Thesis.

Animal Electricity
And
Nervous Force

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Vagueness of the word principle

[illegible] Animal Electricity force evolved during [illegible]

[illegible]

Delivered on 31st March 18[illegible]2

* Untersuchungen über thierische Electricitat
And Abstract by Bence Jones.

Note.

This Paper Professes to be a careful repetition of some of the leading experiments of Matteucci & Du Bois Reymond in Electro-Physiology, with original deductions from these on the relation between nervous force and animal electricity - These experiments were performed during the winter of 1861, and such of them only are here introduced as bore more directly on the elucidation of the question now stated. It should further be mentioned that some of the following Exs are given simply on authority. The following are those which were repeated & verified.

On the electro-magnetic action of the current of the frog.

On the influence of the direction of the current in the nerves upon the contraction of the muscles

On the frog-current proved to depend on a muscular current, which belongs generally to the muscles of all Animals

On the muscular Current

On the determination of the law of the muscular Current

On the difference between the current of the longitudinal & transverse Sections

On the influence of contraction on the muscular current with its negative variation shewn during the act of Contraction in the living body.

On the nervous Current with the determination of its law

On the electrotonic State of the nerves -

The subject of animal electricity under different names and in various aspects has engaged the attention of many distinguished philosophers from the period of Galvani; but the more recent experiments and researches of Nobili, Müller, Longet, W. du Bois-Reymond and *Matteucci, have lent additional importance to similar investigations, by not only demonstrating the presence of electrical phenomena in Animal Tissues, but by further pointing out the remarkable analogy which such phenomena bear to several of the vital processes.

The researches of the last mentioned enquirers in the field of electro-physiology are particularly deserving of attention as furnishing at once the most recent, extensive, and exact data of this nature.

What I propose to do is, in the first place, to point out some of the ways in which we arrive at a knowledge of the existence of the electrical current in Animal structures, and in doing so, I shall have frequent occasion to refer to the experiments of Professor Matteucci - In the second place I propose to enquire how far such experiments throw light

* "Traité sur les Phénomènes Electro-physiologiques des Animaux". Lectures translated by Dr Pereira.
Transactions of the Royal Society of London. 1845. et passim.

upon the ultimate nature and relations of Nervous-force.

I may without further preface proceed to describe some of the methods by which the electrical current may be detected in the Tissues and its laws determined.

The presence of the electrical current is readily demonstrated when two different parts of the muscular mass of a living or recently killed Animal are connected by a conducting body - a frog prepared after the method of Galvani serves this purpose, and affords an easy and delicate mode of exhibiting the Phenomena. The leg of a frog is detached from the trunk by dividing it through the middle of the pelvis, along with its anterior crural nerve. the latter being divided where it leaves the lumbar plexus. The frog prepared in this way is next placed in a glass tube which is protected from the hand of the Operator by means of insulating varnish - The free end of the nervous filament belonging to the leg hangs from the open end of the tube, and is brought in contact by two parts with the muscle whose electrical condition is to be ascertained - An incision being made in the muscle of a living Animal. and one part of the nerve (of the frogs leg) placed in contact with the bottom of the wound, whilst another part

of the same nerve touches the lips of the wound or external surface of the muscle, A series of contractions are now observed to take place in the muscles of the frogs leg contained in the insulated tube. The circumstances under which the experiment is performed leave no room to doubt that those contractions are induced by the passage of an electrical current along the nerve to the muscles of the frogs leg.- Phenomena similar to these are witnessed whatever be the nature of the Animal under experiment, and human muscle does not form an exception to this general statement. If now a piece of muscle which has been for some time detached from the body of the Animal, be placed in a similar relation to the nerves of the frogs leg (which is named the *Galvanoscopic frog) contractions immediately ensue as in the former experiments differing only in their duration and intensity from those induced by the muscle of a living Animal - Such then is a simple and rudimentary but efficient method of ascertaining the existence of an electrical current in the muscles of a living Animal or of one recently killed.- But to place the existence of such a current beyond any doubt - to determine its intensity relatively to the state of life or death, as well as to the position of the Animal in the scale of existence, and discover its duration -

*Dr Bois Reymond names this "Rheoscopic limb."

