CURRENT FROM THE MAIN.

W. S. HEDLEY, M.D.

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THE MEDICAL EMPLOYMENT OF ELECTRIC LIGHTING CURRENTS

BY

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WITH ILLUSTRATIONS

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PREFACE.

The following pages consist chiefly of articles which have already appeared in *The Lancet;* but certain points, especially such as have reference to the constructive details of apparatus, are here dealt with at greater length and with fuller illustration.

February, 1896.

CURRENT FROM THE MAIN.

CHAPTER I.

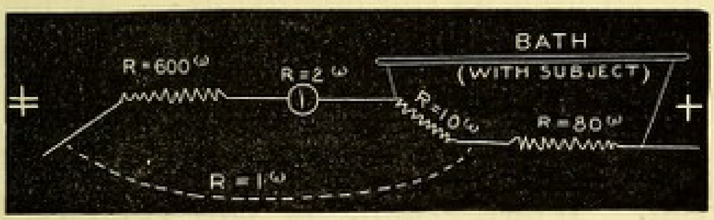
SINCE the publication under the above heading of two articles on the utilisation of public supply currents for electro-therapeutic purposes* great progress has been made in the supply of electricity from central stations. The same interval has brought forth a variety of apparatus as well as a somewhat extensive literature bearing upon the points in question. But it cannot be said that by any writer has there yet been shown a complete grasp of the subject, nor by any instrument have the many serious difficulties of the case ever been adequately met. In view, however, of the great and increasing employment of these currents, and with an experience of their usefulness in medicine, the time seems to have arrived for a complete survey of the whole problem ; and the following remarks offer themselves as an attempt at its solution.

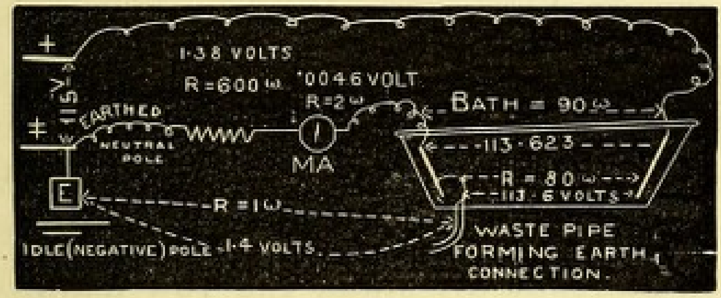
* "Current from the Main." By W. S. Hedley, M.D., *The Lancet*, Dec. 19th, 1891, and April 9th, 1892.

Considering the improvement that has taken place in public supply currents, I am of opinion that for medical employment their chief danger now lies, not in the possible influx of strong currents nor in the chances of a failure of supply, but in leakage currents and in the breakdown of transformers; and of these risks the greater is leakage.

1. *Leakage Currents.*—This source of danger has hitherto been either under-estimated or completely ignored, but it is nevertheless a very serious one, and in the absence of suitable precautions may lead to accidents of a grave kind. Those stations which supply by direct distribution, or distribution from transforming centres, are undoubtedly, and for obvious reasons, more subject to earth leakage than are those in which transformers are used at or near the house. Again, stations supplying electricity on the three or five wire systems, even if they do not actually connect to an earth plate or water pipe, are likely to have the middle wire (the "neutral") at practically earth potential. It is true that any connexion to earth of a main supplying current direct to houses is forbidden by the Board of Trade, but when, for purposes of its own, it suits a company to earth its middle wire this regulation does not seem to bar the practice. Now, if under these circumstances the patient be placed in contact with one of the outer mains (positive or negative) what may be expected to happen? If the connexion to earth be good, even a damp floor, such a patient would be subjected to the full pressure of supply, usually 100 volts or more. It is obvious

that if the contact be of low resistance (for instance, if the patient be in an uninsulated bath) the resultant current through the patient's body might be one of considerable and even dangerous magnitude, perhaps approaching 400 milliampères. It would be useless to interpose resistance between the patient and the uninsulated (neutral) pole, as this portion of the circuit would be shunted by the leakage current, and if the milliampère meter were also placed in this portion of the circuit it would fail to register any of this leakage. The following diagrams* will serve to illustrate the electrical conditions that exist—for example in a bath, when an earth connexion is made.





