An essay on the electricity of the blood / by R.C. Shettle.

AN ESSAY

ON THE

ELECTRICITY OF THE BLOOD.

BY

R. C. SHETTLE, M.D.

[*Reprinted from the Transactions of the St. Andrews Medical Graduates' Association.*]

H. BAILLIERE, 219, REGENT STREET, LONDON.

THE ELECTRICITY OF THE BLOOD CONSIDERED IN ITS RELATION TO THE PROCESSES OF DIGESTION AND ABSORPTION OF CHYLE.

THE TESTIMONY AFFORDED BY THE SPECTRUM ANALYSIS AS TO THE CAUSE OF THE RED COLOUR OF THE BLOOD, AND A REVIEW OF THE ELECTRIC CHARACTER OF SOME OF THE PRINCIPAL FUNCTIONS OF ANIMAL LIFE.

By Richard Shettle, M.D., M.R.C.S., L.S.A.

In the year 1863 I published two papers in "The Lancet," stating I had shown by the galvanometer that a current of electricity existed in arterial blood, which was not present in that drawn from the veins; that I attributed the bright colour of arterial blood to the presence of this principle, acting as a stimulant to the vital fluid and corrugating or drawing in the sides of the corpuscles; further that the phenomena of animal life depended upon the existence of electricity in the blood as a vital force; and lastly that coagulation was the result of this vital electricity compressing the particles of matter in the liquor sanguinis as it assumed a current form when passing away from the corpuscles.

Since that time I have frequently made similar experiments, and with the like result, except on two occasions, when the venous blood produced as strong a deflection of the needle as did the arterial; but in these instances the venous blood was of the same bright colour as the arterial, a fact upon which too much stress cannot be laid; and I now believe the anomalous effects to have been caused by a paralysed state of the peripheral nerves, preventing the abstraction of the vital force in the capillaries. A similar state of the blood occurs during sleep, in the hibernants during the period of repose, and in those dying of starvation. The two first would be instances in which there would be non-abstraction of vital force in the capillaries, from the normal suspension of the functions of the cerebral and sensorial ganglia, a state which is known to exist during sleep. But in those dying of starvation the peripheral nerves would be paralysed, partly from exhaustion of the vital force of the great nervous centres, and partly from the absence of carbon in the tissues; and this notwithstanding the generation of a vital force in the

lungs; for the nervous system, like any other part of the body, cannot carry on the functions of life unless it be supplied with nutriment as well as vital force. These experiments, however, simply referred to the action which takes place in the lungs during respiration, and in advancing these views with regard to electricity as a *vital force* existing in the blood, I desire that it may be clearly understood, that I do not seek to do away with the necessity for chemical action, but to call attention to the fact that under such chemical action, there must be a manifestation of electrical force, and that such force then becomes a vital force.

In the following paper I desire to point out the nature of digestion, and its similarity to ordinary galvanic action; the mode in which chyle is formed, organised, and converted into red blood; the electrical connection which exists between the stomach, spleen, liver, pancreas, and duodenum; and further, to show that the spleen is an electrical organ whose function is to destroy old blood corpuscles, and add to the organisation of new corpuscles; and also very briefly to touch upon the function of the liver.

It appears to me that the instrument known as Wheatstone's bridge, when in action and the four conducting wires are continuous, represents pretty accurately the state of the stomach and the organs with which it is connected by means of the sympathetic, when in their state of *inaction or rest.* An electrical current is known to be passing through the wires of the instrument and the galvanometer, but as perfect equilibrium exists, the needle is unaffected; but when a resistance is interposed in either of the wires, a deflection of the needle takes place by disturbance of equilibrium. So when ordinary capillary action is going on, the vital electricity is being abstracted by the nerve from the blood in the capillary, but without appreciable manifestation of force; but when capillary action is impeded or increased, there is a disturbance of electrical equilibrium by the interposition of a resisting force, and a corresponding manifestation of electrical force.

When food is taken into the stomach its first act is to cause an irritation of the peripheral nerves of the organ; in other words, electric equilibrium is disturbed, the nerves make a demand upon the capillaries, and a sufficient amount of blood is drawn to the parts to restore equilibrium. But in the case of digestion the impression is constantly being made, so long as food remains in the stomach to be digested; and as the food comes into the stomach, after it has undergone the process of mastication, mixed with soda, ptyaline (an alkali), common salt, and other condiments, or stimulants to the nerves of the stomach, it forms an exceedingly good electrolytic body, capable of generating an acid on the surface of the stomach, and so assisting in its own digestion or conversion into chyme.

