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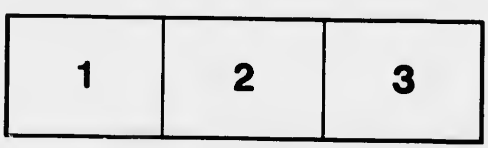
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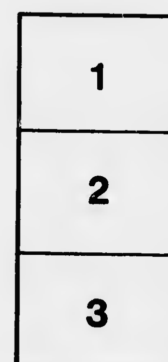
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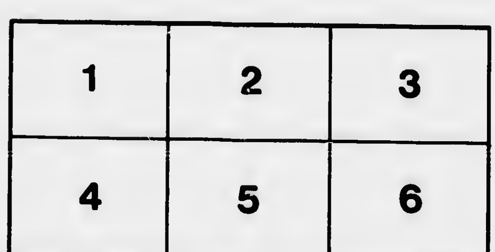
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THE CORRELATION

OF THE

VITAL AND PHYSICAL FORCES

BY

R. MAURICE BUCKE

Dr Campbell
with the author's compliments

THE CORRELATION

OF

THE VITAL AND PHYSICAL FORCES.

A Prize Thesis for the degree of Doctor of Medicine and Master of Chirurgery, defended before the Medical Faculty of McGill University,

Montreal, May 2, 1862.

BY R. MAURICE BUCKE.

(*From the British American Journal.*)

" The one spirit's plastic stress
Sweeps through the dull, dense world, compelling there
All new successions to the forms they wear,
Torturing the unwilling dross that checks its flight
To its own likeness as each mass may bear;
And bursting in its beauty and its might
From trees, and beasts, and men, into the heaven's light."

Although the subject upon which I have undertaken to write is not strictly a medical one, I shall make no apology for having selected it; for in the first place, it is not to be expected that a man so little read in medical science as a student must necessarily be, and who, at the same time, has had no experience at all, could advance new views of any value, or relate any facts (except in rare cases) not known before; for this reason, I say, it can make but little difference upon what he writes.

But secondly, and on the other hand, if he could write anything of any value, if he could add anything to the stock of positive facts or opinions possessed by the medical world, then certainly there is no subject upon which information should be more acceptable, and on which it is more wanted, than the nature of life; a phenomenon which has so often been considered to be an ultimate fact, and philosophic enquiry into the nature of which, has consequently, until lately, been almost entirely neglected.

Furthermore, the subject I have chosen, though not strictly a medical one, yet must be acknowledged to lie at the basis of all branches of medicine; to be in fact the trunk of the great medical tree; for as it has to do with the nature of life, so it is the very ground work of Physiology and Pathology, and as such underlies the whole subject of the practice of medicine; and I think it is not too much to say, that until we have some clearer understanding of life than we at present possess, the great blank which lies between the knowledge of the nature of medicines on the one hand, and their obvious actions on the other, will never be much encroached upon; and until our knowledge *covers* this, the practice of medicine can never be truly a science.

The theories of life have been constantly changing from the earliest times until the present day. This was to have been expected from the fact that thinking men are not apt to rest satisfied with the knowledge of any truth, but seek to explain it by a reference to other truth · to endeavour to establish, in short, some relation between all things that seem in the least degree analogous to one another.

Thus, in the middle of the seventeenth century, we see a sect of medical philosophers, headed by Silvius, holding the iatro-chemical doctrines,* which were supposed to be justified by the discovery of the fact that many of the chemical actions going on within the body were analogous to others observed in the inorganic world.

At the same time and later flourished the iatro-mathematical school, founded in the first place by Borelli,† and afterwards extended by Bellini.‡ The doctrine of these philosophers was based on the observation that many of the vital actions are governed by mathematical laws.§

The insufficiency of these hypotheses gave rise in turn to that of the *Archeus* of Van Helmont, the *Anima* of Stahl, and the *Vis Medicatrix Naturæ* of Cullen.

Still later than this, a belief became somewhat prevalent of so monstrous a nature, that, did we not know by daily experience the almost unlimited extent of human belief, we could never suppose it to have been entertained. It was that all the vital force required to build up any organism was stored up in the cell from which the plant or animal originally proceeded, so that all the force by which an oak, a whale, or an elephant was built up, was capable of being confined within the compass of a microscopic cell, of which thousands, or perhaps millions, would lie upon the point of a penknife blade.

Still later, when it was believed that the vital forces existed in a dormant state in all matter capable of undergoing organisation, light and heat were regarded as vital stimuli or forces which possessed the power of calling these forth from the latent condition. This theory cannot be said to be absurd, it involves no contradiction, and could not be logically denied while it was held that a dormant magnetic power was possessed by iron, that latent heat existed in steam, and the like; but when with Grove we deny the existence of such a property in iron, of such heat in steam, and the presence of latent force in every other case where it is said to exist; we have also a right to deny to carbon, hydrogen, oxygen, &c., the dormant power that is by this theory attributed to them.

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* Bostock's "History of Medicine," pp. 157–8. Francis Delabac Sylvius, a Dutch physiologist and chemist, was born 1614 and died 1672. "Cyclopædia of Biography," p. 917.

† J. A. Borelli, an Italian philosopher, was born 1603 and died 1679. "Cyclopædia of Biography," p. 89.

‡ L. Bellini, a celebrated anatomist, was born 1643 and died 1702. "Cyclopædia of Biography," p. 89.

§ Bostock's "History of Medicine," pp. 164-5.

Until the time that Fowler* wrote, I do not know that any steps were taken attempting to prove any closer relationship between the vital and physical forces than is expressed in the term vital stimuli. Since then, however, the belief in the mutual convertibility of these two set of forces—the vital and physical—has been steadily gaining ground, and is at present held by some of the most distinguished physiologists.

Now it has never been doubted, so far as I am aware, that however unlike in almost every way they may be, the matter which enters into the composition of any organised structure is the same as that met with in the mineral kingdom, but with its elements combined in different relative proportions;† the forces that bind them together in any one whole, whether chemically or physically, are also known to be the same as those seen in the world of dead matter, namely, chemical affinity and attraction of cohesion. But what is generally supposed to separate, by a well marked line, the living from the dead, is, that in the former is perceived the operation of certain forces which do not exist in the latter; which forces, under the name of functions, are most of them exhibited in common by the members of both the animal and vegetable kingdoms, while in the vegetable kingdom, and peculiar to it, we see displayed a power of organizing mineral matter; and in the animal kingdom, and peculiar to *it*, two distinct forces, the nervous and muscular, with special structures provided for their evolution; while at the same time in the inorganic world, are certain dynamical agents such as light, heat, electricity, &c., which specially belong to it, and which although they have always been allowed to have very similar actions upon living beings, and to be of vital importance to them, yet are not considered as belonging to them in the same sense as they do to the mineral kingdom. Now the question which I am about to consider may be thus stated—Is this line of demarcation, which I have attempted to point out, real or only apparent? Are these forces, or rather these two groups of forces, distinct and separate the one from the other, or are the forces which we see manifested by organized beings another and modified form of the forces existing in the inorganic world, borrowed from it, and when used again returned to it; just as the matter of which living beings are composed is taken from that by which they are surrounded, and when used, again returned to the dead world from which it was taken? It is the object of this paper to show that, abstractedly considered, no such line can be drawn;‡ that in fact there is no difference between these two groups of

* I refer to the notice of a paper by R. Fowler in the Report of the British Association for 1849, called "If vitality be a force having correlations with the forces, chemical affinities, motion, heat, light, electricity, magnetism, so ably shown by Prof. Grove to be modifications of one and the same force."

