ELECTROPHYSIOLOGICA:

SHOWING HOW ELECTRICITY MAY DO MUCH OF WHAT IS COMMONLY BELIEVED TO BE THE SPECIAL WORK OF A VITAL PRINCIPLE

II.

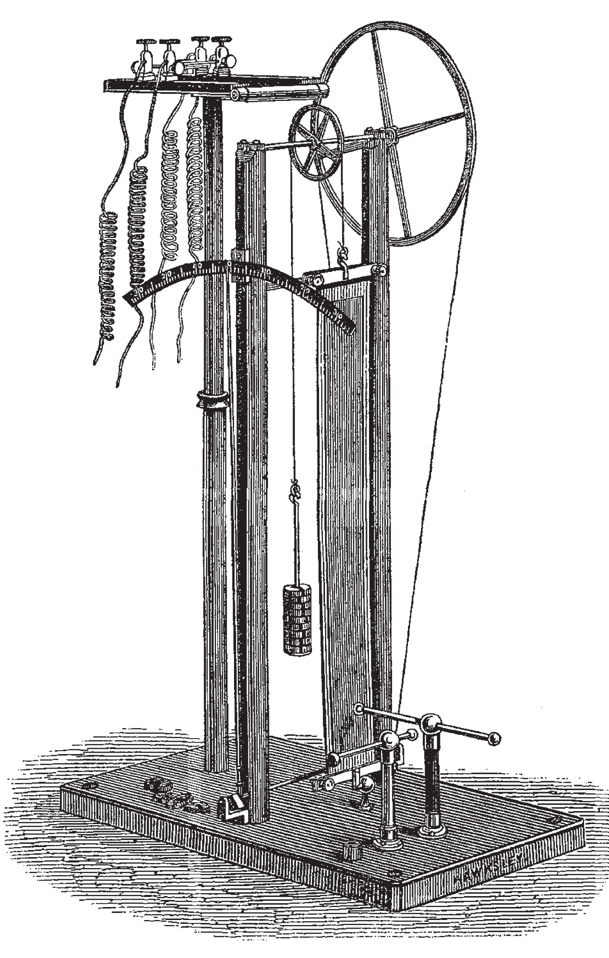
2. *How Electricity may do much of what is commonly believed to be the work of a vital principle in muscular action.*

I HAVE long held that a vital property of "irritability," or "tonicity," was unnecessary in muscular action. As it seemed to me, the state of relaxation in living muscle was to be accounted for by the mutual repulsion of molecules arising from the presence in the muscle at the time of a charge of electricity, sometimes positive, sometimes negative; as it seemed to me, muscular contraction, whether in ordinary muscular action or in rigor mortis, was nothing more than the result of the operation of the elasticity of the muscle upon the discharge, sudden or gradual, of the charge which had previously kept up the state of relaxation. And I still hold that the state of relaxation is caused by the presence in the muscle of a charge of electricity, and that muscular contraction is brought about by the elasticity of the muscle coming into play upon the discharge of this charge; but, since I began to work with the new Quadrant Electrometer of Sir Wm. Thomson, I have been obliged to take a different view of the way in which the charge operates in causing relaxation. The fact, discovered by means of this instrument, that there are two charges of electricity in muscle, positive *and* negative, was fatal to the idea that the state of relaxation was due to the mutual repulsion of molecules consequent upon the presence in muscle of a single charge, positive *or* negative. With either charge singly the idea might be entertained, though it was not easy to understand how, wanting effectual insulation, the electricity could be kept to its work; with two opposite charges, on the contrary, the attraction of each charge for the other *must* neutralise the repulsion arising from the presence of either singly. Nor did I find a way of escape from this difficulty until I began to seek it in a totally different direction, even in the theory according to which the sheath of muscular fibre during rest is charged as a leyden-jar is charged. Is it possible, I asked myself, that the two opposite charges, disposed leyden-jar-wise upon the two surfaces of the sheath, may cause elongation of the fibre by compressing between them the elastic sheath? Opposite charges of electricity *must* attract each other; that was plain enough. Opposite charges attracting each other across an elastic sheath *may* compress that sheath in such a way as to cause elongation of the fibre; that was not impossible. Upon this view, too, there was no difficulty in understanding how each charge was prevented from escaping, and made to work in this manner, by the mutual attraction of each for the other. In a word, the idea that the two charges might act in this way in causing muscular relaxation was far more easy to realise than that which regarded the state of relaxation as the result of the muscular molecules being kept in a state of mutual repulsion by the presence of one charge in the muscle. And so it was that it became necessary to look into this matter a little more closely—to put it to the test of experiment, as best I could.