The first act of the stomach is seen, then, to be simply increased capillary action and the formation of acid gastric juice; the second

and great act is the stimulation of the other organs with which the stomach is connected by means of the sympathetic, and the production of peristaltic action. It cannot be questioned but that these effects are the result of a still further disturbance of the electric equilibrium of the nerves. Thus, if the peripheræ of the sympathetic nerves of the stomach collect and convey force to the neighbouring organs, the peripheræ of the same nerves in those organs will stimulate the capillaries in each organ to increased action, and secretion will be effected at the expense of the *vitality* of the blood in the capillaries, and the electrical circuits will be established between these organs and the stomach and each other, partly by means of their respective secretions and partly by the nerves. Thus the stomach will act as the zincode or generator of force to the pancreas, liver, duodenal glands, etc., and its secretion is found to be acid, *i.e.*, the acid is making its appearance at the plus plate but negative pole, whilst these organs will be converted into the platinode, with the alkali appearing at the minus plate or positive pole. In the one case there would be repulsion of the particles of chyme from the walls of the stomach to the pylorus, and in the other repulsion of particles of pancreatic fluid, along the pancreatic duct to the duodenum, because bodies similarly electrified repel one another; but when these two fluids are brought into the duodenum, there would be an electrical affinity for each other, because they are in opposite electric states, and the acid chyme is thus converted into the alkaline molecular base of chyle. Of course the muscular contractions of the stomach, giving rise to peristaltic action of the organ, are due to a disturbance of the electric equilibrium of the muscular branches of the nerves, and must be the result of periodical discharges of force, the origin of which can be accounted for I believe in the peculiar organisation and action of the spleen.

ABSORPTION OF CHYLE.

When the minute particles of the molecular base of chyle are brought into contact with the villi of the intestine, the villi become erect and elongate themselves into the fluid, absorption of the fluid at once taking place. These villi are seen to consist of a central lacteal tube with open extremities, the walls of such tube being covered with a plexus of capillaries running from base to apex, so that the act of filling the capillaries with blood must tend not only to produce mechanical erection of the villi, but must at the same time serve very materially to dilate the tube, and such dilatation ought also to induce a sucking in of any fluid applied to the extremity of the villus. But I believe the great cause operating to promote absorption of the chyle by the villi is the difference in the electric state of the chyle in the intestine, and the blood in the capillaries of the villi; and although the alkalinity of the two fluids may differ but little, if at all, the blood is a highly organised fluid and

contains in its arterial state a considerable amount of electrical force, whilst the molecular base of chyle is only endowed with that amount of force which is inherent to every particle of matter, and consequently must present matter in an electro-negative state as compared with the blood in the capillary—*i.e.*, the blood in the capillary is acting as the zincode, and the chyle as the platinode. So that in the open mouths of these villi we have a ready channel for the negative chyle current to take, in opposition to the plus current of the blood in the capillaries surrounding the tube, the negative current being directed from apex to base of villus, thus causing absorption of the chyle.

Up to the present time physiologists have not been able to trace any nerves into these villi, but a layer of muscular fibre cells surrounding the tubes has been shown to exist by Kölliker and others, and these have been seen in the act of contraction during the absorption of chyle. Although nerve fibres may, and probably do exist, the mode in which we have seen the chyle to be absorbed by the villi appears to do away with the absolute necessity for the existence of nerves in the villi, even to produce contractions of the muscular fibres; for when a certain amount of chyle in an electro-negative state has been absorbed by the villus it will represent a force in the tube, which ought to give rise to a discharge of force from the capillaries, simply by the affinity of the two forces overcoming the resistance, under which muscular contractions will be set up. It appears, however, very probable that the villi are under the control of the ganglionic system of nerves, and if so, they would be influenced by the intermittent currents already alluded to as taking their origin in the spleen. From whatever source, however, the contractions of the muscular fibre arise, under the influence of such contractions there must be a manifestation of electrical force, and this force must always be developed in equal degree, being regulated by the amount of molecular base a villus can absorb at a time, and the plus current would be directed from the capillary to the molecular base; consequently when such manifestations of force take place there must be a compression of and union of the particles of molecular base, and a conversion of them into larger granules capable of acting as nuclei for the chyle corpuscles.

FORMATION OF CELL WALLS.

The molecular base of chyle is seen to consist of spherical particles of matter, which are supposed to have a coating of albumen. The tendency of these particles is rather to repel one another, than to unite, causing what is termed molecular action. Now molecular action appears to depend upon force emanating from the centres of the molecules and passing equally in all directions, and each molecule being similarly electrified would give rise to an equal amount

of force of an electrical character, and at certain distances from the centre of molecules mutual repulsion of force would take place, causing the molecule to rotate in all directions upon its centre, and giving rise secondarily to the formation of currents in opposite directions. It is to the influence of these currents that, I believe, the coatings of the molecular base are due. If this view be correct, it is evident that the amount of force emanating from a particle of matter must vary with the size and *character* of the molecule, but the structural character being the same, the force developed must depend upon the size of the particles. Consequently when the atoms of the molecular base have been combined in the process of absorption by the villi, so as to form particles large enough to act as nuclei for cells, the force emanating from them would be materially increased, and the *cell walls* generated by such force would be formed at greater distances from the nuclei, and correspondingly increased in strength also. It must be remembered that we are now dealing with matter in a state capable of permitting each particle to exert an influence over other particles, and thus displaying all the phenomena dependent upon its inherent force.

Mr. Lockhart Clarke has published some very valuable papers in the "Medical Critic" on the Nature of Volition, psychologically and physiologically considered, which appear to me to substantiate these views very materially. He says: "Every particle of matter, therefore, possesses an inherent principle or *capacity* of self motion, but whether this principle shall spontaneously result in *actual* motion or not will depend solely on the external and merely accidental conditions, of the absence or presence of resistance and restraint opposed to it by other forces. Now there is reason for believing that these external conditions may be so regulated and provided as to allow physical forces, or the principal of motion inherent in matter, not only to carry on these continuous operations which constitute life in an organism, but even to *originate* at intervals the *occasional* phenomena of outward action and locomotion." Vide "Medical Critic," April 1863.