† "The elements of organic bodies are the same as those that constitute the inorganic world, *save that the relative proportions are different.*" Encyclopædia Britannica, eighth edition, Vol. VI, p. 501.

‡ Compare Buckle's "History of Civilization in England." He says, "What we call the divisions of nature into 'organic and inorganic' have no existence except in our own minds." Vol. II, p. 402. He is speaking of Sir John Leslie, who as early as the end of last century, seems to have had the same idea. He says, "All forces are radically of the same kind, and the division of them into living and dead is not grounded upon just principles." Leslie on heat, p. 133.

forces except in the mode of their manifestation, and that *this* is due to the difference in the material substratum through which they in each case manifest themselves. That in short, the vital and physical forces are correlated the one to the other.

And before proceeding further it may be well to state clearly what is meant to be implied in the following pages by the term "correlation." It may be thus defined,—one force, A, operates upon a certain form of matter and disappears, but in its place a second force, B, is developed; again, B is made to act upon some other form of matter, and in its turn disappears, and now A is reproduced, or perhaps not A, but some other form of force, C, D, or E.

Now this conversion of one force into another, if such we like to consider it, necessarily implies a definite quantitative relation existing between the forces thus capable of being changed the one into the other; that is, a certain amount of force A is equal to, and will produce a certain amount of force B, which in its turn shall be capable of reproducing the same amount of force A as originally existed. Thus a certain quantity of zinc is oxidated in the cells of a galvanic battery and a certain quantity of electricity, the result of the oxidation passes along the wires connected with the battery; but as a second consequence of the chemical action heat is evolved, so that we cannot have all the chemical force continued as electricity; nevertheless a remarkable relation has been shown to exist between these two, for if the electricity be employed in the decomposition of water, it will be found that for every equivalent of zinc that has undergone oxidation in each cell of the battery, an equivalent of water is decomposed;* so that the oxygen that disappears in one place reappears in the other, and the force that is set free in the union of the oxygen with the zinc is again taken up in the act of decomposing the water.

It is rarely, if ever, that we can reproduce so as to measure in another form all the force which has in any case thus merged itself; still in the case of some of the physical forces it has been determined, at least approximately, how much of one is required to produce, or be equal to, a certain quantity of another. Thus the experiments of Mr. Joule,† which Prof. Grove considers the most reliable that have been made upon the subject, show that the heat necessary to raise one pound of water through one degree Fahr., is equivalent to the motor force requirred to raise 772 pounds one foot.

This theory of the correlation of forces, followed to its consequences, naturally leads to the idea of the conservation of force, which supposes that as with matter so with force, there is a certain quantity in the universe, of which none is ever annihilated, and to which none is ever added, that in every case where one form of force disappears, another takes its place; and in like manner every force, which is in any case evolved, is so from an antecedent force which has been converted into it; and as this is true of every form of force so no one of these stands first more than another, and so no one can be said abstractly to be the cause of

* Faraday "On definite electrolysis." Phil. Tran. 1834, p. 77.

† Joule "On the mechanical equivalent of heat." Phil. Tran. 1850, p. 61, and quoted by Grove. "Correlation of physical forces," p. 130.

the rest, for though it may produce any of the rest, yet any of the others may also produce it.*

As for the abstract nature of matter and force, and their relation to one another, it matters little what view we take, and whether following Boscovich,† we conceive matter to be made up of mathematical points without form or size, acting on each other by attractions and repulsions; whether with Grove‡ we consider all forces as properties of matter, and therefore inseparable from it; or taking the more generally received opinion, we suppose matter to be one distinct entity, and force another acting upon it, the question before us remains the same and unaffected.

Now the whole subject of the correlation of forces naturally divides itself into three parts, as follows: 1. The correlation of the physical forces; 2. The correlation of the vital forces; and 3. The correlation of the vital and physical forces.

The first is often considered as proved,|| and there can be no harm in taking it as a postulate, and as such using it in the argument before us. Of course it would be impossible to enter into the proofs of it in this place, and after Prof. Grove's treatise on the subject, anything that I could say would be probably something worse than superfluous.

Though the second division, the correlation to the vital forces, does not properly form part of my thesis, yet for the sake of making the latter more complete than it would otherwise be, I shall say a very few words upon it before proceeding to the main object of inquiry.

The growth of all organized beings, from the simplest vegetable to the most complex animal, essentially consists in the multiplication of cells; all organized beings originating in this, the most simple structure endowed with life. All the forces of every kind which are manifested by organized beings are evolved through the instrumentality of cells, or by tissues which have originated in these, and retain, more or less completely, their cellular character; and further the allmost active vital operations are performed by tissues which retain, with little or no change, the perfect cell as their chief constituent.§ This has given

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* "It," the conservation of force, "must be considered as a necessary truth, and as such is a sound basis of deductive reasoning." Prof. Joseph Leconte. "On the correlation of vital and physical forces." Amer. Jour. of Science and Art, Vol. XXXVIII, p. 305. Though in this instance I quote from Prof. Leconte's paper, it will be readily seen by consulting it that on the most important points I differ from him very materially. On the conservation theory see also Dr. Wood, Phil. Mag., Vol III. p. 46, 1852. Buckle's "History of civilization in England," Vol. II. p. 384, where he also quotes from Faraday's "Discourse on the conservation of force." "Faraday says, "he agrees with those who admit the conservation of force to be a principle in physics as large and sure as that of the indestructibility of matter."

† Boscovich's theory of the universe. Ency. Brit. Seventh edition, Vol. I, p. 606.

‡ Grove "Correlation of the physical forces," Third edition.

|| As by *Faraday* in his "Discourse on the conservation of force," *Buckle*, "Hist. of civilization in England." Vol. II, p. 384. *Wood*, Phil. Mag. Vol. III, p. 64, 1852. *Leconte*, Amer. Jour. of Science and Art. Vol. XXXVIII, p. 305, &c., &c.

§ Carpenter's "Elements of Physiology," p. 49.

rise to the term "Cell force," which term expresses every form of force put forth by organized beings; according to this, therefore, the relation the cells bear to each other, will be also the relation which the different forms of cell force (vital forces) bear to each other.