In order to this, I began by inquiring whether the idea in question was possible or not. I wanted to be certain that the mutual attraction of two charges of electricity, dispersed leyden-jar-wise upon the two surfaces of the sheath of the fibre, would cause elongation, and that the discharge of this charge would be followed by contraction; and, after several abortive attempts, I found what I wanted, and more than I expected at first, by the means which are represented in the accompanying figure.

Vulcanised india-rubber sheeting being at once elastic and dielectric, it occurred to me that this material was the very thing for putting to the test of experiment what I believed might happen in the elastic and dielectric sheath of muscular fibre. I therefore took a band of this sheeting, provided it with the conducting surfaces necessary for charging and discharging it as a Leyden-jar is charged and discharged, and had constructed an apparatus for showing whether or not the anticipated changes in length were produced by this charging and discharging. The band (which is to be regarded as the counterpart of a *strip* of the actual sheath of the muscular fibre) is 14 in. in length by 2 in. in breadth, the commercial number of the india-rubber sheeting being 30. The necessary conducting surfaces to allow of the charging and discharging are made by painting the band on each side with fluid dutch-metal, care being taken to leave at the edges a sufficient unpainted margin to secure the necessary insulation of the two painted surfaces. The frame-work of the apparatus consists of two strong brass pillars, 18 in. in height, and 4 in. apart, rising from a flat brass stand. Across these pillars work two axles, horizontal in direction and parallel to each other—the one at the top, the other near the base, immediately above the stand. At the middle of the upper axle, midway between the pillars, is a wheel with a grooved edge, 2 in. in diameter, which may be called the driving-wheel; at one end, which projects beyond the pillar on that side, is another and larger wheel, 6 in. in diameter, also with a grooved edge, which may be called the multiplying-wheel. At one end of the lower axle, beyond the pillar on that side and immediately under the multiplying-wheel is a collar with a grooved edge; at the other end, also beyond the pillar on that side, is a socket for carrying a long index, of which the free end moves backwards or forwards before a graduated arc fixed immediately over the socket upon the same pillar near its top. The two axles move together, the upper telling upon the lower by means of an endless band which at one and the same time bites in the grooved edge of the multiplying-wheel at the end of the one, and in that of the collar at the end of the other; and thus the movements of the index before the graduated arc are made to represent a very considerable exaggeration of the movements of the upper axle. The india-rubber band is clipped at each end in a clamp, acting by screws, and having a hook on its free edge; and, being so clipped, it is fixed in a a vertical position by passing the hook on the clamp at its lower end into a socket provided for it on the stand, and by attaching the hook on the clamp at its upper end to a string which passes over the grooved edge of the driving-wheel to a short hanging rod with a button at its lower end, upon which rod are to be slipped coin-like weights, notched in the centre for this purpose, which weights have to be so adjusted as to put the band gently upon the stretch. In this way the band is so fixed that it cannot lengthen or shorten without these changes being made to tell upon the index, for as it lengthens or shortens, the driving-wheel which moves the index must be made to turn this way or that by the string which bites into its grooved rim in passing from the band to the weights. For charging and discharging, two short pillars are fixed to the stand in front of and at a short distance from the bottom of the band, that for the former purpose having an ebonite shaft, that for the latter being altogether metal; and through holes in the caps of these pillars the rods which are intended to serve as the actual channels for the charge and discharge are made to slide horizontally backwards or forwards in a suitable direction. In charging, the electricity is supplied to the metallic surface on the front of the band by pushing forwards the charging rod so as to touch this surface, and at the same time taking care that the discharging rod is drawn back so as to leave the necessary break in the circuit. In discharging, the discharging rod is pushed home so as to complete the circuit between the two opposite metal coatings of the band by touching the centre of the charging rod. And for the rest, all that need now be said of the apparatus (this is not all that has to be said, but what remains has to do with a totally different set of experiments, and had better be reserved until the time comes for dealing with these experiments) is, that in order to allow of this charging and discharging, the metal surface at the back, instead of being insulated all round like the metal surface at the front of the band, is put in communication with the earth by bringing it down a little so as to allow it to be clipped by the metal clamp which fixes the band to the stand.