Dr. Lionel Beale, in a paper "On Life" read by him at the meeting of the British Association held at Birmingham 1865, says "All growth, all active change, is due to the living or germinal matter, which is perfectly transparent and structureless; changes are not excited in this by external agencies, but the first impulse proceeds from within the living matter itself, and is in effect the operation of vital force or power." It would almost appear from the above that Dr. Lionel Beale is really but unconsciously describing the electric force itself, the analogy is so strong.

In illustration of the fact that discharges of electricity in the system will cause the compression of particles of matter, I cannot do better than refer to the formation of the solid which takes place under ordinary muscular contraction. Thus, when muscular fibre contracts there is a manifestation of electrical force, both in the

muscles and nerves, and matter existing in the fibres of the muscles becomes converted into a solid, losing at the same time all power of contracting again, and is then carried off as waste matter, although it may be destined to serve some other useful purpose in the animal economy. Although physiologists agree that there is an expenditure of vital force under the development of contractile power, but notwithstanding the discoveries of Du Bois Regmond, Matteucci, and others, they do not state in what that vital power consists. I therefore offer the following opinion as a solution of the question, so far as muscular action is concerned, which embraces in a degree, all other vital actions. During life the muscles and nerves are kept in a state of tone by a mutual action and reaction upon each other under capillary action. In a state of rest the nerve is acting as the platinode, and the blood in the capillary as the zincode, the plus current consequently being directed from the capillary to the terminal of the nerve, so causing nutriment to be deposited at the platinode, as in any other part of the body. But during natural action or contraction of a muscle, the nerve, by a discharge of force from the brain under the influence of the *will*, becomes converted into the plus force, and matter already existing in the muscular fibre is compressed and shut up in the form of a solid.

The following experiments also show the power electricity possesses of combining and arranging the particles of matter, and converting them into solid structures.

Experiment No. 1.—If water be mixed with the sap of plants, and the solution be carefully filtered through blotting paper, and a simple galvanic circuit be immersed, a very short time will suffice to form a film on the surface of the water. This film will gradually increase in thickness, and if examined microscopically will be seen to consist of minute particles of matter exhibiting vigorous molecular action, and although I have not absolutely seen cells formed in such specimens, I have seen cell after cell appear, and then, drawn by some invisible agency to a part where there had been previous accumulation of tissue, adapt themselves one to another so as to form tubes, apparently by a bursting of that portion of the cell wall which had adapted itself to the previous cell.

Experiment No. 2.—If we dissolve forty grains of gutta percha in six drachms of chloroform, put the solution in a wide-mouthed bottle, and then immerse a galvanic circuit and accurately close the mouth of the bottle with a cork, the gutta percha, which upon its solution was much lighter than the chloroform, very shortly acquires a higher specific gravity than the chloroform, and sinks to the bottom of the vessel. A good shaking will again cause intimate mixture to ensue, and before the gutta percha again sinks it will assume a flocculent appearance, and the movement of these flocculi will constitute a very delicate test of heat.

I now resume the consideration of the further organisation of the chyle.

The property of coagulation of the chyle appears to be coeval with the formation of chyle corpuscles, for before the chyle passes through the mesenteric glands it possesses feeble properties of coagulating, and the number of chyle corpuscles at such period is very limited. Now after the formation of cell walls, the force existing in the nuclei would still be exerting its influence upon surrounding matter, and when taken out of the body and allowed to remain at rest or when it is exposed to the influence of other matter upon it, (vide Mr. Lister's Croonian Lecture, delivered 1863,) currents would be given out in definite directions, and these currents would cause the compression of particles of matter, *because one form of electricity cannot be developed without the other, and the union of the two electricities would cause the formation of a solid*, in the same way as we have already seen it to be done in the ordinary action of a muscle. We can therefore readily understand that the amount of coagulability must correspond with the amount of organisation or vital force existing in the corpuscles. And, as I hope clearly to show when considering the function of the spleen, each time a corpuscle undergoes capillary action, *especially* if such takes place in a *glandular structure*, an addition is made to its contents and consequently to its inherent force, irrespective of any addition or abstraction from its vital force.

COLOUR.

But after the chyle has passed through these mesenteric glands it possesses a pale reddish *yellow* colour, (which we shall see must be regarded as an evidence of the amount of action going on in the gland,) and when allowed to stand for a time undergoes a regular coagulation, acquiring before it passes out of the thoracic duct a decided red tinge, which increases on exposure to air. I believe the production of this colour is *due simply to the action of electricity on matter*, and especially upon the salts of sodium, potassium, and iron; and the information we derive from the spectrum analysis very materially supports this view. Thus, the first change from white would be to a pale reddish yellow; the spectrum analysis tells us that in the production of colour the reaction of sodium is the most delicate of all metals, and Swan could detect by its means the 2,500,000th of a grain. Potassium and iron are less delicate tests, and give a red line, which colour we have already seen is not acquired by the chyle until shortly before it passes out of the thoracic duct, and has gained considerable property of coagulating.

SPLEEN.