Now this much being granted, it will be seen by the following considerations what an exceedingly close relationship this must be; for firstly, in the simplest forms of life there is no division of either structure or function, we have but one form of cell by which all the functions of the plant or animal are performed, that is by, or through which, all the forms of cell force put forth by such plant or animal are evolved; so that here the same liberates several forms of vital force. Secondly, in the highest organisms, although a particular form of cell is provided for the evolution of each force, yet they are all lineally descended from the single primordial cell in which the animal originated. Thirdly, although when a form of cell is once set apart for the evolution of any particular kind of force, it generally continues to evolve that and no other, yet it is a curious circumstance, and one that is hardly explicable upon any other view than that here taken, that under special conditions a form of cell may cease to liberate the form of force for which it was designed, and give off another quite different from it. Thus mucous membrane and skin are convertible into one another by a change in their external condition; and either (in the case of conversion of skin into mucous membrane) the epidermic cells are altered in their functions so that they secrete mucous, or else there is an earlier change in the direction of the force, by which means true mucous epithelium is grown upon the basement membrane which was the cutis vera. Just the same may be said of the change of mucous membrane into skin, and, in fact, of all such cases of conversion.

Innumerable other instances of this kind could easily be given. Thus the little hydra, or fresh water polype, may be turned inside out, and that which was the external surface will perform the office of digestion as well, or nearly so, as the membrane originally provided for that purpose; the gastric juice being poured out by its cells and absorption taking place through it, in a manner apparently quite normal.* Again in the case of gemmæ of *Marchantia polymorpha*, to be noticed again in another connection, the external influences determine entirely the respective sides that shall furnish the stomata and the roots. It is needless further to multiply instances, and I shall only remark that all cases of vicarious secretions † must be looked upon in the same way, and proceed to the fourth consideration, which is, that cell action in one place can, in virtue of its correlation with all other forms of this same force, control cell action elsewhere; and on this view we can most readily explain the influence of the nervous system over all the other functions of the body; for as electricity, developed by chemical

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* Carpenter's "Elements of Physiology," p. 253.

† On the subject of vicarious secretion, which my space does not permit me to dilate upon, see Carpenter's "Human Physiology," pp. 303-5, also p. 823. Todd and Bowman's "Physiological Anatomy," p. 700. Draper's "Human Physiology," p. 190. That instances of vicarious action should be rare in the higher animals, as man, should excite no surprise, for in them the cells have (so to speak) grown a long way apart from one another, but in some of the lower animals it seems to cost scarcely any effort.

action in one place, controls chemical change in another to which it has been conducted, so cell force in the form of nervous agency being conducted by its proper medium, nerve fibre, can accelerate, check, or alter cell action in other parts of the body;* and in this way we can understand how any sufficient cause acting through nervous agency, may, as in the case of shock, altogether stop some action essential to life, and so cause the death of the individual;† or if not stop the cell action, so pervert it that it shall be incompatible with a continuance of vitality.

Now of course it will not be supposed that when I speak of cell force I mean to express that the cells have the power of originating that force; further on it will appear whence I consider it to be derived. My idea of the agency of cells, as such, is simply this, that whereas any force in its origin, *as that force* must be produced by a conversion of some other into it, and that for this purpose some particular material substratum must exist in the passage through which the change takes place, so I believe the cell is the form of matter through which the physical forces, in the ordinary course of nature, pass in their conversion to those which we call vital.

The subject which I have, perhaps rashly, undertaken to treat of,—"The Correlation of the Vital and Physical Forces,"—I shall examine in three parts, which division is of course arbitrary, the subject itself being properly one and indivisible; but for convenience of writing and thinking upon it, such partition will be found to be of great consequence.

The three parts are, (I.) firstly, where the conversion takes place in the ordinary processes of life, through the chemical force; (II.) secondly, where the physical forces pass into the vital, and conversely the vital into the physical, by direct contact with living or recently dead tissue; and (III.) thirdly, the influence of the physical forces, principally light and heat, upon the living plant or animal in the ordinary state of nature.

Part I.

I commence by stating it as my belief that generally conversion takes place through the chemical force, that is to say, when any one of the physical forces merges itself into one of the vital, it does so by inducing a chemical change, and so liberating chemical force, which is then in virtue of the form of matter through which it acts, continued as a vital force; the form of this latter which is thus called forth, will depend upon the kind of tissue, that is, the form of cell through which the chemical force passes, in which it is liberated, and in which it merges itself into the vital force which is its resultant; and conversely, when a vital action manifests itself as physical force, it does so in the first place by inducing chemical change, and is then continued in the physical force which is the resultant of this change.

Supposing this to be the case, the following laws will be found of the utmost importance.

Law I. When bodies not already chemically united with others enter into combination, force of some kind is evolved, and the amount of this force will be

* Carpenter's "Human Physiology," pp. 739-743.

† Carpenter "On the mutual relation of the vital and physical forces." Phil. Tran.

in the direct ratio of the strength of the affinity existing between the bodies thus uniting.* In the same ratio also will be the intimacy of the union, the divergence of the characters of the resulting body from its constituents,† and the stability of the new compound.‡

Law II. When a compound body suffers decomposition, the force required to effect this, will be exactly equal to the force given out in the formation of that body from its elements.

Law III. If now the elements of a compound body enter into more intimate union—which presupposes the decomposition of the already formed body—the resulting force will be in the direct ratio of the strength of the affinity exercised by its elements, &c., as in law one, but minus the force which was required to decompose the pre-existing body.

Law IV. If a body be decomposed and give its elements to the formation of another body whose stability, &c., as in law one, is less than that of the body so decomposed, the force actually expended in effecting such change will be in the ratio of the strength of the affinity which existed between the elements of the preformed body, minus the strength of the affinity existing in the new compound.||

Now the force evolved in composition and required to effect decomposition may be (1) heat, as in ordinary combustion, and indeed in almost, if not in every act of chemical union, even when the main part of the force given out takes some other form. The converse of this is well seen in the case of the decomposition of the carbonate of lime by heat, and also very beautifully in the following experiment by Robertson.§ A substance capable of supporting intense heat without fusing, and at the same time incapable of being acted upon by either of its elements, (such as platinum or iridium) raised to a higher point of ignition and then immersed in water will decompose some of it, and bubbles of oxygen and hydrogen will rise to the surface. The heat required to effect this decomposition is, according to the experimenter, equal to 2386°. (2) This force may be electricity as when that is evolved by a galvanic battery, or conversely, when it is made to decompose water, the alkalies, &c. (3) It may be light as when this is given off along with heat in ordinary combustion, and this

* To illustrate this part of the law, I refer to Dr. Wood's experiments "on the heat of chemical combination." Phil. Mag. Vol, II, of the 4th series, p. 208, also Vol. IV, of the 4th series, p. 370.

† This part of the law will not apply to organic chemistry.

‡ Even if solution be regarded as chemical action, as it probably should be, (See "Thoughts on Solution and the Chemical Process," by T. S. Hunt. Amer. Journal of Science and Art, Second series, Vol. XIX, Jany. 1854,) it is no exception to this law, for when cold results, or the opposite of any force, it is due to the change in consistence which one of the bodies concerned has undergone. See Grove on "The correlation of the Physical forces," p. 174.

|| It does not, strictly speaking, devolve upon me to explain why, in the union of bodies, force is given out, and the converse. A very ingenious theory on the subject is put forth by Dr. Wood, who also gives his opinion as to why bodies unite, which is one step further back still from my subject. See Phil. Mag. Vol. III of the 4th series. Compare Grove "On the correlation of the Physical forces," pp. 175-8.