* The Galvanometer constructed by Du Bois Reymond is by far the best instrument with which to preform these experiments, and is in every respect incomparably superior to those of Gourgon and Pohnkorff and all others previously in use. For particulars regarding construction arrangement &c vide. The works of Du Bois Reymond already referred to. We have used Du Bois Reymonds instrument in preforming our experiments.

† Du Bois Reymond describes this the "Law of the antagonism of the Longitudinal and Transverse Section — The Longitudinal surface being positive and the Transverse Section being negative."

It is necessary to have recourse to the Galvanometer - an instrument with which many are now familiar. Suppose we now wish to discover the laws which regulate the muscular current in different animals a series of experiments are instituted in the manner formerly described - Having exposed the pectoral muscle of a living pigeon, the two platinum extremities of the Galvanometer are quickly conveyed to the part, - One to the interior of the wound, whilst the other impinges on the external surface of the muscle - The instantaneous and marked deviation of the needle not only informs us, as did the previous experiments of the existence of the phenomena we are in quest of but we now for the first time arrive at the knowledge that the muscular current maintains a specific direction which is uniformly from the internal to the external, that is, from the deep to the superficial parts of the same muscle. Continuing our investigations by means of like experiments upon animals occupying different grades in the scale of life - we are soon enabled to give expression to another law not less constant or universal (nay) that the muscular electrical current of warm blooded Animals is much stronger than that of those who derive their temperature from the element in which they live.

and while its intensity rises with the animal in the scale of existence its duration observes a rule inversely proportioned to its strength.- Thus the current of the rabbit or pigeon is more intense than that of the frog or eel, but those of the latter are longer in their duration.-

We have now to describe the mode of obtaining the electrical current from what is termed the muscular pile. To obtain this pile a number of frogs are prepared in the manner which has already been described in speaking of the galvanoscopic frog.- The legs are next separated from the thighs; by disarticulation and thrown aside. The thighs are then divided transversely into two parts, the inferior halves of which only are retained in forming the pile.- These half thighs are arranged in a series upon an insulating tray in which are cavities containing a saline solution The demi-thighs which thus constitute the elements of the pile are placed in a row touching each other in such a way that the same surface of the limb is always turned in the same direction; so that each extreme of the pile communicates with a separate cavity in the tray and its saline contents - the one by means of the external and the other the internal

portion of the muscle of which each is composed, thus forming the negative and positive poles. An instantaneous deviation of the needle in a constant direction at once marks the completion of the circuit which is effected by bringing the terminals of the Galvanometer into contact.

A pile formed of the muscles of the frog in this way demonstrates the muscular current. The experiment may be varied by using the muscles of fishes, birds or Mammals, and provided the elements of the pile are properly arranged in the manner described, a result invariably similar may be anticipated. - The intensity of the current thus evolved is always in proportion to the number of the muscular elements composing the pile from whatever Animal the muscles are taken. - Thus a pile of ten dem-thighs may produce a deviation of the Galvanometer Needle from 5° to 40° while one composed of four similar elements may not succeed in raising the Needle to a deviation of more than one sixth of that amount - The direction of the current as in former experiments is indicated as constantly rising from the internal to the external surface of the muscle. A pile

constructed on this method of living Animals produces phenomena accordant in all respects with those obtained from the examinate pile except in their duration and intensity both of which are slightly augmented when the current is developed from the muscles of living Animals

It may not be out of place to notice at this stage the influence of the organic condition of muscle on the development of the electrical current. When we examine the muscles of Animals which have for some time been deprived of aliment, or in which the circulation of the blood is slow or greatly impeded, a well marked diminution in the intensity of the current is observed; whilst on the contrary muscles which have an unusual determination of blood whether from good feeding or local irritation, develope a muscular current which is not only more intense, but continues much longer.