After food has been taken the spleen commences to enlarge, and continues to increase in size for about five hours, when it attains its maximum size, that is about the time *when the process of chymification ceases*, the enlargement being caused by an accumulation of

blood in the substance of the organ; after the process of digestion has ceased it gradually decreases again, so that when digestion has terminated for some hours it contains very little blood, and is correspondingly small. It is believed that a certain amount of stagnation of blood occurs in the spleen during its state of action, and it is known that its blood, as compared with that of other organs, contains large quantities of iron and soda. It is known that animals may live after the spleen has been removed, but its removal has been followed in some instances by regeneration, and in others by enlargement of the glands of the neck and axillæ; Maggiorani has noticed a deficiency of iron in the blood corpuscles, and in dogs operated upon by Mr. Dalton, unnatural appetite and ferocity of disposition followed. As a natural sequence, its removal when not followed by regeneration must throw more work upon other glands that perform a somewhat similar office, but as other glands cannot act perfectly in such duty, we must expect corresponding changes in the blood, and also we must expect that the habits and disposition of the animal will be changed through the blood.

I proceed to show as briefly as possible the nature of the blood changes as they are known to occur, and the mode in which such appear to me to be brought about. (1) In the venous blood there is found to be a marked decrease in the total amount of solid matter, dependent upon the diminished proportion of red corpuscles. (2) A marked increase of albumen, to even double the previous amount. (3) Increase of fibrine almost constantly, and sometimes to even five or six times the previous amount. (4) The venous blood is remarkable for containing a larger portion of colourless corpuscles, believed to be derived from the white parenchyma, which it also contains; Hirt counted one colourless to 2,179 coloured corpuscles in the blood of the splenic artery, and one to 60 in that of the splenic vein. (5) The venous blood also contains a number of fibrinous flakes and peculiar cells (including rod-like crystals) of reddish yellow colouring matter, which seem to be red corpuscles in a state of degeneration. (6) Diffused amongst the colourless parenchyma (but in very variable amount) coloured cells are found, some of which are unchanged blood corpuscles, whilst others appear to be blood discs in various stages of retrograde metamorphosis, gradually diminishing in size, and assuming a golden yellow, brownish red, or even blackish colour, or having the pigmentary matter crystallized in rod-like form in their interior, or again breaking up into pigment granules.

MALPIGHIAN BODIES.

Before proceeding to show cause for these changes of the blood, I think it well to call attention to the splenic artery, which is remarkable for the rounded malpighian bodies which are studded over its ramifications. It appears to me that these malpighian

bodies perform a most important function in the action of the spleen, viz., that of accumulating and discharging electrical force, and thus acting as the prime conductor of the ordinary electrical machine; the spheroidal form causing the electric force disengaged in them to pass away in quantity and intensity, unlike ordinary capillary action which represents the discharge of electrical force quietly and continuously as it would be from points. Consequently the discharge from these bodies would represent on a small scale the discharge which takes place from the brain when we wish to move a muscle.

If we examine the minute structure of these malpighian corpuscles we find that internally they correspond with the structure of the gland itself, but the walls are covered with capillaries, which also permeate their structure throughout. Their number and size correspond with the condition of the animal, being much the most numerous in animals that are well fed, and diminishing to a remarkable degree in those that are starved; thus showing that if they are not essential to the proper organisation of the blood, they are at least closely connected with it. Now if under ordinary capillary action, each capillary has its nerve, (as we have good reason to suppose is the case, for the point that is introduced into a capillary can scarcely draw blood without causing pain,) and the one is acting as the zincode to the other, the arrangement which is here seen to exist must entail electric force being given off with a certain amount of shock, because it is known that the malpighian corpuscle is not represented by a corresponding enlargement of the nerve, and there must be some interruption to the current, for each wave of the blood in the artery would give rise to a wave of electrical force, and then a cessation, for the current of blood would not be as continuous here as it is in ordinary capillary action, and the current or shock of electrical force would be given off at the moment when the blood had filled the malpighian corpuscle, that being the moment at which the greatest amount of force exists in the malpighian body, and a portion of such force could not be given off without entailing a discharge of the whole amount.

FORMATION OF FIBRINOUS FLAKES.

I have already attempted to show that coagulation of the blood depends upon electrical force passing through the liquor sanguinis, but coagulation is also known to be favoured by rest, and if these malpighian corpuscles act as I suggest, we readily see a cause for the formation of the fibrinous flakes which are found in the splenic venous blood, viz., the passage of currents of electricity through the liquor sanguinis, whilst the blood is somewhat at rest, in the lacunæ or channels of the splenic structure. Nor does it appear unreasonable to believe that the *elaboration of albumen and fibrine in the liquor sanguinis amounts to more than different stages of the same*

process, the result of different degrees of electrical action upon the necessary elements existing in the liquor sanguinis, of which the formation of fibrinous flakes is the limit, representing in fact a process analogous to ordinary growth of tissue.

The second effect of these discharges of electrical force would be to act upon the corpuscles of the blood, producing, as I hope clearly to show, a destructive action upon those which have become changed in character by passing a certain number of times through the circulation, and are thenceforward no longer calculated to carry life to the tissues, they assist to organize those which are of more recent origin.