§ Robertson "On the effect of heat in lessening the affinities of the elements of water." Transactions of the Royal Irish Academy, Vol. XXI, p. 2.

is better seen in cases of slow combination such as phosphorescence, where light is much the most manifest of the forces evolved, and where heat is developed in such small quantities that for a long time it was doubted if any is liberated at all. Conversely it is well known that light has the power of decomposing several of the salts of silver, hydrocyanic acid, &c., and in contact with the green leaves of plants, carbonic acid and ammonia. So I might go on with the other forms of physical force, but to no purpose, as these examples will be sufficient to illustrate my meaning, and I am not now concerned with the correlation of the *physical* forces.

I shall now attempt to apply in some measure the laws which have been laid down to the manifestations of force presented by the two forms of life on this planet.

And first of plants.

Now the function of the vegetable kingdom in relation to the animal, is this; it takes the substances given out by the latter in its excretions or decay, such as water, ammonia, carbonic acid, &c., and certain salts of potash, soda, lime, &c., and from them it reforms the complex organic molecules from whose decomposition they were derived. This is the material view of the matter.

But these complex bodies are of much looser constitution (so to speak) than are the simple bodies they yield on their disintegration, so that for the change effected by the vegetable kingdom force is required, and by and by we shall see whence it is derived; at present we shall consider the first stage of vegetation, namely, germination, which will be seen to be essentially different from the after-growth of the plant, and closely allied to animal vitality.

The seed, then, is placed in the ground, and subjected to the influence of heat and moisture; soon the organized matter contained in it enters into decomposition; some of the albuminous matter becomes a ferment by means of which the starch is converted first into dextrine, and then into sugar, and dissolved. A part however does not stop here, but receiving oxygen from the air passes downwards by a regular process of oxydation to the lowest and most stable condition it can attain, and remains as water and carbonic acid.* In the meantime in the place of the seed we have a young plant, for roots have struck downwards, and a stem bearing leaves upwards. Up to this time no force but heat has acted upon the young plant, and now without light action will cease, unless it be some slight breaking down of tissue in one place and building up in another.

But now let us see from whence came the force which has from the matter contained in the seed built up a regularly organized fabric. To understand this let us weigh the plant thus formed, and supposing we had weighed the seed we shall find—putting out of account any water that may have been absorbed by the young plant—that some of the matter which it contained has disappeared. It will not be found in the earth in the vicinity. A moment's reflection will show us that it has disappeared, chiefly in the form of carbonic acid; for when germination began oxygen was absorbed by the seed, and carbonic acid and

* Gray's "Structural and Systematic Botany," p. 329. Encyclopædia Britannica, 8th ed., Vol. VI. p. 519.

water were formed. But carbonic acid and water are much more intimate and stable compounds than those which were broken down in their formation, therefore force must have been evolved in the act of their composition beyond the force that was required to break up the already existing compounds, (Law III).* This force operating through a pre-existing fecundated germ-cell manifests itself as vital force, and in accordance with, and under the direction of the laws of life, builds up the fabric as far as we have seen.

But now, still supposing light to be excluded, the plant comes to a stand-still, it has no force within itself that is capable of adding the dead matter around it to its structure. If some of it, from the operation of physical causes, becomes partially decomposed, some of the matter, by means of the oxydation of the rest, thus liberating the necessary force, may be used by the plant, but beyond these very narrow limits its growth cannot go on, and in these operations it is always necessarily losing weight. There is no force outside of it that can help it, heat has done its utmost in furnishing the requisite conditions for the performance of the chemical changes that have so far provided it with force; chemical affinity can now do nothing for it, for every manifestation of this requires a part of its own substance; unless indeed in such cases as the fungi, where the pabulum for the growth of the plant consists, as in the animal kingdom, of organic compounds; here the oxydation of the complex molecules taken into the plant, furnishes both the material for its growth and the force that is to apply that material, and make it part of the structure of the plant.

But now let a ray of light fall on the cotyledons and we shall find it immediately followed by the formation of chlorophyle, the decomposition of carbonic acid and ammonia in contact with the green leaves; water at the same time is absorbed, with which the free carbon unites, forming lignine, starch, sugar, &c., and with these elements, (C H O) the nitrogen of the decomposed ammonia combining, forms acids, neutral substances, mild or acrid bodies, alkaloids, &c., and finally the proteinaceous compounds albumen, fibrine, and caseine.

I shall not stop to inquire into the chemical processes by which these bodies are formed, indeed very little is known for certain on the subject except this, that these bodies are built up from the elements of the more simple ones mentioned above—carbonic acid, water, ammonia, salts, &c.—with the constant evolution of oxygen and absorption of light,† and this is perhaps sufficient for our present purpose, as I have not space to enter into minute details; and whether albumen, fibrine, and caseine are formed directly from the liberated elements of water, carbonic acid, ammonia, &c., or what is considered more likely, are formed from bodies which possess a certain degree of complexity, as starch and sugar, by the addition of nitrogen, sulphur, and phosphorus, derived from ammonia, sulphuric acid, &c., or finally, whether we suppose the nitrogen also to be derived

* Compare with the process I am describing the act of combustion of wood; here also we have ternary compounds—almost identical with those in the seed—breaking up and by the addition of oxygen forming the same simple substances as in the other case, every one knows of the force given out here, and that it is entirely due to the operation of law III there can be no doubt.

† Encyclopædia Britannica, 8th ed., Vol. IV, p. 519.

from complex bodies such as malamide, ($C^8 H^{10} N^2 O^6$) is of little consequence in the consideration of the question I am now concerned with.

However the process be looked upon we have here again the decomposition of one body, and the formation of another, but in an inverse order, as it were, to that observed in the former case; for whereas in that the body which was formed had more stability than that which was decomposed, and there was in consequence a surplus of force; in this case the body formed is in a much lower state of combination than that decomposed, therefore (Law IV) force has been required, and this force we have seen is supplied in the form of light.

There is another question, in connection with this supply of force to plants, of great interest and importance, but which I think may be best considered when I come to speak of the influence of light and heat on growth and development, where they do not seem to act so directly through the chemical force.

If we pass now to the consideration of animal life, we shall find it to be under the influence of the same laws as those which govern the life of vegetables, but to be in one sense diametrically opposed to the latter; for firstly, as to matter, it requires for its maintenance to be supplied with organic compounds, animals not possessing the power of appropriating to themselves mineral matter;* and secondly, as to force; it is supplied with no dynamic agency from any external sourrce, at least not in the same direct manner that plants are.

This difference may be briefly expressed by saying that through plants the other physical forces are converted into chemical force; and in animals this chemical force is reconverted into the ordinary forms of physical force, and so returned to its former state. In each case, by its passage through particular forms of structure, taking on, in some part of its course, the various forms of force called vital. And did this hold good throughout it would afford an exceedingly beautiful and useful line of demarcation between the two kingdoms, but unfortunately as with all other distinctions, the exceptions to it are numerous, though with them we need not now concern ourselves, as they have not the least effect upon the theory for which I am contending.