We had already occasion to notice a certain relation subsisting between the constitution of the Animal and the intensity of the current. Such facts might lead us not unwarrantably to attribute the development of electrical phenomena in muscular substance in some measure if not entirely to the influence of the blood on the tissues during the chemical

process of their nutrition and transformation, on the hypothesis of the blood impregnated with Oxygen and the muscular fibre composing the elements of a pile, the former of which represents the liquid acid and the latter the metallic zinc.- To recur from this digression.- Several experiments have been instituted with the view of determining the action of poisons on the duration and the intensity of the muscular current - the results of which have been to show that the muscles of Animals poisoned by Sulphuretted Hydrogen almost entirely lose their electrical property.- But this at present appears to be the only known exception.- Carbonic Acid, Arseniuretted Hydrogen, Hydrocyanic Acid, making no appreciable difference, whilst the influence of narcotic poisons seems rather to encrease than abate the intensity of the muscular current.

Muscular Contractions by induction present us with another series of phenomena in electro: physiology, that have elicited much curious speculation and innumerable experiments, have sought to explain their origin and determine their laws.- The question is now set at rest, by referring the phenomena to the fact which recent discovery has brought to light,

that electricity is evolved during the act of the contraction of a muscle.— The current thus developed being conveyed by means of a conductor to the muscles, for example, of the frog's leg induce contractions in the latter which are coincident although weaker than the primary contractions through whose influence they have been excited.— The Galvanoscopic frog is perhaps the most delicate instrument by means of which induced contractions are best exhibited.— The leg of the frog being insulated & the free end of its anterior crural nerve already described being laid upon the contracting muscle of a living animal, or upon that of one which is dead, whose muscles are made to contract by the application of electrical stimuli &c, the phenomena are speedily evinced.— Numerous elaborate experiments have lately been made with a view to detect the current during the period of the voluntary contraction of muscles and M. du. Bois. Reymond*. thinks he has satisfactorily demonstrated its existence. Professor Matteucci on the contrary who has bestowed immense research towards the elucidation of this point affirms that he has failed to obtain indubitable evidence of the current when operating on a circle composed of as

* On the law of Muscular Current, and on the modification which that law undergoes by the effect of contraction

This experiment is now rendered susceptible of perfect demonstration by means of the delicate Galvanometer of Du Bois Reymond already referred to. In performing it the fore finger of each hand is dipped into the conducting vessels so that the two arms are included in an opposite direction in the circuit of the Galvanometer — When the circle is completed a greater or less degree of deflection of the needle occurs even before Muscular contraction takes place — The needle, when the integument of the immersed fingers is entire, soon returns to Zero and becomes stationary — It is then that the muscles of the arm, without the position of the limb being changed, are made powerfully to contract — When the experiment is properly performed and the arm sufficiently muscular, well marked deflection of the needle takes place — This deviation indicates an upward direction of the current in the contracted arm, and inversely, in the relaxed limb — The contracting arm thus acting the part of the negative metal in the arch — We have repeatedly demonstrated this experiment

many as forty persons, the muscles of whose arms were made to contract at the same moment.*

"We now propose to advert to the phenomena of the Direct and Inverse Currents, which are of no inconsiderable physiological interest and importance. The mode of conducting the experiment is the following.— We expose in a living Animal, for example the dog, the muscles of the thighs removing entirely the superjacent structures, then transmit through the muscles the electric current, from an ordinary pile of thirty or forty elements, applying one end of the pile to the upper, and the other to the lower part of the thigh.— If the positive pole is placed above, and the negative below the current traverses the muscle in the direction in which the nerves ramify.— But if this arrangement be reversed, the positive pole being place below and the negative above the current, in a contrary direction (var) from the circumference towards the centre.— When the electric current traverses the muscular nerves of the thigh of a living Animal in the direction of the distribution of the nerves

x happens

that is, towards the direction of the periphery, a powerful contraction takes place, a contraction which is not confined to the muscles directly traversed by the electric current but extends to the muscles of the leg and foot.— When on the contrary the electric current is made to pass through the muscle in a direction opposed to the distribution of the nerves that is towards the nerve centre, the Animal utters loud cries and gives other indications of suffering pain.