To make this clear I must define as exactly as possible the changes which must be effected upon the corpuscles as they pass through the systemic capillaries. I have already given an opinion that in capillary action, the capillary is acting as the zincode and the nerve as the platinode, but this action might be reversed without detriment to these views in the main ; for the diamagnetic* property it would acquire under the absorption of carbon would alter its character as an electric, and thus render the corpuscles incapable of exerting a stimulating influence upon surrounding bodies. In this way we get a closed circuit established between the systemic and pulmonic capillaries through the medium of the nervous system. The current of the blood not only establishing a current of fluid to supply nutriment or matter to the tissues, but also supplying the nervous system with electrical force, which then acts, I believe, like a Deluc's dry pile.

Now the effect of establishing such a closed electrical circuit would be to produce electrolytic action at the poles or terminals ; and taking the body as a whole, and not considering here the circuits which must be established in the brain and other nerve centres, the brain would act as the platinode, the cerebro-spinal nerves as the conducting wires, and the blood would represent the zincode, the current of course passing from the blood to the nervous system, of which the brain and all nervous centres would be storehouses of force similar to a Deluc's pile. Such would be the action going on, according to the known laws of galvanic or voltaic electricity, and it follows as a natural sequence that wherever a break occurs in the circuit, electrolytic action must be set up. Now this break does occur between the extremity of the nerve and the tube of the capillary, and the plus current passing from the blood, would carry nutriment with it to be deposited round the nerve or negative plate, the force itself for the most part passing on through the wire or nerve to the brain, whilst the negative

---

* The author believes (and is taking steps to prove how far he is correct in his opinion) that the *arterial blood is magnetic*, and *only becomes diamagnetic as the vitality passes off when abstracted from the body and coagulation takes place ;* or when under the influence of the nerves in the body, *it loses its property of giving life to the tissues.*

current would pass not only to the capillary but to the blood corpuscle, carrying with it particles of matter negatively electrified, which would represent waste tissue. In this way oxygen would be carried to the tissues and carbon would be drawn away from them, and the arterial blood in its conversion into venous might be rendered diamagnetic by the absorption of the carbon, and the abstraction of a certain amount of oxygen. But other principles besides oxygen and carbon would be amenable to the same law, and especially the salts of the liquor sanguinis. Consequently each time a corpuscle passed through a systemic capillary an addition must be made to the solid in its interior, and thus the chyle corpuscle with central nucleus of small size will at length become converted into a solid mass; capable, it is true, of exerting a greater amount of attractive force for electricity, but unfitted to maintain the life of the tissues, because the amount of solid in the interior would retain such force by its own inherent force. Thus, closely examining the changes which must take place in the blood corpuscle under ordinary capillary action, the cause of certain discrepancies of opinion as to the corpuscles having nuclei with even double cell walls as supposed by some, and their being solid with an indefinable cell wall as supposed by others, is easily understood, and is doubtless owing to investigators meeting with corpuscles in different ages or stages of growth; and this view is strongly supported by the observations of Professor Bennett, who discovered that the colourless corpuscles of the blood were of two distinct sizes, the small corresponding in size with the nuclei of the larger ones.

The establishing of these closed circuits is of immense importance with regard to the production of sensation, for we find that sensation is the result in all cases of an interruption to the current by a resisting medium, for the exemplification of which I must again refer to Professor Wheatstone's hridge. Thus, pressure upon the capillaries or nerves of the finger will interrupt the current, and give the sensation of touch. A ray of light thrown on the retina produces from the same cause an effect upon the brain, and the form of the object will be defined by the mode in which such rays fall upon the retina. Neither are we without proof of this fact: for if a ligature be applied to a nerve, and the nerve irritated above the ligature, that is towards the brain, no contractions ensue, but the animal exhibits signs of suffering; on the other hand, however, when the nerve is irritated below the ligature, strong contractions of the inferior muscles take place, without suffering being evinced. In electro-telegraphy we find that if a message be sent by a wire from a certain point to a distant station, say from London to Manchester, a continuous insulated conducting wire must extend between the instrument and battery in London and the instrument in Manchester which is to receive the signals, and there must also be a continuous conducting communication to

complete the circuit between Manchester and London. It was discovered by Steinheil that the earth itself may be made a substitute for the second conducting wire, thus proving that by creating a disturbance of electric equilibrium at a given point, the return current, notwithstanding its passing through so great a space as that of the earth, makes its appearance at the point at which primary disturbance had taken place. Now if we let the grey substance in the spinal cord represent the wire conducting an impression from a peripheral nerve to the brain, we shall at once perceive the use of the two roots of the spinal nerves, viz., to separate the afferent and efferent fibres. And supposing the brain and spinal cord to represent an electric circuit completed through the medium of the anterior and posterior roots of spinal nerves, the ganglia developed on the posterior root would act as an accumulator of force, in a similar way to a Leyden jar or Deluc's pile; and an impression being made upon the peripheral nerve by an interruption to the current, such impression would be conveyed first to the grey matter of the cord by the posterior root of the nerve, and thence through the grey matter to the brain, when a sensation would be produced answering to a deflection of the galvanometer needle, and a corresponding amount of electric force at once transmitted from the brain, through the motor tracts to the same point in the spinal cord where the impression had first been made. Such electric force would then, if necessary, be distributed to the muscles of the parts from which the impression had originated, and thus electric force would be converted into motor force.