Now these two facts are easily seen to be intimately connected with one another; for as the food of animals is organic matter, that is, matter in a state of weak union, of highly complex chemical constitution, the elements of which readily, upon the least provocation enter into more intimate combination, at the same time (Law III) evolving force, so animals may be said to appropriate force along with the matter they eat.

Further, plants receiving force from without, do not again while they continue to live, or even perhaps till long after their death, give out that force but hoard it up; whereas animals taking in this force with their food, give it out in the performance of all their functions, such as innervation, muscular action, secretion, &c., and after the animal body has arrived at its full size, so that it requires no force or matter to be used in building it up which is not again given out in

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* I do not speak here of the water used by animals, because although they inject and in a sense assimilate it, it evidently can take no active part in the economy, as do the organic articles in their food, and though it is extensively used, it is so as a purely passive agent.

its breaking down, it stands in the same relation to force that it does to matter, not retaining any but giving out in some form or other all that it receives. But it will of course be observed that this is not the case as long as any processes of growth or development remain to be accomplished.

Let us now consider the animal organism in the same way as we have done the vegetable, and to do so let us begin with the egg.

The egg being subjected to a certain degree of heat, probably required to give mobility to the particles of which it is composed, and not itself meant to be converted into vital force, soon enters into the same sort of decomposition as did the seed in the former case, oxygen is absorbed, and carbonic acid and perhaps water is given out, through the minute pores of the shell or sac as the case may be, in which the egg is enclosed. As a consequence of the formation of these simple and stable bodies from the elements of other complex and unstable bodies, together with free oxygen, force is evolved. (Laws I and III). At the same time gradually, from a shapeless mass of albumen, a living being is built up. To effect this force is required; on the other hand force is known to be given out. Moreover we know that on the one hand it is *gradually* liberated; and on the other required at *somewhat the same rate.* Surely the conclusion forced upon us is that the force here evolved is applied when force is known to be used—rather than say, here force is annihilated; there created—or here force becomes latent; there it is roused from its dormant state. For is it not unphilosophical to suppose a cause which is more than adequate to produce an observed effect?

Now after the young bird is liberated from the shell, if it be weighed and the shell with it, it will be found to contain considerably less matter than did the egg from which it proceeded; we have seen where that matter has gone. And if the tissues of the young bird be analysed they will be found to contain, at least some of them, molecules such as hemato-fibrine $= C^{298} H^{228} N^{40} S^{2}$ O^{92}), more complex, less stable, and held together by a weaker affinity, than were those of the original constituents of the egg, thus displaying (besides the morphological and histological transformations that have taken place,) the results of the expenditure of force. (Law IV.) We have also seen whence that force was derived.

In another place I stated that my idea of the agency of cells, as such, is that they represent the form of matter through which the physical forces pass in their conversion into the vital. Now the form of vital force manifested by cells varies with their structure; and for any one kind of action we must have an appropriate form of cell. But contained in all seeds and eggs capable of life, we have a special form of cell, through which, undoubtedly, the chemical force acts as vital power when it builds up the plant or animal, and which if absent makes the material link incomplete; and the chemical force instead of passing to the vital, is given out in other forms, chiefly as heat. But whether the egg or seed be capable of life or not, still in its decomposition it must result, from the laws laid down, that the same amount of force will be given out by the time that its elements, in either case, have reached the same chemical level.

Now after the young bird or mammal, as the case may be, has used the food laid up for, or supplied to it by the female parent and has to shift for itself, it receives no force from without, as does the plant in a similar situation, and here, and not till we arrive at this point does the difference above mentioned begin, but its food consisting of such matters as being in a state of loose combination readily admit of the evolution of power by entering into greater intimacy of union. (Law III). At the same time, as if this were not sufficient, a free element of pre-eminently strong affinities is taken in by the animal to combine with them, as they run down to form the simple compounds.

But here it may be said that the young animal has not only to furnish energy for the performance of its organic and animal functions—respiration, circulation, locomotion, innervation, &c.,—but also it has to grow; increase in size. Its tissues continually breaking down in the performance of their respective functions, it has to restore them continually, and not only this, has to add steadily to their bulk. Whence comes the supply of force that shall be adequate to these wants? And here we see the purpose of the vegetable kingdom in its relation to the animal, perhaps more beautifully displayed than from any other point of view. For the vegetable having received force from without, holds it in trust, as it were, for the animal kingdom; and in the use of vegetable food it is known that the animal does not raise the compounds contained therein to any higher state of combination than that in which it receives them—except in the case of hemato-fibrine, and perhaps a few other instances. To build up its nitrogenized tissues it receives albumen, fibrine, and caseine; for its adipose tissue it takes in fat, though it can also form this last from starch or sugar; its gelatinous and cartilaginous tissues are supplied from the albuminous bodies by a process of diminishing complexity, and so on.

But this is not of much importance, after all, for the result would be the same, namely, that on the one hand animals receive compounds of great complexity and of loose chemical construction; and on the other hand their excreta consist of chemical forms of great comparative, and some of great actual simplicity, between the elements of which there exists great strength of affinity, thereby furnishing the conditions (Law III.) for the evolution of vast quantities of force, which being directed into the proper channels by means of the various forms of cells, through which it acts, performs all the functions of the body.

But here, if this be granted, another difficulty will arise in most minds, which at first sight might seem almost insurmountable, for, it will be asked, is it possible that such an immense amount of power of various kinds, put forth by animals, can be derived from the decomposition of what seems to be the comparatively small quantities of food they digest? To illustrate this forcibly, I was once for five days and four nights exposed to a temperature of from zero or below that point to a few degrees above the freezing point: during this time I was supplied with no food, no artificial heat, and travelled every day on foot through deep snow from morning till night. Now, I ask, could the muscular force employed, the heat evolved, and the vis nervosa put forth (without speaking of other forms of force liberated in less amount), have been derived from the decomposition of the tissues lost during that time? I make no doubt that the reply must be in the affirmative.

The answer to this difficulty resolves itself into two distinct parts. 1. The consideration of the quantitative relations of the forces in question; and 2. The economic powers of animals compared to those of a machine of merely human contrivance.

1. In the first place it must be acknowledged that we know little, if anything, of the relations of quantity borne to each other, by the chemical force on the one hand, and the various forms of vital on the other. But if we could get the resultant of any vital force when it merges itself into one of the physical forces, this being better understood, could more easily be compared, and this, fortunately, we can do in the case of the muscular force which as motion we can measure;—and I think it may safely be granted that far more than half the force given off by the body takes this form, thus enabling us to make a fair rough approximation to the result we are seeking. For if the relationship which exists between motion and heat be recollected—that the motor force capable of raising 772 pounds one foot, is only equal to the heat required to raise one pound of water through one degree Fahr.,—and if we then consider what a small amount of chemical action is necessary for the production of a considerable quantity of heat—how much heat, for instance, a little oil burned in a lamp will yield, while, at the same time it gives off vast quantities of light—I say if these two considerations be put together, surely a great part of our difficulty will be removed—for the direct antecedent of muscular action being chemical force, the disproportion that seemed to exist between them will no longer appear so striking.