* These diagrams are only intended to show by an example the possible danger to a patient from leakage currents. 115 volts is the full pressure of the mains. The total current under the above conditions is 1,420 m.a., and the resistance in the respective branches is 612 ohms and 1 ohm, and, as current is inversely proportional to resistance, the current in the circuit of high resistance (the galvanometer circuit) will be 2·3 m.a., and in the earth circuit 1,417·7 m.a. But both circuits are common to the bath.

There is one "series" R = 80 and there are two parallel branches (R = 600 + 2 + 10 and R = 1). Then the total resistance $= \frac{612 + 1}{612 \times 1} + 80 =$ 80·998, and the total current $\left(\frac{115}{80 \cdot 998}\right) = 1420$ m.a. The current in the respective parallel branches will be as 612 : 1—in other words, the milliampère meter will register 2·3 m.a. Had the patient been placed in contact with the uninsulated (neutral) wire and the resistance been interposed between him and the insulated pole (positive or negative), he would not, even if placed in an uninsulated bath, have been in the circuit of any earth current. This would hold good only so long as the condition of the mains was good. Should a fault break out on one of the outer wires (positive or negative) the state of affairs would be in no way different from the case just considered. What, then, is the remedy for this risk? Clearly insulation. It should be taken as an axiom that the current from public supply mains should *never* be applied either as a shunt or direct to the patient without interposing between him and the earth an insulating substance of such a nature as would undoubtedly stand the full main pressure across it without passing a current of 1 m.a. In the case of three wire systems the "full main pressure" would be double that of supply, and in five wire systems four times that of supply. This necessity for insulation would apply equally to all systems, whether continuous or alternating, direct or transformed. In the usual electrical applications security would be attained by standing on a very dry floor or, more certainly, on a varnished kamptulicon mat. But in the case of the water bath, connecting as it does with a good earthing device in the shape of waste pipes and water pipes, the case is altogether different, and certain additional precautions then become necessary. With these duly carried out effective insulation can certainly be secured. In the first place it is obvious that the bath should not be made of metal. Hard wood or porcelain are suitable materials, the latter by preference. The bath should stand upon glass mushroom insulators filled with a heavy resinous oil (similar to those used for insulating storage batteries) or it might be placed upon hard vulcanised rubber blocks. The inlet stopcocks for both hot and cold water should be placed some distance from the bath, and in such a position that it would be impossible for the patient, when in the bath, to accidentally make contact with them. An insulating piece of porcelain or vulcanised rubber should be inserted in both inlet pipes between the stopcocks and the bath. If the waste pipe be attached to the bath an insulating piece should be inserted as close to the bath as possible. But danger may be even more easily and effectually averted by fixing directly below the waste outlet of the bath a shallow tank or sink to receive waste water from the bath, the waste pipe being attached to this sink. Neither the tank nor the waste pipe should make contact with the bath.

There has just appeared, and it will be read not without misgiving, the report of a discussion at the recent conference of the Board of Trade upon the question of raising the limit of low-pressure supply. It cannot be said that on this occasion the calculations of the commercial electrical engineer were hampered by any undue regard for the safety of human life. It was claimed by several of those present that they had received harmless shocks from what are now considered to be high-pressure circuits. One gentleman asserted that he had felt no ill effects from a 600 volt shock. In view of the fact that so much depends upon contact and the manner of taking a shock, and that little or no information was given on this point, it is difficult to form an opinion from such a statement. Did the gentleman in question touch one pole only of a 600 volt circuit? If so, what was the earth insulation of the other pole? Was his body in contact with the earth? Or, presuming that he simultaneously placed one hand on each pole of the 600 volt circuit, what was the surface area of skin contact, and what the condition of the skin? In the absence of information on these points the statement referred to cannot be considered to have any real value. Had the surface area and condition of the skin been favourable for a low resistance contact, it is more than possible that the gentleman in question might ere this have been "put to earth" in a sense other than an electrical one.