This latter experiment is attended also by muscular contractions, but these are less violent and confined to the muscles directly subject to the electric current.— The former of these experiments affords an illustration of the Direct current, and is accompanied by its peculiar phenomena of muscular contractions; the latter presents us with an instance of the * Inverse current, and is attended on the other hand by the phenomenon of sensation — The two experiments last adduced, are fitted to suggest the striking analogy subsisting between the vital principle termed Nervous force and electricity.— Nervous force transmitted in the direction in which the nerves ramify, that is from the centre produces contractions and the electrical current

* This is termed the Secondary Current by M. Du Bois Reymond

propagated in the same direction induces physiological results precisely similar. Again, nervous force in passing in the direction contrary to that in which the nerves ramify, that is, towards the centre induces sensation whilst sensation is precisely the phenomenon induced by transmitting the electric current in the same direction.

A paper on the subject of animal electricity would be very incomplete without some notice, however brief, of those animals which are endowed with a special apparatus for the production of that important organic principle. For this purpose we shall select the Raia-Torpedo, One of the group of electrical fishes whose structure and functions have been very carefully studied.

When a living Torpedo is grasped with the hands, a powerful shock is felt resembling that produced by a voltaic pile composed of a 100 or 150 elements. These shocks succeed each other with great rapidity and strength until the animal becomes exhausted, when they cease - The discharges by means of which these effects are produced have been carefully examined and identified by most of the conspicuous phenomena proper to the

electrical current producing (viz) the Spark, electro-chemical decomposition, action upon the needle &c &c. The electrical phenomena evolved by these creatures is connected with a particular specialization of structure which in the Torpedo consists of a lobe of the brain, a curious organ called an apparatus, and an independent set of nerves connecting the lobe and the apparatus. — This apparatus or electrical organ, situate near the head, is composed of 400 or 500 prismatic masses placed side by side, each of which is formed of superimposed vesicles. — From the general arrangement of parts the entire organ resembles an honey-comb, It is not requisite to subserve our purpose to offer a minute account of the structure of this organ. — It will suffice to remember that it is chiefly composed of nervous structures placed in contact with a fluid resembling water but containing about 10 per cent of albumen. —

Let us glance for a moment at one or two physiological facts connected with the electrical discharges of these fishes. — In the first place they appear to be subject to the control of the will of the Animal, a fact that alone discovers a relation subsisting between volition nervous force

and electricity so intimate as to compel us in the instance under consideration to regard them as correlated and convertible forces.- Numerous experiments made upon the apparatus of the Torpedo render it probable that the developement of the electrical principle in that organ is less dependent upon its local circulation of the blood, than we found to be the case in muscle.- The tendency of this consideration would lead us to view the derivation of these phenomena as therefore more exclusively due to the Nervous system

That the electrical functions of this fish are dependent on a special lobe of the brain is a fact susceptible of easy demonstration by the removal of all other parts of the encephalon, except itself, without it in any degree being impaired, any irritation on the contrary however slight of the membrane or substance of the special lobe itself is instantly attended by repeated discharges which are always projected from that side of the animal from which the irritation proceeds.- From these facts, it may readily be inferred that the removal of the special lobe in question puts a termination to the phenomena.