2. That the animal body should be far superior to any machine of mere human contrivance as an economist of force, is nothing more than we should expect, and may fairly infer from its origin, being planned and formed by a Mind and Hand so infinitely superior in wisdom and power to those that work among us. And it must be regarded as a result of this economising that so great a proportion of the force given off takes the form of motion, which as we have seen is a much cheaper form of force—so to speak—than any of the rest.

Part II.

I pass on now to the consideration of the second part of my subject, and if any impression has already been made by the foregoing arguments I doubt not but that it will be materially strengthened by those now about to be adduced.

I shall speak then in this place of those cases where the physical forces pass into the vital; and conversely the vital into the physical by direct contact with the living or recently dead tissues.

It is known that to effect the conversion of one physical force into another, some special material must be used through which to act, and this material differs somewhat in the case of each instance of correlation; though at the same time many and very diverse bodies will often supply the necessary condition for the same change. Now, however, we have an entirely distinct modification of force to deal with, and it might easily have been predicted *a priori* that some special material substratum would have to be employed to effect the conversion of ordinary force into this new one. And this, in fact we find to be the case, for to effect the conversion of these forces, the one into the other, we must always have organized matter through which to act, and though this is not of necessity alive, in the ordinary acceptation of that term, yet it must be in a state closely allied to vitality, as recently dead tissue, or as in the case of the seed which is said to be in a state of "dormant vitality." And here we have as it seems to me, an almost, if not quite, insuperable bar to the doctrine of equivocal generation; which can never be received till some exception be pointed out to the law I have laid down.

It may be considered as proved by the following facts that nerve force and electricity are not identical. For (1) no electric current can be detected in a nerve along which nerve force is known to be passing. (2) By ligaturing a nerve its conducting power for electricity is not in the least impaired; while for nerve force it is destroyed. And (3) if a piece of nerve be removed and the ends thus left be connected by means of a conductor, electricity will still pass along it, but nerve force will not.*

But it must equally be allowed that some exceedingly close relationship does exist between them, for if a current of electricity be passed along a motor nerve, even for a part of its course, contraction of the muscles supplied by that nerve is the result. If an afferent nerve be experimented upon the same way, whether a nerve of common sensation, the optic, auditory, gustatory, or olfactory, a pricking sensation is experienced, flashes of light seen, sounds heard, a peculiar taste, or a phosphoric odor perceived, in accordance with the function of the nerve operated upon.†

Now if in the case of the magnetization of a bar of iron by the passage of a current of electricity round it, a conversion of the electric force into the magnetic be conceded, such connection can scarcely be denied in these cases in which a perfect parallelism to that of the magnetization seems to exist. But to follow out the analogy—for magnetism will under the proper conditions produce electricity—the converse should hold, namely, that the nerve force will produce the electric; and this is seen in the most remarkable manner in the case of the electric fishes of which the *Torpedo*, the *Gymnotus electricus*, and the *Silurus electricus* are best known. In them a special division of the nervous system is set apart for the production of nerve force, which by means of a particular form of apparatus—supplying the special material substratum required in this case—is converted into electricity. That in this case the nerve force is in fact converted into electricity, or bears some very analogous relation to it, is as well capable of proof as that in other cases it excites the contraction of muscles, for from the electric lobe proceeds a large nerve trunk, which when it reaches its destination in the electric apparatus, divides into minute branches which ramify profusely in all directions. Now if this nerve be divided, the apparatus fails to evolve electricity; if partly divided or injured, the discharge is weakened; if the electric lobe be removed, destroyed, partially taken away, or injured, similar results follow; and if the lobe be irritated the discharge is increased. If now the nerve be divided, and the cut end belonging to the peripheral extremity be acted upon

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* Lectures on Physiology by Prof. Fraser.

† For the facts in this paragraph as well as for several others of the same kind further on, I am indebted to Dr. Carpenter's article in the Phil. Tran. for 1850 on "The mutual relations of the Vital and Physical forces."

by electricity, mechanical irritation, chemical re-agents, or heat, the result will be a passage of *nerve force* along the trunk of the nerve, and an evolution of *electricity* from the apparatus.

It will be observed that by reading motor centre for electric lobe, and muscle and muscular force, or motion, for electric apparatus and electricity, all the phenomena connected with a motor nerve centre, a motor nerve trunk, and a muscle, in their relation to one another, will have been given in the above description. It is, however, probable that there is a great difference between the relation that nerve force bears to electricity in the one case, and to the motion produced in the other. For whereas in the case of the muscle the nerve force is certainly not converted *directly* into motion, but bears a more distant relationship to it, as we shall see further on; on the other hand in the case of the electric fish it is highly probable that the electricity is developed directly from the nerve force by the conversion of the latter into it, at least the extreme exhaustion and even death of the animal after actively using the organ for some time,* and the fact that no other origin of it has been pointed out, would seem in some degree, to justify us in coming to this conclusion.†

If we pass now to heat we shall find exactly the same relationship prevail; there can be no doubt but that our perceptions of heat and cold depend upon a conversion of heat into nerve-force taking place in the peripheral extremities of the nerves which transmit such impressions. The argument for the establishment of this, and which would apply in all similar cases, would take something of this form, Given a force applied to the extremity of a nerve, and *then* a force of a different character passing along that nerve. Either (1) the subsequent force, which passes along the nerve must be generated *de novo*—i. e., created; or (2) it must have been roused from a dormant state; or (3) it is the resultant by conversion of the force which has in any case excited it. Now we have seen reasons above for rejecting the two first conclusions, it only remains to us therefore to accept the last explanation.

Heat applied to a nerve of special sense produces the sensation that is caused by a normal stimulus of that nerve through its special organ. Thus, applied to the optic nerve, flashes of light are seen; to the auditory, noises heard, and so on; applied to the course of a motor nerve it produces motion in the muscles supplied by it; in all cases, causing a current of nerve force to pass along the nerve to which it is applied as the first step in its operations.‡

Conversely, there are phenomena that make it highly probable that although we must attribute most of the heat developed in the human body to *direct* chemical action, some of it may be derived from a conversion of nerve force into it. In this way we may account for "the sudden elevation of temperature that occurs under the influence of nervous excitement, whether general or local; the equally sudden diminution that marks the influence of the depressing passions,

* Encyclopœdia Britannica, 8th edition. Art. Electricity.

† Compare Carpenter's "Principles of Comparative Physiology," pp. 408–471.—Encyclopœdia Britannica, 8th Edition, Art. Electricity; and Carpenter on the "Mutual relation of the Vital and Physical forces," Phil. Tran., 1850.

‡ Carpenter, Phil. Tran. 1850.

and the rapid cooling of bodies of which the nervous centres have been destroyed notwithstanding that respiration is artificially maintained, and the circulation continues.*"

Chemical re-agents applied to nerves in their course will produce all the effects which we have seen to follow the application of heat and electricity;† while, as the converse of this, it is well known that nerve influence may change the chemical properties of the secretions in the most marked manner, and even probably produce chemical alteration in the blood itself, or the solid parts of the organism;‡ and that it excites chemical change in the muscles there can be no doubt.