For the purpose of more conveniently describing the causes of the changes which the blood undergoes in its passage through the spleen, it will be better to consider the corpuscles as existing in three different classes or states, but of course they would exist in every stage of transition, from the lowly organized chyle corpuscle, to the effete blood corpuscle.

1st.—Those recently formed, which have only passed once through the pulmonic capillary, and, not having their own organization complete, are consequently unable to carry vital force to other structures.

2nd.—Those which have become solid, and are no longer capable of acting as dispensers of vital force.

3rd.—Those which are in an intermediate state, and possess this power in the highest degree.

When a charge of electric force is given off by a malpighian corpuscle in making its way to the nearest nerve fibre, and from thence to the nearest ganglia of the sympathetic, it would act upon the different classes of blood corpuscles enumerated above according to their state. Now there are two reasons why this plus charge from the malpighian corpuscles, should select this second class of blood corpuscles in preference to either of the other classes, first, the amount of solid in them exceeds the amount in the others; secondly,

the solid contents of the corpuscles have been built up from their first passage through a systemic capillary by a negative current from the nerve, so that they would represent, not only a greater amount of matter, but that matter also in an opposite electric state. Now the particles of iron and soda, (both electro-positive bodies,) which we have already seen exist in considerable quantity in the spleen, would possess an attracting influence for the nerve current; and as the third class of corpuscles as arterial blood possess a plus current, the abstraction of such current from them in their conversion into venous blood, would cause a negative current to flow into them. This would carry with it the iron and soda, thus adding to their contents and to their property of acquiring organization. But as the first class, or most recently formed corpuscles, exist in a negative state, they could scarcely derive any force from the nerve, although they might and probably do take up iron and soda by their own inherent force. Possibly also small corpuscles are here converted into larger ones by a similar process to that I have described as taking place in the absorption of chyle; still the fact of their being so converted would not give them colour until they had again passed through the pulmonic capillary, and had had such elements acted upon by the electric force. It must be evident that the effect of the plus current from the malpighian corpuscle on the blood discs already converted into solids must be of a destructive character, causing the rupture of the cell walls and disintegration of the contents; and the electric force is quite capable of arranging some of the particles of matter thus set free, and converting them into crystals; whilst other atoms (such as uncombined iron) would be separated, and thus enabled to assist in the organization of the other two classes of blood corpuscles. This destruction of the coloured corpuscles would materially alter and *increase the proportion* of the colourless corpuscles. Now all these changes which the blood undergoes in the spleen would be greatly assisted by the comparative state of rest or slow movement the blood assumes in its passage through this important organ. But in addition to the changes effected on the blood of the spleen, and already commented upon, we ought to have the temperature of the splenic venous blood higher than that of the arterial, for we find that the passage of electricity through conductors is attended with the evolution of heat, the rise of temperature being proportional to the square of the quantity transmitted in equal times. Now we really do get this elevation of temperature, for the splenic venous blood is, with the exception of the blood of the hepatic vein, hotter than any other blood in the body, a very significant and instructive fact. Regarding the spleen as a whole, we find that in its active state it must be a powerful electro-positive body to the neighbouring organs, and upon due consideration we see that the malpighian corpuscles represent in some respects the gland in miniature. Thus

they are the originators of interrupted currents of electrical force, minute, it is true, to a degree, but the discharge from all these corpuscles occurring at or about the same time, must in the aggregate give rise to the production of very considerable force, commencing, I believe, the *peristaltic action* of the stomach, and regulating the amount and moment of the discharge of the secretions of the pancreas, liver, duodenal glands, etc.; whilst by causing muscular contraction in the villi of the intestines, it would most materially assist in pumping chyle into the lacteals; but the formation of secretion by the liver, pancreas, etc., appears to me to result from a stimulus sent direct from the stomach to these various organs.

LIVER.

The mechanical changes that the blood undergoes in its passage through the liver may be easily understood if referred to *electric* action. Thus it possesses little if any power of coagulating, the coloured corpuscles are flaccid, of a violet hue, and show but little tendency to a rupture of their cell walls, the colourless corpuscles are seen to exist in very irregular forms, and, as I have already stated, the blood of the hepatic vein is of higher temperature than any other blood in the body. The blood of the hepatic vein, as compared with that of the portal vein, contains more fat and sugar, and is far poorer in water; the cells contain less fat, less salts, and especially less hematine or at least iron. This blood is, however, somewhat richer in extractive matter, and the specific gravity of the cells is higher than that of the cells of portal blood.

With regard to temperature, we have already found that the temperature of the blood was raised by its passage through the spleen, and have referred such to an electrical law. It consequently follows that the blood of the vena portæ, from the admixture of the splenic blood with that from the gastric and mesenteric source, must reach the liver at a higher temperature than venous blood usually attains. This is one cause of increased heat, but the great cause of the blood coming out of the liver hotter than it passes into it, is doubtless owing to the large amount of electro-chemical action which takes place in the gland, combined with the *very impure state of the blood* after it has been broken up in the spleen. And this opinion is confirmed by another electrical law, for we not only find that the passage of electricity through conductors is attended with the evolution of heat, but that the amount of heat developed *is inversely with the conducting power.* It necessarily obtains that if electrical action goes on in any form in the liver, the blood, with the large amount of *débris* it contains, must afford that amount of resistance to the passage of the electric current which would cause this development of heat. Again, the large amount of action that is known to take place in the liver, if of an electro-chemical nature, must be carried on in great measure at the expense