2. *Breakdown of Transformers.*—The second source of danger (one which, of course, can occur only with transformed systems) is that due to the break-

down of the insulation between the primary and secondary windings of a transformer. This risk does not belong exclusively to alternating current systems. Continuous current transformers are now used in several public installations, notably at Oxford (1,000 volts primary) and at Chelsea (500 volts primary). In the event of a breakdown of the insulation the secondary mains would have their potential above earth very considerably raised, and should it happen that there are weak places in the network of secondary (distributing) mains (of which the patient's body, unless well insulated from earth, would form one) an excessive current would pass, with probably fatal results to the patient. The Board of Trade regulations provide that every secondary circuit of a high-pressure main shall be fitted with an approved form of apparatus for automatically connecting the secondary mains to earth in the event of their potential above earth rising to a dangerous degree; but in this case there is the not improbable contingency that when the occasion for its action arises such an apparatus will be out of order, and even if it be working well, it cannot act until the potential above earth of the mains has risen to this dangerous degree. And after that, there is still an interval, short but quite appreciable, required for the action of the device in question. It must be borne in mind that during this time the excessive potential is acting upon the patient unless he be very well insulated, and, further, that it does not take long, with good contacts, to kill a man with 1,000 or 2,000 volts. What, then, are the precautionary measures here? Never to rely solely upon the insulation of the patient from earth when the supply is a transformed one, but always to place a substantially made transformer in the circuit. With alternating currents a "Woakes"* or "Miller and Woods"† transformer may be used; but it should be tested with at least the pressure of the primary mains between its primary and secondary windings before being installed for work. With continuous currents from a transformed system it will be well to interpose a motor, and make this drive by belt a small dynamo, which should *not* be fixed on the same metal bed-plate. The dangers due to leakage and the breakdown of the transformer represent practically the whole of the difficulties that have to be contended with so far as the company's mains are concerned. The risks of failure of supply and serious rise of supply pressure need not, in the case of English companies at least, now be seriously considered. The companies for their own sakes take every possible precaution to guard against these accidents, and usually with complete success. Under any circumstances it is desirable to fix upon each pole of the electro-therapeutic circuit a reliable magnetic cut-out. The best apparatus of this kind is that known as the "Cunynghame," of which the

* This instrument has on one bobbin three separate secondary coils; one supplies cautery, the second light, and the third gives current for application to the patient.

† This device is provided with a number of terminals on the secondary winding, such that any voltage from 2 upwards and any current up to 20 ampères can be obtained.

following is a description. Two planished ends of a copper solenoid dip into two mercury cups forming the terminals of the instrument, and on the current reaching a predetermined amount the solenoid is "sucked over" (drawn back upon) a curved, soft iron core-piece, the position of which is fixed but adjustable. The solenoid is fastened to one end of a radial arm, which is pivoted at its lower end in such a way that a slight movement of the solenoid brings it vertically over the turning centre and into a position of unstable equilibrium; any further increase of current will cause the solenoid to drop by force of gravity and at the same time withdraw the contact points from the mercury cup, thus breaking the circuit. If desired, the mercury cup could be short-circuited by a resistance of such an amount as would reduce the current in the circuit to half or quarter of the breaking current. For example, let it be supposed that the magnetic cut-out has been set to break circuit at 200 m.a., and that the electromotive force of supply is 100 volts, then the resistance to the circuit must be $\frac{100}{\cdot 200} = 500$ ohms. Now, if the magnetic cut-out be short-circuited with a resistance of 500 ohms, the current, instead of ceasing altogether, would be diminished to $\frac{100}{500 + 500} = 100$ m.a.; or, if 1,500 ohms be used as a short-circuiting resistance, the current would have been diminished to $\frac{100}{500 + 1500} = 50$ m.a. Where two magnetic cut-outs (one on each pole) are used, it would be well to short-circuit both instruments with resistances, and to set one to act a little in advance of the other. Fusible cut-outs and lamps in the circuit have been recommended as safeguards, but it has been more than once pointed out by me in *The Lancet* that at best such devices are unreliable for the purpose in question, and may lead to the serious discomfiture of those who put their trust in them. It is well known that fuses cannot be guaranteed to act within 5 per cent. of their nominal current; it is necessary also to remember that even then they take quite an appreciable time to heat and melt. Again, the difficulty of obtaining small fuses of reliable gauge is greater than with fuses of larger capacity. With lamps the result is even more uncertain. The resistance of carbon diminishes as the filament grows hot until the state of incandescence is reached, after which resistance remains practically constant. Again, the temperature to which it is raised under normal lighting conditions depends entirely upon the efficiency (watts per candle) at which the lamp is intended to burn; therefore it is evident that as a fuse a lamp's breaking point must vary considerably. With high-efficiency lamps—*i.e.*, with lamps which absorb small wattage for candle-power—the ratio between the nominal current and the fusing current will be less than with low-efficiency lamps. Used as a "backing" resistance—*i.e.*, as a choking or current-reducing resistance of steady value—a lamp to ensure anything like reliability should have a considerable current passed through it—certainly full incandescence should be attained. As safeguards, therefore, for electro-therapeutic purposes fusible cut-outs and lamps are entirely out of the question.