We have a striking instance of the conversion of light into nerve force in the phenomena of sight, the mode of which conversion being a matter of little importance in our present inquiry. Whether we are inclined to accept Draper's|| very ingenious explanations of it or not, the fact that such change does take place can scarcely be denied; the argument for the proof of this conversion would be similar to that used on a former occasion when speaking of heat.

Conversely, although most cases of animal luminosity may be fairly referred to slow combustion, or phophoresence, in the part where such effect is manifested, yet this explanation does not seem adequate to account for all instances of this kind; and it is believed that in some cases, more particularly in the cases of the marine *Annelidæ*, and some other of the *Articulata*, a conversion of nerve force into light takes place.§

The relation between nerve force and motion has been considered as being a more remarkable instance of conversion than any of those above specified.¶ But this does not seem to me at all so clear as at first sight it might appear to be. For it is certain that in the relationship existing between motor nerves and their muscles, no conversion of nerve force into motion takes place, but, as we shall hereafter see, a connection of an entirely different character obtains. However this may be the converse of it holds good; for motion in the form of mechanical irritation applied to a nerve at its periphery, or in its course, will be followed by a nervous current along that nerve and by excitation of its centre. That is to say, when applied to a nerve of common sensation it causes pain; to the eyeball or optic nerve, flashes of light; to the auditory, sounds; by striking the tongue quickly and lightly with the tip of the finger, a distinct taste is developed, sometimes saline and sometimes acid. ☞

I have said that the motion produced by the contraction of a muscle cannot be regarded as a continuation of the nerve force which called that muscle into action. It seems sufficient reason for this assertion that there is another, and distinct source known to which to refer for the proximate antecedent of the mo-

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* Carpenter, "Principles of comparative Physiology," p. 401; see also his "Human Physiology," pp. 417 et seq.

† Carpenter, Phil. Tran. 1850.

‡ Carpenter, "Human Physiology," pp. 740–746.

|| Draper's "Human Physiology," pp. 392 et seq.

§ Carpenter, "Principles of Comparative Physiology," p. 447. Compare Todd and Bowman "Phys. Anatomy," pp. 224 et seq.

¶ Carpenter, Phil. Tran. 1850.

☞ Baly's translation of Muller's Physiology, p. 1002.

tion, namely, the chemical change taking place in the muscle; the relation of which to the force put forth is so well shown by the different amount of urea formed under the different circumstances of activity or rest of the muscle.* Still that there is an intimate relation between the current in the motor nerve and the muscular contraction is well known, and also that in a certain sense a quantitative relation exists between them, the degree of contraction in the muscle being entirely dependent, *cæteris paribus*, upon the amount of stimulation or nerve force conveyed to it by the nerve supplying it. The relation then between nerve and muscular force, though intima e, is certainly not that of direct conversion, but seems to be extremely analogous to that which light bears to the force produced by the union of hydrogen and chlorine when their combination is determined by the action of its rays upon them; for the amount of nerve force, as of light, supplied in any given time, other things being equal, determines the amount of chemical change in the muscle or in the mixed gases, and consequently the amount of force (Laws I. and III.) that will be put forth or evolved, but in neither case does the determining agent supply the force thus yielded. But the nerve force as well as the light, (according to the theory here advocated) must have a resultant when it ceases to exist as such, and I would suggest the possibility of that resultant being the heat, or part of it, that is always produced during normal muscular contraction.

If we consider now that on the one hand all the physical forces are mutually convertible into each other, and on the other that nerve force is considered as the highest form of power put forth by organised beings, besides being (as must be granted) probably correlated to all the rest; it must be allowed that the foregoing facts go far towards establishing the relation contended for here, between the vital and physical forces, for if each one of the two groups of force have its own forms of force convertible into each other, then it only requires one connecting link to establish the unity of all the forms of both groups. But because we cannot point out any one link that would fulfil this condition so as not to allow of any cavil, it is necessary that we should have a large number of instances of conversion, each of which should be as reliable as possible under the circumstances, so that by many probabilities, all pointing in one direction, we may establish that which cannot be shown to be absolutely true by any one direct fact.

Instances (or at least seemiug instances) of conversion coming under this division of the subject might be multiplied, but it would be tedious to do so, and would serve no purpose, for if those instances already adduced are not received as cases of correlation, any others would hardly be so; and if they are so looked upon there is no need of adding to them, and it must be obvious to every one that if this view be the true one, every vital manifestation must be an example of correlation, since every vital force, in its origin as such, must proceed from a physical one. I shall, however, briefly consider muscular action for the purpose of seeing whether this theory is capable of throwing any light upon it.

Each form of cell, as we have seen above, has its own proper form of "cell

* Draper's "Human Physiology," pp. 444 et seq. and Carpenter's "Human Physiology," p. 391.

force," which it evolves under certain determinate conditions; this force has for its antecedent that set free by the chemical changes going on in the cell itself, the conversion being effected by the particular form of matter (the cell) through which the force passes. Now as the cell is the form of matter (*par excellence*) through the agency of which the physical forces are changed into the vital, so each form of cell has its own form of vital force which must result from the fact of its having its origin *as vital force* in that cell.

As the proximate origin of the force liberated by each cell is to be found in chemical change, so the stimulus that calls that cell into action is something that will determine the taking place of that chemical change, and may be itself exceedingly small in quantity compared with the force which at first sight it might seem to produce.

The cells* of muscle are chemically composed of exceedingly complex bodies; the affinity exercised between the elements of which seems to be very slight and their stability remarkably feeble; from which it results that their elements may easily be made to change their chemical condition (Law II.); and also that when they fall into low forms of combination in which the affinity exercised by them will be great, a large quantity of force will be set free (Law III.); and in this fact we have the reason for the great complexity in chemical constitution which obtains in tissues through which much force has to be evolved, that is, whose functional activity is great.†

This being the state of affairs what is next required is, first, another force which shall so act upon the complex bodies as to cause the chemical change, and second, a form of matter, in the passage through which this force set free shall assume the form required; these two conditions we have fulfilled in nerve force on the one hand, and muscular tissue on the other. But any other force may take the place of the nervous as when an isolated muscle is called into action by heat, electricity, mechanical irritation, etc.; and again the cell may be in some way so altered that it shall lose its property of directing the force set free into the normal vital channel, and then we shall have another form of force evolved, which in accordance with the rule, in cases of chemical combination, will be mostly or entirely heat. This aberration is seen during life in certain morbid states of the system as in pyrexia (?), and after death of course it always happens; and if the circumstances attending the death be such as to leave the elements in a more than usually unstable condition we shall have a rise in the temperature of the dead body, as is often seen in cases of cholera, yellow fever, etc.‡

In health, because it would seem some little chemical change, probably connected with nutrition, must always be going on, when the muscle is at rest and therefore not liberating any of its proper force, electricity in small quantities, (for the

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* I follow Sharpley and Carpenter (Prof. Fraser's lectures on Physiology,) in considering muscles as ultimately composed of cells: in reality it does not appear to me to be of any consequence for our present purpose whether we call them such or fibrillæ.

† For it would seem to be a law, to which there are certainly seeming exceptions from the operation of other laws interfering with it, that the more complex a body is, the weaker is the chemical affinity exercised by its elements.