The action of certain poisons on this

* Mattenucci Philosophical Transactions Reprint

group of electrical fishes is remarkable as further tending to establish a co-ordination between their peculiar functions and that displayed by the nervous system of other animals when acting under similar conditions. — Strychnia for example administered to the Torpedo quickly kills it, but not until after exciting a great number of rapid and violent discharges*. — Small doses of the same poison produce a state of excitement in which the slightest irritation produces shocks — These rapid and violent discharges, and the muscular tetanic spasms induced in other animals under the influence of the same poison are strikingly analagous

The Torpedo and fishes of the electrical group in general, possess the power of communicating shocks at points of their body distant from the special electrical organ of the animals. — This phenomenon is curious and suggestive, and its explanation claims a moments consideration — How are we on physiological principles to account for the fact that electricity developed by a special organ, situate near the head, is discharged at the caudal extremity and other parts of the same animal remote from the special apparatus —

a fact of which the experimenter is instantly made aware when happening to touch the tail of a lively Torpedo? - We must evidently look for the explication of this phenomenon in the operation of the general law of Reflex-action - The electricity generated by means of the special apparatus is transmitted, on this principle, to the spinal cord, and through the cord, to other parts of the body receiving excito-electrical stimulus, entirely through the agency of nerve structures, an opinion which is not only corroborated but rendered certain by the experiment of dividing the cord of the animal, when it ceases to be longer capable of transmitting shocks to any part below the point of spinal section - - This conclusion points out to us the perfect efficiency of nerve structures as conductors of electrical currents; and negatives any objections advanced on a contrary hypothesis.

We have now seen that electricity is being constantly developed in all animal tissues, but most powerfully in the muscles, and we have examined the laws by which the muscular current is determined.

The Galvanoscopic frog has at once

illustrated, besides setting in the clear light of demonstration, the interesting fact that electricity is developed during the act of the contraction of muscles.

The Phenomena however of the Direct and Inverse currents offer important data towards determining the relation of nerve-force to electricity. The current sent through the muscular mass in the direction of the branching nerves is followed by contractions similar to those induced under the stimuli of nervous-force acting normally. Again the electrical current propagated in an Inverse direction to the former educes phenomena coincident with those of nervous force playing in this direction.

The Phenomena now adduced, present us with that aspect of the question in which we see electricity playing into nerve-force whilst all the facts connected with the discharges of electrical fishes, no less plainly bring before us the evidence of another law (vice) that of nervous force playing directly into electricity. The two series of independent and opposite phenomena taken together completely establish the correlation of the two forces.

* Lectures on Natural Philosophy. [Young]

Do we then stop here, and rest satisfied with the view of their relation thus presented to us, or cannot Science advance a step nearer towards their entire identification? Before adverting to this difficult problem it is necessary to offer a few reflections on the nature of electricity in general.

This occult agency or principle has hitherto been regarded by Philosophers* as a peculiar ethereal fluid pervading the pores, if not the actual substance of the Earth and of all material bodies, passing through them with more or less facility, according to their different powers of conducting it. The effects of this fluid are distinguished from those of all other substances by an attractive or repulsive quality which it appears to possess the power of communicating to different bodies. —

When the equilibrium of the forces is destroyed, the electric fluid is put in motion, and those bodies along which it freely passes are considered as conductors, that are more or less perfect as they freely allow or impede its transmission Such then is a summary statement of the Physical Doctrine on this subject to which

we have been long accustomed to conform our opinions. - Recent researches however, conducted by the most distinguished living experimentalists* in this interesting branch of science are daily bringing to light new and profounder relations subsisting among the physical forces, which cannot but tend to modify, if not fundamentally alter all our views in this quarter.

Electricity under the former hypothesis is a fluid, under the latter it is regarded more as a force; and while the philosophers of a former period conceived the electrical current, and the body transmitting it, to be generically different substances, possessing an unknown relation to each other, the investigators of to-day recognize their identity, and discover in the electrical condition of a substance only an altered state of its molecules induced under the operation of the law of attraction or repulsion acting in a definite direction. - Electricity is then no longer that universal fluid always the same in substance where-ever existing, and continuing to retain an unalterable identity of essential character however diverse the intermedia of its transmission. - A body is thrown into

* Grove on the Correlation of the Physical Forces
Faraday. Philosophical Transactions of Royal Society. Lond: Harrison

a state of molecular polarisation when under the influence of a certain physical law, we shall suppose attraction, and during that condition of molecular disturbance, it sends off a part of itself, an emission of its own proper substance takes place, and this emanation is electricity.