Having cleared the ground of the only serious difficulties that lie in the way of utilising lighting currents, there now only remain to be considered their physical characters, their therapeutic qualities, and the control apparatus by which such currents may be best adapted to the varied requirements of practice.

CHAPTER II.

1. *Continuous currents*: (*a*) *Physical characters.*—Although the current produced by the electro-motive force of the continuous current dynamo is unbroken and always flowing in one direction, it cannot be said to be absolutely uniform in strength. That is to say, the current obtained, for example, from a single dynamo having a commutator of only a few sections is undoubtedly a "pulsatory" current. But such are not the conditions that exist in dealing with continuous currents from modern central lighting stations. In the latter case a number of dynamos, usually running at different speeds and having commutators of numerous sections, are used "in parallel" with accumulators of large capacity. The current emanating from such a source cannot be called "pulsatory." Its line of electro-motive force with the now universal "constant potential" system may be regarded as practically straight.*

(*b*) *Chemical effects.*—It is a law of physics that electrolytic action is directly proportional to the

* There are possible sources of variation of the dynamo current owing (1) to what is known as the "hunting" of the engine, a kind of see-saw movement of its governors; and (2) to the "regulation" necessary to maintain "constant potential" under varying loads.

quantity (coulombs) of electricity passed, irrespectively of electro-motive force or of any other condition. With a varying current there is an apparent anomaly. In this case instruments depending for their action upon thermal or magnetic forces do not read "true ampères." Are central station continuous currents sufficiently varying to share this anomaly? In other words, does a given reading of the milliampère meter represent the same amount of electricity whether the source of supply be a Leclanché battery or a continuous current electric light circuit? I have carefully tested this point by means of a Gaiffe's coulombmeter with a given current for a given time from these two sources respectively, and find that within the range of experimental accuracy (within 2 per cent.) the results are the same.* That is to say, from either source equal intensities, as indicated by the galvanometer, do an equal amount of electrolytic work in an equal time.

(c) *Physiological effects.*—With an unvarying current physiological effects appear to depend solely upon current—that is to say, equal intensities give equal effects, irrespectively of the relative amount of electro-motive force and resistance in the circuit. With varying currents these effects are influenced by the maximum current, and also by the rate of change of current value—*i.e.*, by the suddenness with which the change is made. In the present

* It is well to remember that when a wire rolled round a drum is used as a resistance the galvanometer may be influenced by its too great proximity owing to mutual induction.

connection this rate of change of current value as a factor in physiological effects has a very important bearing. It is well known that the insertion of resistance in a circuit alters the form of current curve. The latter becomes less abrupt in its ascents and descents. There is also the further fact that excitation of a nerve or muscle at make or break bears a direct ratio not only to the intensity of the current, but to the suddenness of the fall of potential. Applying this to the present case it follows that if the control apparatus be of such a kind as to place a high resistance in series with the patient the change at make and break must be comparatively gradual; therefore as a stimulus such a make and break is comparatively less effective; therefore to produce the same physiological effects a stronger current becomes necessary. Thus the general conclusion is reached that the results of diagnostic tests obtained through a high resistance in series with the patient are not strictly comparable with results obtained where an electromotive force only sufficient for the purpose has been used. In point of fact the experimental conditions have not in both cases been quite the same. This theoretical difference undoubtedly holds good in practice.