of the vital force of the blood, a large portion of which has already been deprived of its vital power; and as the amount of chemical action would correspond with the amount of electrolytic action, it necessarily follows that the blood must be most completely deprived of all vital force in its passage through the liver. For it must be remembered that in this organ we have a very different apparatus to that which exists in the spleen, the liver appearing to be constructed upon a principle especially adapted for favouring capillary action. Indeed, so close is the arrangement of hepatic tubes, that when the vascular network is injected, as it must be when secretion is going on, no vacuities or interspaces can be seen. By a complete removal of the vital force of the blood, we establish a cause for its non-coagulability, and for the flaccid state of the corpuscles. But their violet hue is doubtless owing to their having imbibed matter through the negative current during capillary action, which would also add to their specific gravity; whilst their exhibiting but little tendency to rupture of their cell walls, would be a necessary consequence of the comparatively small quantity of water this blood contains. The irregular shapes that the colourless corpuscles assume would result from the removal of any force they may have acquired which might have a tendency to become converted into a vital force, and perhaps also of some of their inherent force. The large amount of electrolytic action here taking place would also be sufficient cause for the loss of water the blood sustains, and its elements are doubtless necessary for the elaboration of those chemical compounds formed in the liver, the consideration of which I cannot enter upon now, although it does appear to me probable that under electrolytic action such may be produced artificially, by a series of carefully conducted experiments. In support of this view of the cause of the loss of water, I must refer to some instructive and interesting experiments made by Helmholtz on the chemical changes induced in the tissues by muscular action. Powerful contractions were induced by electricity in the amputated leg of a frog and were kept up as long as the irritability was retained. The flesh of the two limbs was then analysed, and it was found that in every instance the water extractive was diminished in the electrized muscle, to the extent of from 20 to 24 per cent.

I cannot conclude this paper without referring to the discoveries Mr. Lockhart Clarke has recently made with regard to the pathology of diseases of the nervous system, and especially of tetanus, as these discoveries show, I believe, most satisfactorily the nature and cause of such diseases, and they afford absolute proof that electrical currents are constantly circulating in the nervous system. I cannot do better than quote his own words with regard to the morbid appearances he detected in one case of tetanus, which will be found to be a type of all. He says,—

"The sheath of the cord was natural in appearance, and had a reddish hue, owing to the fulness of the vessels on the sur-

face of the cord. Over its whole extent the cord was covered with large injected vessels, which were nearly as thick as whip-cord, they were near together, and ran more or less parallel to the length of the cord. The white and the grey matter were both congested, and the puncta were very conspicuous everywhere. In sections of this cord I found the grey substance in particular very much congested, and not only were the vessels unnaturally dilated, but each was more or less surrounded by a granular and originally fluid exudation, in which the natural tissue of the part became broken down and ultimately dissolved. In a microscopical preparation a large triangular mass of this exudation is represented where it occupies the bottom of the anterior median fissure, and has destroyed a part of the anterior median commissure, by extending to the right. The same parts of the grey substance of other sections are also represented more highly magnified, and in one figure a quantity of granular exudation has enveloped and partially destroyed some blood-vessels and the pia mater which supports them. The exudation extending round the bottom of the anterior column, destroying a portion of the anterior commissure, and following the course of an evidently diseased blood-vessel into the middle of the anterior cornu, where it has destroyed a part of the grey substance," &c. &c.

I need not carry the quotation further, for if these morbid appearances prove anything at all, they prove that the nervous system has made greater demand upon the blood vessels for nerve force, than those blood-vessels, under ordinary capillary action, are able to supply; and consequently a rupture not only of the capillaries but of the larger vessels also takes place, by which means the substance of the cord itself becomes disintegrated; and the effused portion would render it an inferior conductor of impressions or nerve force, be that force what it may. But we really have no difficulty in determining the nature of this force, for by reference to an experiment of Du Bois Reymond's, which may be easily repeated, we find that the slightest scratch on a finger will cause a deflection of the galvanometer needle. Du Bois Reymond conducts the experiment as follows. "The forefinger 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, even before any contraction of the muscles is made, at the moment when the circuit is completed the needle is more or less deflected in one or the other direction. This deflection is caused by some heterogeneity of the skin of the fingers, and up to the time when Du Bois Reymond published his paper on the subject he had not determined the law of its production." (*I would however venture to suggest that it is due in great measure to some inequality of force in the two sides of the body.*) "If there be ever so slight an abrasion of the skin of one of the fingers the deflection is said by Du Bois Reymond to be incomparably greater, and the current is directed through the galvano-

meter from the finger which was hurt to the unhurt one. In other words, if instead of the human body a heterogeneous metallic arch were placed with its two ends in the two conducting vessels, the wounded finger would act like the zinc or positive metal, and the sound finger like the platinum or negative metal. When one of the fingers has an abrasion, the permanent deflection which remains is so considerable that it interferes with and prevents any more delicate observations." The above is quoted from Dr. Bence Jones' work on Animal Electricity.