Such views are by no means hypothetical, and are no less consistent with the known laws and properties of matter, than supported by arguments directly deducible from extensive and accurate experiments.

The colour of the electric spark or * of the voltaic arc is dependent upon the substance of the metal from which it emanates. — The arc from zinc is blue, — that from silver green, while that from iron is red and scintillating, which are precisely the colours yielded by those metals when undergoing ordinary combustion. —

— A portion of the metal is actually transmitted with every electric or voltaic discharge; and in the latter case, where the quantity of matter acted upon is greater than in the former, the metallic particles emitted by the terminals can be readily collected, tested and weighed.

The partial disruption and severance of itself which electrified matter undergoes proves off

at the point of least resistance. —

Our time forbids me to adduce further proofs of the sound experimental evidence upon which these doctrines are based. — I pass on to apply the principles involved, to the elucidation of the question under review (viz) have we data to warrant us in regarding electricity as identical with Nervous-force? It is obvious that our language on this subject must undergo some change; since all former attempts to establish an identity between those two principles proceeded upon an assumption which later and profounder investigations into the nature of electricity have shown to be untenable. — The electricity of mine must differ from that of iron, by all the difference that distinguishes the one metal from the other; whilst that developed in animal tissues, or circulating as Nervous-force, must be as dissimilar to the two former as the structure of a muscle or a nerve is unlike the constitution of inorganic bodies. —

— Absolute identity upon this theory is therefore unattainable. — The term electricity however although no longer indicating a force alike, under all circumstances may still nevertheless

we retained as the convenient designation of a principle, whether of organic or inorganic origin that professes many phenomena in common.

Let us now cursorily review the bearings of the entire question as modified by these arguments. — You will remember that the existence of the law of correlation of the two forces under consideration has been already fully established. — The correlation of the two forces however it will be observed leaves the question "still undetermined (viz). "what is nervous force in itself"? — Let us turn a moments consideration towards this confessedly intricate problem.

"When the electrical current is directed upon a substance, let us suppose for example a piece of metal, a change is quickly induced in that body which we call polarity and whatever peculiar phenomena the metal exhibits during the electrified condition, we are accustomed to refer to a disturbed or altered equilibrium of its molecules produced directly by the action upon them of the electricity. — In this procedure we faithfully obey the rules of inductive enquiry and there is no violation of the causative or logical law. If we now expose the nerves of a

living animal, and subject them to a similar current, we witness as in the metal the induction of a series of phenomena. — In the metal we discover an augmented attraction or repulsion; while in the fibres of the living animal muscular contractions or sensation are the manifestations that apprise us at once of the existence and direction of the current. — But what hitherto has been the language of philosophers in reference to the latter experiment? The electrical current, it is ~~maintained~~ when applied to a nerve, awakens nervous force and the contractions or sensations that ensue are due to the operation of the latter principle, that is, to the nervous-force and not to the electricity. — I do not stay to point out the fallacy of such reasoning, or the total inconclusiveness of deductions drawn from premises belonging to the <u>petitio principii</u>. — The laws of causation and logical sequence compel us, in the latter as in the former experiment, to refer the subsequent phenomena directly to the electricity. —

The nerve, through the action of the current directed upon it, is thrown into a state similar, though not identical, to that of the metal, and to this condition of molecular