Approaching the vexed question as to whether with the lighting circuit (of, say, 100 volts) passed through a controlling resistance pain is greater than when the current is drawn from a battery of low voltage, the answer will depend upon *how* the resistance is placed. I hold that there is a difference between applying, say 10 m.a.

at 100 volts through a resistance placed *in series* with a patient and applying 10 m.a. with only just sufficient electro-motive force to overcome the resistance of the patient's body; and this will hold good whether the 10 m.a. be obtained from Leclanché batteries or from any other source. The reasons are as follows: (1) that at any break in the circuit the full voltage of supply is obtained, and (2) that upon completing circuit there is a much reduced electro-motive force across that portion of the circuit which was previously broken; therefore it follows that between the moment of completing the circuit and the establishment of steady "value" of electro-motive force there must have been a time rate of change, since no work can be done instantaneously. Now consider step by step what would appear to be the sequence of events in this case. On first closing the circuit there will be at that instant no current; following quickly there is to be expected a current rush, probably in excess of the normal, and this rush of current would probably steady itself (together with the electro-motive force) by oscillations of short period.*

* To explain this the analogy of the water-pipe will be found useful. A small water-pipe with a stopcock at its middle connects at each end with a water vessel or tank. Both vessels are partly filled with water, but one at a higher level and at considerably greater pressure than the other. If the stopcock be suddenly opened there may be expected (1) a sudden rush of water in the direction of the vessel of low pressure; (2) a rebound as it cushions against the otherwise stationary water, followed by oscillations within the pipe; and (3) a gradual and steady flow until both vessels are equal in height and pressure. If the modern

It is noticeable that with a dynamo current used through a resistance "in series" with the patient greater pain accompanies and a greater skin reddening follows the application than when a continuous current battery is used with a cell collector, and that both effects are decreased by pressing upon the electrode; in other words, by making a better electrical contact. In looking for an explanation of this it is to be remembered that an imperfect contact may have a high electro-motive force across it, and that heat generated in any circuit or part of a circuit is in proportion to the watts absorbed. This may give rise to some local heating.* With high potential currents the available electro-motive force is greater, therefore the possible heating effect may be comparatively great. Under these circumstances there must be, of course, a certain amount of electrolytic action; but it is difficult to imagine that the pain here can be due entirely or even chiefly to the products of this electrolysis acting on the terminations of the sensory nerves. Electrolytic phenomena bear a direct ratio to current, but pain is admittedly greater the higher the electro-motive force, even if current be the same. The importance of a good contact (well warmed, well wetted, and carefully adjusted

electrical theory of wave motion in or of ether be accepted it is not difficult to adapt this analogy to the circumstances of the case in question.

* According to the C^2R law that the watts absorbed and heat generated in any part of a circuit are equal to the square of the current multiplied by the resistance.

electrodes) is known to all who use such currents on the living body, especially with imperfect apparatus. This holds good of every electrical application, but it is currents of the kind under consideration that bring these points more prominently forward and make it worth while to turn for a moment to the general question of "contact." "A good contact at the electrodes" is a familiar formula and a recognised necessity in electro-therapeutics, and many forms of electrode have been devised to secure it. Of these the hydro-electric application, *i.e.*, the water-electrode, adapting itself as it does to every minute inequality of surface, is at once the most effective in this respect, as well as the least painful. Other things being equal, pain is greater in any electrical application in proportion to the intensity of the current. The reason of this is to be found in the greater accumulation of the pain producing products due to electrolytic decomposition. But if there be "a bad contact" pain may be increased in several other ways: (1) by increase of current density owing to its concentration on a comparatively small number of points, as in the case of a dry or badly adjusted electrode; (2) by the fact that a bad contact may have a high electromotive force across it, as already explained; (3) by the more or less sudden and frequent changes in current value which are likely to occur with a bad contact. It has been contended * that the pain thought by Duchenne to be the result of current density, as above explained, is not really due to this