This deflection of the galvanometer needle gives positive proof of the passage of an electrical current from a wound, and the greater the extent of such wounded surface the greater the amount of electrical force given off. Now by lacerations of the nerves or simple irritation of them, as in idiopathic and hysterical tetanus, the same effect is produced, but whilst in simple irritation of the nerves the tetanic spasm ceases soon after the source of the irritation has been removed, provided such irritation has not been too long continued, in laceration of a nerve we generally get fatal results after the disease has been once thoroughly established.

Now if electricity be the real nerve force, and if there be continuous currents passing to and from the nerve centres and the peripheral extremities of the nerves in their state of rest, keeping them in an electrotonic state, then any injury of a nerve, by means of which continuity of current would be interfered with, would cause the nervous centres to take on action, and we should get electrical force manifested by contractions of the muscles. In fact, the injury of a nerve would act precisely in the same way as Wheatstone's bridge with a resisting medium always interposed in one of the wires. And the result of this excessive action upon the nerve centres would be primarily to exhaust nerve power ; and secondarily to cause all those lesions of the nerve centres which Mr. Lockhart Clarke has shown to exist in this disease, by nature endeavouring through the blood-vessels to supply the force in sufficient quantity to meet the increased demand, but failing in such effort the vessels give way with the above results.

In thus imperfectly sketching the mode in which it appears to me the food is disintegrated and converted into chyle, and subsequently into *organised red blood endowed with a vital force*, I have endeavoured to follow as nearly as possible that course which should prevail, if that *vital force* be really *an electric force.* For it is clear that if such be the case the various processes and functions of life must be carried on and governed by *the same laws that govern electricity in general.* At any rate, the laws which have already been found to obtain cannot be set aside, although our knowledge of those laws may require to be somewhat *enlarged.* I especially refer to the conversion of electricity into a vital force. It is far from my wish, however, to assert dogmatically that the system I have followed is strictly correct, for the capillary may be acting as the platinode

instead of the zincode to the nerve, and we know that the terms plus and minus as applied to the electrical forces are only names used to distinguish the two currents, one of which cannot be developed without the other manifesting itself in equal degree. In other ways also we may have to reverse electrical action, but such really is of no importance with regard to these processes being governed by electrical laws, and are only details of the plan requiring to be worked out. My great object in writing this paper is to draw attention to my experiments proving the electrical character of the arterial blood, that such experiments may be repeated and investigated by competent and unprejudiced persons, when, if found to be correct, all these details will follow as a matter of course. It is well known that in the earth itself electric currents are constantly circulating, and that the amount of these currents varies in different localities. It is also well known that bodies hold different positions in the scale, by which means they are rendered positive and negative to each other, and although not insulated from each other, their normal position in such scale is not changed, unless it be under electrolytic action (I do not, of course, here refer to free electricity such as we get displayed in the various phenomena of atmospheric electricity) or to the decomposition of one of the elements, for the carrying on of which process a definite arrangement of the bodies is essential. It is also known that some bodies are *magnetic* and others *diamagnetic* only, and the structural arrangement of their component particles appears from the researches of Tyndal and Knoblauch to be one great cause of the phenomenon; still such property is retained in spite of their being uninsulated from each other. Now as the animal frame is built up of matter which we have already seen to be subservient to the laws above named, we may fairly assume that the same principle may be acting upon matter in the body as upon matter out of it. And even with much greater effect, because the animal structure is so built up of solids and liquids that it would appear to be purposely constructed to favour electrolytic action. If the blood be charged with a plus or minus force, and such force be given out in capillary action, then electrolytic action must go on, and this electrolytic action may convert the venous blood into a diamagnetic body.

By referring to animal chemistry we find that the brain contains a large amount of phosphorus, the proportion being from 1-20th to 1-30th of the whole solid matter, a body standing high in the scale of electro-negative elements; and as all nerve fibre partakes of the same chemical characteristics, we can at once assign a reason for the electric force of the blood being abstracted by the nerve under capillary action. We are thus taught by animal chemistry the change that must be effected in the electric state of the corpuscles and the various tissues and secretions, and there can be no question that a careful study of animal chemistry will practically do very much to simplify the treatment of disease. We can thus ascertain

that which is deficient in the system, or that which by its presence may give rise to abnormal action by retarding electric or magnetic action, one or both. In the one case we shall add the principle which will promote normal conductivity, in the other we shall employ remedies to abstract that which is acting on the animal machinery as impurity does upon conductors generally, and thus restore normal action. It cannot, however, be denied that in thus considering the vital processes which take place under the phenomena of *animal life*, we reduce those processes to the action of certain physical laws; but I trust no one will on that account look with irreverence on the *one Great Cause acting as the mover* of all, and upon this point I believe it is due to myself, and to others who may enter upon the consideration of this grand subject, to be very explicit; it is expressly written in the Divine Word, that "the blood of it is for the life thereof," and irrespective of the lesson we are taught by the extreme beauty and order of the mechanism employed in the processes of life we have been considering, and which must establish the wisdom and power of the Creator, I believe I have here proved these words to be strictly correct; and in attributing the phenomena of animal life to *continuous currents of electricity never ceasing without a corresponding cessation of the functions of life*, I have as precisely as possible defined the nature of animal life, and thereby have opened out a vast and most interesting field of research, the important bearing of which upon the scientific study and practice of medicine, cannot in my opinion be over-estimated.