* It was not until after this was written that I became acquainted with the views of Du Bois Reymond upon this subject, and I find there exists substantial agreement of opinion — That distinguished experimenter holds the opinion that when a nerve is acted upon by an electrical current it is thrown into a condition of Electrolysis analagous to the state in which Metals exist under like conditions — The Electrolysis commences with the "polarization of the Electro positive and negative elements of the Electrolyte" The transit from the natural to the Dipolar arrangement excites a disturbance of equilibrium which shows itself on contraction or on pain when the circuit is completed." That Du Bois Reymond holds this opinion is rendered further evident by his adoption of the word "Electrotonic" to denote the Electrolytic condition of the nerve — This being the term employed by Faraday to express the state of Polarization or disturbed equilibrium in which metals exist under the action of an Electrical Current. vide Abstract of Du Bois Reymonds Discoveries by Bence Jones This Note added 29th March 1862

polarity, we are bound to ascribe the so-called vital phenomena of contractions or of sensation which follow the experiment.*

The question whether the Nervous force is capable of being resolved into a state of polarity or of molecular disturbance of the nerves is quite an independent enquiry, and one that requires to be determined on its own particular basis.— Let us now glance for a few moments at the bearings of this enquiry.—

The source of what we call force, whether operating in the physical or organic world must ultimately be sought for, and resolved, into molecular motion — This condition of bodies takes place with every change of temperature, attends every chemical process, and may be detected as the underlying principle or substratum of that series of phenomena belonging to the physical and organic forces of nature; — And the prodigious piston with its gigantic concomitant masses of machinery kept in motion by the molecular expansion of water into steam impresses this idea upon our minds, not less truly than the growth and maturation of the minutest histological entity; or those processes carried on in nature which we only discover by the magnitude of their results.—

— To bring nerve force and its phenomena under this universal law, is therefore not only consistent with the operation of every law and process in nature with which we are acquainted, but is moreover demonstrated by the electrical current, which by inducing molecular motion or disturbance in one direction reproduces the phenomena of contraction, and in the inverse that of sensation — Assuming then that nervous agency is referrible to this law, there remains but another question to be answered (viz) what in nature produces this molecular state of the nerves, upon which their phenomena depend? Is it the principle of animal electricity? We have already seen that this principle is developed in animal tissues; and that a current of inorganic electricity produces all the requisite conditions — Did your time not admonish me to hasten to a close, I might have enlarged more fully upon the fact that electricity is a necessary and constant product of the operation of the other forces, a consideration that lends additional confirmation to the preceding arguments — We may conclude therefore, that nerve force is a disturbed molecular equilibrium, passing in one direction or in the inverse, the direction determining the

nature of the concomitant phenomena, and secondly that this state of the nervous system may be induced, and efficiently maintained by the constant evolution of animal electrical currents, whose nature, laws and conditions are not yet determined.

Notwithstanding these conclusions which we conceive to be correct, we would by no means place the question upon too narrow a basis; for we must not lose sight of the fact that Nervous force may be excited through the agency of other causes than that of electricity. - Heat, Light, Motion, Chemical Affinity, Magnetism and Electricity, each may in turn furnish the requisite stimuli; and in point of fact they do so, for each of those principles is more or less concerned in carrying forward the vital operations -

But we certainly cannot view these as so many isolated and independent forces. or modes of force each solely engaged in the production of its own phenomena - Chemical Affinity originates, or more strictly speaking merges itself into heat or motion, or both, whilst these again as quickly lose their identity, in the instantaneous production of one, or of all the other forces.

– Whilst in this manner, the correlation or conversion of force, the one into the other, necessarily advances through an interminable cycle. it is worthy of observation that one of these principles enumerated appears to be the constant product of the transmutation or metamorphosis of each of the others; and whilst thus exhibiting distinctly its own intimate relation to all the rest, becomes the bond or link of their union, and the means by which, we discover their reciprocal relations. – That force or principle is electricity – It thus appears that the other so-called vital agencies, apart or conjointly, may act as co-efficients in the induction of nervous force – – This consideration however, does not materially affect our previous position, and we are therefore still entitled to conclude, that the principle of animal electricity, whether we consider its prevalence or its known modes of acting is mainly concerned in bringing about that altered molecular state or balance of the nerve structures to which their peculiar phenomena is due.