* "Archives d'Electricité Medicale," Sept. 15th, 1895.

cause, but that it depends upon the resistance of the electrode relatively to that of the subjacent skin, and the resistance of the epidermis and horny layer relatively to that of the underlying parts. With reference to the latter difference of resistance it might bring about a fall of potential which by the C^2R law might produce heat, or by alterations of intensity (from a bad contact) there might arise various physiological effects. With reference to the former, viz., the resistance of the electrode relatively to that of the skin as a cause of pain, it is claimed that this has been proved by experiment with electrodes of different resistances. The explanation offered is that intensity being constant and resistance in different parts of the circuit being variable, the electromotive force must undergo alterations corresponding with the resistance. Thus with an electrode whose resistance is less than that of the skin, " there will be an increase of potential, whose effect will explain the excitation of the sensory nerves at that point."* If the resistance of the electrodes be greater than that of the skin, a fall of potential will occur; and thus will be explained the great pain caused by electrodes of high resistance or that caused by imperfect wetting of the skin. Without doubting the experimental data, it is nevertheless difficult to feel satisfied with the deductions drawn therefrom. To speak of an *increase* of electromotive force in a current traversing a conductor (which is not itself the seat of an electromotive force), seems to involve a misappre-

* *Ibid.*

hension of Ohm's law. The potential of an external applied electromotive force must always be greater at the point of entry into a conductor than at the point of exit. In other words there must always be a *fall* of potential as the current travels. Therefore resistance has been described as "the drop of potential corresponding to a current of unit strength" traversing a conductor. There may be points in the circuit where the fall is greater and points where it is less, but it will always be a *fall*. In the experiments referred to, the fact would in some measure seem to have been overlooked, that inasmuch as an increase of R. necessitates a greater E.M.F. to obtain a given current, therefore with an electrode of high resistance the pain-producing quality is materially increased in the circuit of high resistance. In those cases where the specific R. of the electrode is lower than that of the underlying skin, the experimental evidence adduced in the paper quoted would seem to lend itself to the suggestion that the "contacts" were imperfect.* In point of fact the resistance of the electrode would appear to be a consideration really outside the part of the circuit where pain is produced. If, however, the contact be bad (and it does not seem quite clear that the question of contact is eliminated in the experiments referred to), any of the pain-producing conditions above enumerated

* And apart from contact it must be taken into consideration that where bare electrodes are used the products of electrolysis are set free at the actual surface of the skin, whereas with covered electrodes such products occur chiefly in the moistened covering.

may come into play. But it is very difficult to see how the specific resistance of the electrode can be considered one of them. The foregoing considerations lead up to an infinitely important point, one which it is the chief object of these pages to insist upon—viz., that it is only by using an instrument constructed on the principle explained in *The Lancet* of May 4th, 1895, that a large proportion of the risks and difficulties special to dynamo currents are to be avoided. It is by means of this arrangement that a central station continuous current can easily be obtained of only the electro-motive force necessary for the purpose required. If this be the case (it is mathematically certain and practically demonstrable) it is obvious that many of the points just discussed need never arise in practice.

2. *Alternating currents.*—Those lighting circuits which are of an alternating kind may be described as currents not strictly sinusoidal, but partaking of the sinusoidal character and having alternations at the rate of about 5,000 to 6,000 a minute. It need not here be repeated that a strictly sinusoidal current takes its name from the fact that it "follows the law of sines as regards its variation in time." It is a current which gradually attains its positive and negative maxima and shows no lost time and no actual interruptions. Its potential rises and falls with perfect regularity. It is represented graphically by a "curve of sines," and may be contrasted with the sudden and "dissymmetrical" changes of potential shown by the pointed and irregular curve of a coil's alternations.