In the actual experiment with the band, all that has to be done is first to charge and then to discharge, watching the index the while. It was anticipated that the band would elongate with the charge, and shorten with the discharge, and this is what happens in fact; for on charging, the index at once moves before the graduated arc in the way which shows that the band elongates in proportion to the charge, and on discharging it suddenly jumps back again to the position it occupied before the charging, these forward and backward movements being through 40° or 60°, or even over a still wider range, and not merely through one or two degrees. The band plainly elongates in proportion to the charge. The band as plainly shortens in proportion to the discharge, suddenly or gradually, as the



case may be, suddenly if the charge be augmented until it overleaps the barriers of insulation, or if the discharge be brought about by pushing home the discharging-rod, gradually if the band be charged and then left to discharge itself slowly by keeping back the discharging-rod. And these results are constant, provided only before charging and discharging the weights attached to the band are so adjusted as to balance without overbalancing the elasticity of the band—a matter which is easily managed with but little patience and practice.

All, in fact, that was anticipated is fully borne out by the experiment. And thus it may be taken for granted that elongation of the muscular fibre *may* be caused by the attraction of two opposite charges of electricity disposed leyden-jar-wise upon the two surfaces of the sheath of this fibre, and that contraction of this fibre *may* follow the discharge of these charges; for what is assumed to happen in this case is nothing more than what does actually happen with the band of india-rubber sheeting under perfectly analogous circumstances.

But if this be the way in which muscular fibre may be affected by its natural charge and discharge, how will it be affected by an artificial charge of the same kind? Will this artificial charge—the sheath being still a dielectric—act like the natural charge, the charge imparted to one side of the sheath inducing an equivalent amount of the opposite charge on the other side? Will the artificial charge, presuming it to be larger in amount than the natural charge, overrule the natural charge? Will the artificial charge, thus larger in amount than the natural, produce a greater degree of elongation in the muscular fibre than that which is natural to the fibre? Will the contraction following the discharge of this artificial charge be greater in amount than that which is natural to the fibre, because the elasticity of the muscle has freer play under these circumstances? These questions, and others also of a like nature, are suggested by the experiment upon the elastic band; for not only does the band elongate with the charge and shorten with the discharge, but the elongation and shortening are manifestly in proportion to the amount of the charge and discharge. Nor are these questions unanswerable. On the contrary, answers may be found in more ways than one—in the examination of the phenomena of electrotonus more particularly; and these answers are in no way ambiguous in their meaning.

In electrotonus are strange modifications of muscular action. In electrotonus, too, as I have shown elsewhere,* are strange modifications of the electric condition of the parts, there being everywhere in the region of anelectrotonus a positive charge overflowing from the positive pole of the battery employed in the production of electrotonus, there being everywhere in the region of cathelectrotonus a negative charge overflowing from the negative pole of the same battery. In anelectrotonus there is a positive charge, not only present, but at work; in cathelectrotonus there is a negative charge, not only present, but at work. At work certainly, for as I have shown, the movements of the needle of the galvanometer characteristic of electrotonus are caused by the movement, not of a voltaic current, but of these charges through the coil of the instrument, the movement of cathelectrotonus by the flow of the negative charge, that of anelectrotonus by the flow of the positive charge. At work also, as I have also shown, in modifying muscular action. At all events, the presence of a positive charge in anelectrotonus and of a negative charge in cathelectrotonus are facts, and therefore I am justified in looking to the phenomena of muscular action in the two electrotonic states with a view to find answers to the questions now under consideration.

At the onset of the inquiry, however, a grave difficulty has to be coped with—a difficulty as to facts, for the actual facts are not what they are believed to be. In a word, it is not true that the action of anelectrotonus upon muscular action is essentially different from that of cathelectrotonus. Differences there are no doubt, but not any that will prove to be of moment in the present place. It is a fact that muscular action is suspended, not in anelectrotonus only, but in cathelectrotonus as well as in anelectrotonus. It is a fact that muscular *elongation* is a phenomenon common to both electrotonic states. Nor are these the only points in the history of electrotonus which require to be looked into carefully. So that, before proceeding further in this matter, it is necessary to ascertain what are the facts which have here to be dealt with.