‡ Carpenter's "Human Physiology" p. 410.

change is small) takes its place; but as soon as the muscle is called upon to give out its proper form of energy, its evolution ceases.*

And on these same principles we shall be able to explain the fact that irritable men of sanguineous temperament, (that is, as I understand it, men the elements of whose tissues are in a less stable condition than obtains in other people) have more of this free electricity than others.†

Part III.

To pass now to the third and last division of the subject, namely, the nature of the influence of the physical forces, principally light and heat, upon the living plant or animal in the ordinary state of nature.

And first of heat.

All organized beings are dependent in a greater or less degree upon the temperature of the medium by which they are surrounded; but plants and cold-blooded animals are so to a much greater extent than warm-blooded, from the fact that in them the vital forces are not derived wholly from the chemical changes going on within them, but are in part, and sometimes in great part, obtained directly from this very temperature, and the light that usually accompanies it.

It would seem that in plants, though light by its action on carbonic acid and ammonia supplies them with a great part of their food: heat is the force which, by its passage through the living tissue being changed to vital force, has to perform in great part the assimilative and nutritive functions. I say in great part, for in the union of the elements that had been set free by the agency of light, some force must be evolved, though this from the feebleness of union in the bodies formed must be small in amount (Law I) I am free to confess that I am not very clear on this point in my own mind. And here a question (alluded to above) arises of great interest and importance. In those bodies as starch, sugar, lignine, cellulose, etc., etc., which constitute the great mass of plants, and in which hydrogen and oxygen are in the proportion to form water, and where they are derived from water, are they in any degree separated? that is, has the affinity exercised by them in water been weakened when they are combined with carbon to form these new bodies.‡ I have no doubt that this must be answered in the affirmative, and if so the result is obvious, we must have a force to effect this decomposition beyond the force that is evolved in the formation of the new body (Law IV). If then to supply any of these needs plants are dependent upon heat, as, to fulfil their other wants they are on light, it is clear that a certain amount of heat will be re-

* Carpenter's "Human Physiology" p. 425.

† Carpenter's "Human Physiology" p. 429.

‡ A carefully conducted experiment, such as I do not know has ever been performed would readily settle this question—for if the H and O are separated, as I suppose, a given quantity of dry wood would yield more heat in its combustion than would as much charcoal as there was carbon in the wood in its combustion; but if the affinity between them is not at all lessened it would yield less, for we should have to subtract from the amount of heat evolved by the carbon, the strength of the affinity existing between the H O and the C in the wood. Is it not the union of the oxygen and hydrogen in wood, forming water, without the participation of carbon in the combustion, that constitutes the main part of the process in the formation of charcoal by suppressed combustion?

quired for any given amount of growth and development exhibited by the plant; that is, a quantitative relation must exist between the force supplied and the vital force put forth which depends upon it; and this is seen to be the case in the most striking manner, for according to Bousingault "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 at the temperate zone, its rate of growth being in a precisely direct ratio to the amount it receives in any given time."

Very much the same thing is seen in the case of the lower cold-blooded animals though what is the nature of the relation existing here between the physical and vital force, I do not pretend to say; it may be that the former merely furnishes a necessary condition for the evolution of the latter from other sources; or it may be changed into it directly; or again the heat may alter its form and becoming chemical force may so pass into the vital; be this as it may, the relation exists and is well seen in the case of the *Crustacea*. For 1, the variety of their 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 southward. 2. 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; but they are also more important. 3. Not only are those *Crustacea* which are most elevated in the sea deficient in the polar regions, but their relative number decreases rapidly as we pass from the equator towards the pole. 4. The average size of the *Crustacea* of tropical regions is considerably greater than that of the tribes inhabiting frigid or temperate climes. 5. It is where the temperature is most elevated that the peculiarities of structure which characterize the several groups are most strongly manifested. And 6. There is a remarkable coincidence between the temperature of different regions and the prevalence of certain forms of *Crustacea*.*

The rate of performance of their functions in cold-blooded animals depends much upon the temperature in which they live. Now as the respiratory process is an exponent of the rate of life of any animal, that is of the rate of chemical change taking place in the organism, it follows from the above that should this be stopped, the length of life of the animal will be in the inverse ratio of the temperature to which it is exposed; and so we find it, for when frogs were confined in a limited quantity of water and not allowed to come to the surface to breathe

They	died	in	12	to	32	minutes	when	the water	was	90°
"	"		35		90	"	"	"		72
"	"		350		375	"	"	"		50
"	"		367		498	"	"	"		30

At the lowest temperature mentioned the prolongation of life was not due to torpidity, for all the functions of the animal were performed, but slowly.‡

* Milne Edwards "Histoire des Crustaces tome iii pp. 555 et. seq. quoted by Carpenter in his article in Phil. Tran. 1850.

‡ Dr. F. W. Edwards "On the influence of physical agents on life."

In the production of larvæ from the eggs of insects, we see very much the same relation between heat and the vital force as in the case of plants; for the rate of development is in the direct ratio of the heat supplied, and the final transformation may be accelerated or retarded at pleasure, within certain limits, by regulating the amount of heat which they receive; but in every case—in eggs of the same insect—the same amount of heat is required, and must be supplied to effect the same transformation.*

The regularity observed in the period of gestation in warm-blooded animals, is no doubt due in great part to the regularity of temperature that they are capable of sustaining under nearly all circumstances, and which is necessary to the continuance of their vitality, and I would be inclined to think (though I cannot anywhere find it so stated) that the temperature of warm-blooded animals decreases as age comes on, from the single fact (if it be a fact) that the period of gestation is prolonged in accordance with the advance of age.

Besides the influence exercised by light in the decomposition of carbonic acid and ammonia in contact with the green leaves of plants, there is no doubt that it is a force which is extensively used in the process of development, that, in some cases, at least, it determines the manner and direction of growth in a very remarkable degree. A very curious example of this kind is furnished by the experiments of Mirbel upon the gemmæ of *Marchantia polymorpha.* He found after thoroughly testing the matter, by repeated trials, that during the development of these little discs, stomata are formed upon the side exposed to the light, while root fibres grew from the under surface; and 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.†

This division of my subject might be almost indefinitely extended, but I have not attempted to do more than notice some of the more salient points belonging to it, which is all my space will admit of.

Higher in the scale of organization there are to be found such facts as the influence of light in the development of tadpoles into frogs;—multitudes of the like instances will present themselves to the mind of every one.

Finally, to test a theory we examine it in all its ramifications, and if it be found to be absolutely opposed to fact in any one case it cannot stand. So if any physical or vital force, however inconsiderable in amount, can be shown to be produced in the ordinary course of nature, as we observe its operations, which do not proceed from some antecedent physical or vital force, such theory can no longer be entitled to belief or consideration. But if, on the other hand, there are vital forces of which we do not know the antecedent force, or that they have any except from analogy, it is the business of the holders of this view to endeavour to clear up, and show the connection between such forces and their correlatives, either in the organic, or in the inorganic world; or to show, if such be the case, that none exist, and so destroy a false hypothesis.

* Carpenter, Phil. Tran. 1850.
† Carpenter, Phil. Tran. 1850.