The alternating light current differs from the sinusoidal chiefly in the comparative irregularity of its curves, an irregularity depending upon the construction of the dynamo, the "capacity" and "self-induction" of the circuit, and other causes. The faradic current differs from both the foregoing in the fact that its positive and negative maxima are very suddenly attained and are unequal in extent; the current is therefore a "dissymmetrical" one. From these physical differences arises a dissimilarity in physiological effects. Inasmuch as the excitant action of an electrical current bears a direct ratio to the suddenness of the fall of potential it follows that the sinusoidal current will be better tolerated than the more brusque alternations of the coil. Also on this account it is equally evident that the latter for certain purposes can never be altogether supplanted by the currents of smoother curves. On the other hand, where effects on general nutrition rather than on muscular contraction are sought, the latter currents present decided advantages. It has been shown by d'Arsonval that in a person subjected to alternating currents of a sinusoidal character, although the current be scarcely felt and excite no muscular contraction, the nutritive exchanges undergo an augmentation of from 40 to 50 per cent., the "respiratory capacity" being almost doubled. These effects are probably owing (1) to the large amount of electrical energy that can in this way be borne by the body, and (2) to an influence on nutrition due to the decompositions and recompositions that must ensue on the passage of an alternating current through the tissues. Now the alternating currents of commerce, partaking as they do of the sinusoidal character, make it possible to pass large amounts of energy through the body, whilst at the same time their comparatively sudden falls of potential determine a certain amount of muscular contraction. They therefore present a means of increasing the nutritive exchanges (1) by a direct action in virtue of their sinusoidal type, and (2) by an indirect action in virtue of the muscular contractions they induce.* Applied chiefly through the medium of the water-bath, this alternating lighting current is daily employed in practice. It seems to act as a general tonic and to stimulate the nutritive exchanges. Its employment has been followed by good results in chloro-anæmia, rickets, muscular atrophies of myopathic origin, obesity, gout, sciatica, and rheumatism, the latter in its articular as well as in its muscular manifestations. This current is easily handled for medical purposes, and its use is now by no means uncommon. Certain observers, among whom Gautier and Larat were the first, have carefully recorded and tabulated their experiences.

There now only remain to be dealt with the details of the control apparatus or "reducer of potential." For these I am indebted to the kindness and skill of Mr. Quin, electrician to the Brighton Corporation, to whom I had made known the difficulties and requirements of the case. He has been good enough to place at my disposal the follow-

* "Revue Internationale d'Électrothérapie," p. 289, 1895.

ing drawings and descriptive particulars of a simple and efficient apparatus adapted to meet the varied demands of direct electrical treatment.* It is based upon the principle of the variable shunt already recommended and described by me,† but it presents some novel features: (1) The resistance is not altered step by step, but gradually throughout its whole range; (2) the switch and resistance are so interlocked that it is impossible to open or close the main circuit until the potential across the shunt circuit is *nil*; (3) it has a very wide range; and (4) it has an adjustable stop so that any range from zero to the limit may be obtained. It will at once be seen that this apparatus forms a convenient means of obtaining continuous current for the purpose named. In common with batteries it has the advantage that the pressure across the patient's circuit is only that absolutely necessary for the purpose in hand, whilst it is without many of the disadvantages inseparable from batteries—their uncertainty, polarisation, cost, and the ever-recurring trouble of recharging. Its use is not recommended upon transformed systems without the intervention of a good transformer.

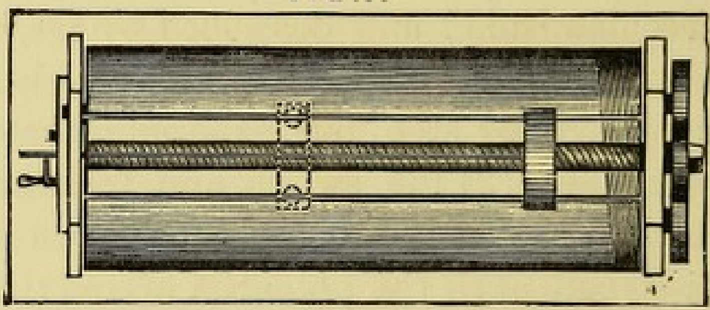
Figs. 1 and 2 are the plan and elevation respectively; Fig. 3 is the end elevation showing the interlocking arrangement; and Fig. 4 is a diagram-

* This apparatus will also actuate the coil. The requirements for light cautery and the charging of accumulators are simple and adequately met by existing apparatus in the catalogues of the instrument makers.