The true history of muscular action during electrotonus may be well seen in the gastrocnemius of a frog by means of certain experiments for the exhibition of which the apparatus already used in the experiment with the elastic band is furnished with certain parts which have yet to be described. These parts consist of a pillar and a platform resting upon it horizontally, the pillar rising from the side of the stand opposite to that occupied by the charging and discharging rods. The pillar has a telescope arrangement, by which its length may be altered, and a screw-collar, by which it may be fixed at any length. The platform consists of a four-sided metal floor, five inches in length by three in breadth, with a narrow and rather thick border of ebonite in which are two binding screws for holding electrodes upon each of its sides, with a long roller at one of its ends, and with a moveable gutta-percha cover of such a shape and size as to allow it to be slipped on and off between the ebonite borders, and fixed when on by having its edges made to play under the hollowed-out inner margins of the borders. In the actual experiment what has to be done is—to remove the elastic band and the weights attached to it—to fix the platform, so that it is a little behind and above the level of the driving-wheel, with the end to which the roller is attached turned towards this wheel—to fix the wires from the battery and induction apparatus to the binding-screws on the platform, the wires from the battery being carried to the side on which the screws are farthest from the roller (the battery, I should have said, consists of four medium-sized Bunsen-cells, and the induction-apparatus is one in which the secondary coil may be slipped altogether away from the primary—a Du Bois-Reymond's inductorium, in fact),—to prepare a frog's limb by stripping off the skin and dissecting away all parts of the thigh except the sciatic nerve,—to remove the gutta-percha cover from the platform, and pin upon it the prepared limb with its heel close to one end, care being taken not to injure the nerve or muscle in doing this,—to tie to the tendo-achillis the string which belongs to the weights,—to put back the gutta-percha cover into its place with the limb thus pinned and arranged upon it, the string attached to the tendo-achillis being brought out over the end which comes next to the roller,—to carry this string over the driving-wheel to the rod carrying the weights,—and to adjust these weights so as to put the gastrocnemius gently on the stretch,—and lastly, to draw out the nerve, and carry it first across the electrodes belonging to the induction-apparatus and then across those belonging to the battery, these electrodes, to allow of this, being made to point inwardly to a sufficient distance across the platform, two from one side, two from the other. In this way, when the circuits are closed (they are open at first) the nerve may be acted upon by voltaic and faradaic electricity as in an ordinary experiment in electrotonus. In this way, any change in the length of the gastrocnemius must tell upon the index, just as the changes in the length of the elastic band were made to tell, only in the contrary direction.

These arrangements being made, two experiments have to be tried, the one for exhibiting the action of anelectrotonus upon the gastrocnemius, the other for exhibiting that of cathelectrotonus, and each differing from the other only in the relative position of the voltaic poles, the positive pole being next to the insertion of the nerve into the muscle in analectrotonus, the negative pole being in this position in cathelectrotonus.

In the experiment for exhibiting the action of anelectrotonus upon the muscle—that with the positive pole in the position next to the insertion of the nerve into the muscle—there are three distinct steps, the first taken before setting up the state of anelectrotonus, the two others after this time.

The first step, or that which is taken before the establishment of anelectrotonus, is to tetanise the muscle with faradaic currents only just strong enough to act upon the muscle at all in this way. In this case the circuit of the induction-apparatus is closed, but not that of the voltaic battery, and therefore the nerve is acted upon by faradaic currents before the establishment of anelectrotonus. At first, the faradaic currents used are strong enough to tetanise the muscle effectually; then these currents are weakened by drawing away the secondary coil from the primary until the tetanus comes to an end; last of all, the tetanus is brought back again to the very slightest degree by moving the secondary coil back again towards the primary coil, and leaving it at the point where the currents produced in it just begin to have a tetanising action. This is the first step in the experiment.

The second step consists in the establishment of anelectronus while the nerve is still being acted upon by these feeble faradaic currents. Hitherto the circuit of the induction apparatus was closed, while that of the voltaic

* "Dynamics of Nerve and Muscle." Macmillan, 1870.

battery was left open. Now the latter circuit is also closed, and with this result—that the index gives a sudden great jump in the direction showing contraction, and then, immediately moving in the opposite direction to that signifying contraction, takes up a position on the other side of zero—at 15° or 20°, it may be—a movement showing, not contraction, therefore, but elongation. Eliminating, as non-essential, the strong contraction which happens at the closing of the circuit—for this has to do, not with anelectrotonus, but with the *extra-current* which traverses the nerve between the poles at the closing of the voltaic circuit—what happens, therefore, on the establishment of anelectrotonus is, first, *suspension of the tetanus* caused by the feeble faradaic currents; and, secondly, *elongation of muscle*. This is the second step of the experiment, and these the results.

The third step follows upon the second. Its object is to ascertain whether the tetanus may be made to return during anelectrotonus by slightly increasing the strength of the faradaic currents acting upon the nerve; and the way of arriving at this is to leave the voltaic circuit still closed, to go on moving the secondary coil of the induction apparatus nearer to the primary, and to stop the moment the faradaic currents acquire strength enough to call back any tetanus. And this is what happens—that after moving the secondary coil but a short distance towards the primary, the index shows, not only that the tetanus has reappeared, but that it has reappeared in greater force. Before the establishment of anelectrotonus, the tetanus caused by faradaic currents only just strong enough to tetanise the muscle carried the index to 20° or thereabouts; after the establishment, the tetanus caused by faradaic currents only just strong enough to exert a tetanising action moved the index to 40° or 60°. In a word, contraction may happen in anelectrotonus, and when it happens it is considerably increased in amount. This is the third step of the experiment, and this the result.

