ, but also in its subsequent maintenance. For, as was first definitely stated by Prof. LIEBIG, the vital force, which is applied in Plants to the extension of the structure, is appropriated in Animals to the development of muscular and nervous power; and this development, depending as it does upon a continual disintegration of the tissues which are its instruments, requires as continual a reconstruction of them. The organizing force required for this reconstruction or maintenance, appears, like that employed in the original operations of development, to be supplied by Heat; and it is a confirmation of this view, that we should find a provision (in those classes of animals which are constructed for the greatest development of nervo-muscular power) for the maintenance of a constantly high temperature, by the combustion of a portion of the organic compounds supplied to them as food.—Of the amount of *light* which is appropriated by Animals, we have no means of forming an estimate; but from the limited nature of its action on their economy, it probably bears an insignificant proportion to that which is applied to the purposes of vegetable nutrition. Thus, then, the forces on which the animal is essentially dependent, are the *affinities* which hold together the elements of its food, and which are embodiments (so to speak) of the light and heat by whose agency they were combined; the *heat*, which it derives in part from the physical universe, and in part from the combustion of some of its alimentary materials; and the small amount of *light* required by them, which is supplied from external sources alone. These forces may be considered as in a state of *continual restoration* during the whole life of animals, in the heat, light, and electricity, and still more in the motion, which they develope; and, after their death, in the production of heat and light during the processes of decay. During animal life there is a continual restoration to the inorganic world of carbonic acid, water, and ammonia; and the amount thus given up by the animal organism bears an exact proportion, on the one hand, to the amount of heat and motion which are generated by it, and on the other to the amount of organic compounds consumed as food. So that, on the whole there is strong reason to believe that *the entire amount of force of all kinds* (as of materials) *received by an animal during a given period, is given back by it during that period*, his condition at the end of the term being the same as at the beginning. And all that has been expended in the building up of the organism, is given back by its decay after death.

In bringing this communication to a close, the author would remark, that he has not sought in it to increase the knowledge of existing *facts*, so much as to develope new



*relations* between those already known. He has preferred, in fact, rather to build upon the foundation afforded by the generally admitted facts of Physiological science\*, than to go in search of phenomena, his account of which might be questioned by those indisposed to admit his leading ideas. If those ideas be correct, they will be found, he believes, to afford a precision to Physiological doctrines which they have never before possessed; and to open out a vast number of new lines of inquiry, which promise an ample harvest of results, not only valuable in a scientific view, but likely to be fertile in applications to various departments of the therapeutic art. At any rate, it is very important that Physiological science should be considered under the same *dynamic* aspect, as that under which the Physical sciences are now viewed by the most enlightened philosophers; and he trusts that the present attempt may thus aid in its advancement, even if it should answer no higher purpose.

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*Supplementary Note.*—[Since the foregoing paper was written, the author's attention has been drawn to the fact, that Mr. NEWPORT had been led, in the year 1845—"by the close relation shown by Dr. FARADAY to subsist between light and electricity, and by MATTEUCCI between electricity and nervous power, and by the known dependence of most of the functions of the body on the latter,"—"to consider light as the primary source of all vital and instinctive power, the degrees and variations of which, he suggested, may, perhaps, be referred to modifications of this influence on the special organization of each animal body." (See "Athenæum" for Dec. 6, 1845.) These views were embodied in a paper "On the Natural History of *Meloë*," presented to the Linnæan Society, and printed in the 20th volume of its Transactions. But as the passages in which they had been enunciated were omitted by the desire of the Council of that Society, no other public record of them exists than that just cited.—Nov. 20, 1850.]

\* [To his mode of stating some of these facts, the author is aware that exceptions may be taken; but he trusts that it may be perceived that his argument is a *cumulative* one, and that his conclusions rest upon a large number of *independent* probabilities. Consequently, even if *some* of his data should be found questionable, it does not follow that the validity of his general doctrine is disproved.—Nov. 20, 1850.]