In the experiment for exhibiting the phenomena of cathelectrotonus—that in which the negative voltaic pole is placed next to the insertion of the nerve into the muscle—all the steps are the same, and so are the results. The setting up of cathelectrotonus suspends the tetanus caused by feeble faradaic currents, and causes elongation in the muscle. The tetanus brought back during the cathelectrotonus by currents only just strong enough to have a tetanising action is in increased force. The degree of elongation is the same as in anelectrotonus. The increase of contraction is the same as in anelectrotonus. The only difference, indeed, between the two experiments is this, that somewhat feebler faradaic currents serve to recall the tetanus in cathelectrotonus than those which were required to do this in anelectrotonus.

Nor are these facts at variance with those which are brought to light when the state of electrotonus is produced by a smaller amount of battery power—by a single element, for example. In this case it often happens (not always) that the tetanus caused by salt or very feeble faradaic currents is suspended by anelectrotonus, and intensified by cathelectrotonus. It seems as if there was an essential difference between this action of the two electrotonic states upon nerve and muscle, but after what has just been seen this is by no means a necessary conclusion. It has been seen that anelectrotonus has a greater power of suspending tetanus than cathelectrotonus, therefore tetanus may be suspended by anelectrotonus when it is not suspended by cathelectrotonus. It has been seen that during both anelectrotonus and cathelectrotonus contraction when it happens is greater than that which happens in the non-electrotonised state; and therefore, during cathelectrotonus, if tetanus be not suspended, it is likely to be intensified. This is all. The facts are in keeping with those which have gone before when they are properly looked into, and there is no ground in them for supposing that there is an essential difference between the action of anelectrotonus and cathelectrotonus—no ground for supposing that the effects of using a small battery power in the production of electrotonus are in any way different from those which attend the use of a larger power of this kind.

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CONJOINT MEDICAL EXAMINATIONS *

We are able to open the new year with the satisfactory announcement that the last difficulty has been removed which impeded the action of the great medical examining incorporations of England in uniting to frame a conjoint scheme for a minimum examination, which will constitute, in fact, a single and uniform portal to the profession. All the committees of the bodies concerned have signified their approval of the following scheme:—

In view of the legal difficulties which have been stated by the Society of Apothecaries to prevent that society taking part in the formation of an examining board in this division of the United Kingdom, it was resolved:

I. That a board of examiners be appointed in this division of the United Kingdom by the co-operation of the Royal College of Physicians of London, the Royal College of Surgeons of England, and of such other of the medical authorities in England, mentioned in Schedule (A) to the Medical Act, as may take part in its formation; it being understood that, liberty being left to such co-operating medical authorities to confer, as they think proper, their honorary distinctions and degrees, each of them will abstain from the exercise of its independent privilege of giving admission to the "Medical Register."

II. That the Board be constituted of examiners, or of examiners and assessors appointed by the several co-operating medical authorities.

III. That examiners be appointed on the following subjects: Anatomy and physiology; chemistry; materia medica, medical botany, and pharmacy; forensic medicine; surgery; medicine; midwifery; or on such subjects as may be hereafter required.

IV. That no examiner hold office more than five successive years, and that no examiner who has continued in office for that period be eligible for re-election until after the expiration of one year.

V. That the examiners be appointed annually by the several co-operating medical authorities on the nomination of a committee, called herein "The Committee of Reference;" but no member of the Committee of Reference shall be eligible for nomination as an examiner.

VI. That a Committee of Reference, to consist of an equal number of representatives of medicine and surgery, be appointed as follows: One representative of medicine and one representative of surgery to be appointed by each of the Universities in England; four representatives of medicine to be appointed by the Royal College of Physicians of London; four representatives of surgery to be appointed by the Royal College of Surgeons of England.

VII. That one-fourth of the Committee of Reference go out of office annually, and that, after the first four years, no retiring member be re-eligible until after the expiration of one year.

VIII. That the duties of the Committee of Reference be generally as follows: 1. To determine the number of examiners to be assigned to each subject of examination. 2. To nominate the examiners for appointment by the several co-operating medical authorities. 3. To arrange and superintend all matters relating to the examinations, in accordance with regulations approved by the co-operating medical authorities. 4. To consider such questions in relation to the examinations as they may think fit, or such as shall be referred to them by any of the co-ope-

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