† *The Lancet*, May 4th, 1895.

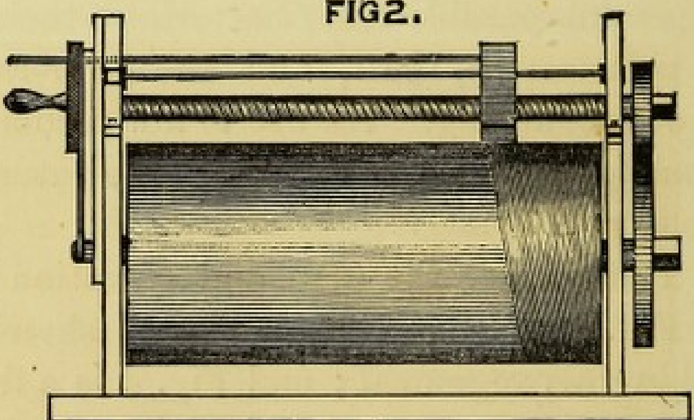
matic sketch of the connexions. It will be seen that the resistance wire (which should be of platinoid or other high resistance metal) is wound

FIG. I.



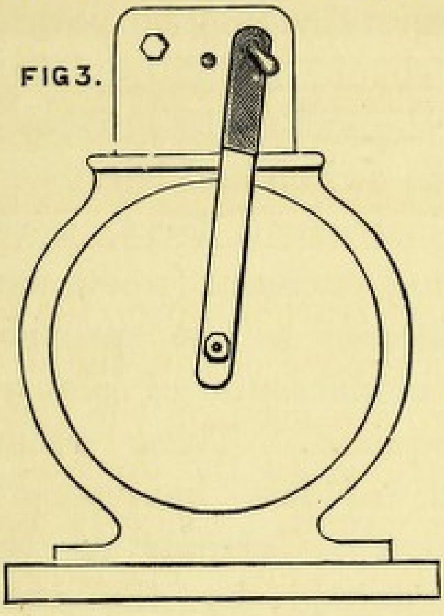
upon a drum of rather large diameter, the wire being laid in a groove cut in the drum. Different sections of wire are used on the various portions of the drum, according to the demand for current in the therapeutic circuit. The total resistance of this wire is about 1000 ohms. The drum is mounted on a spindle and is capable of being revolved by means of a crank handle applied to the square end of its

FIG 2.



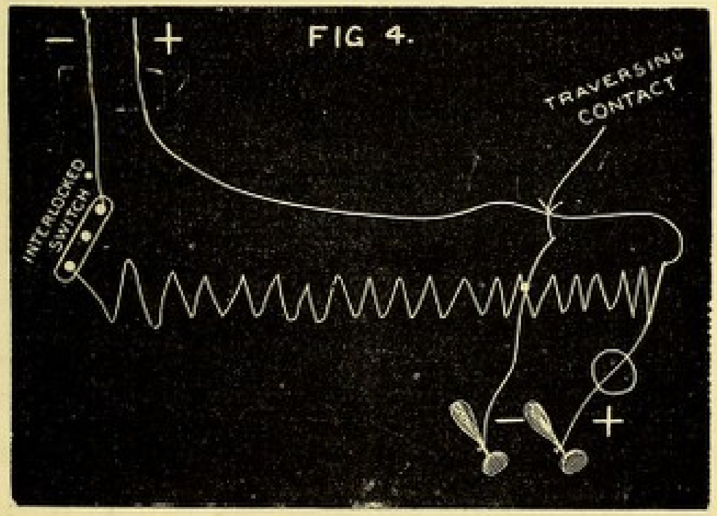
own spindle or through gear, if the handle is applied to the square end of the top spindle. The drum spindle, if carried right through, should be fitted with an insulated coupling piece, as at each end it forms one terminal of the resistance wire. The top spindle (geared to the drum spindle) is threaded along its length, forming an endless screw. It is insulated from the end on which the switch is fixed, and also from the traversing contact which it

FIG 3.



drives. Two guide-bars for the contact are provided, which are insulated at the geared end, and in

FIG 4.

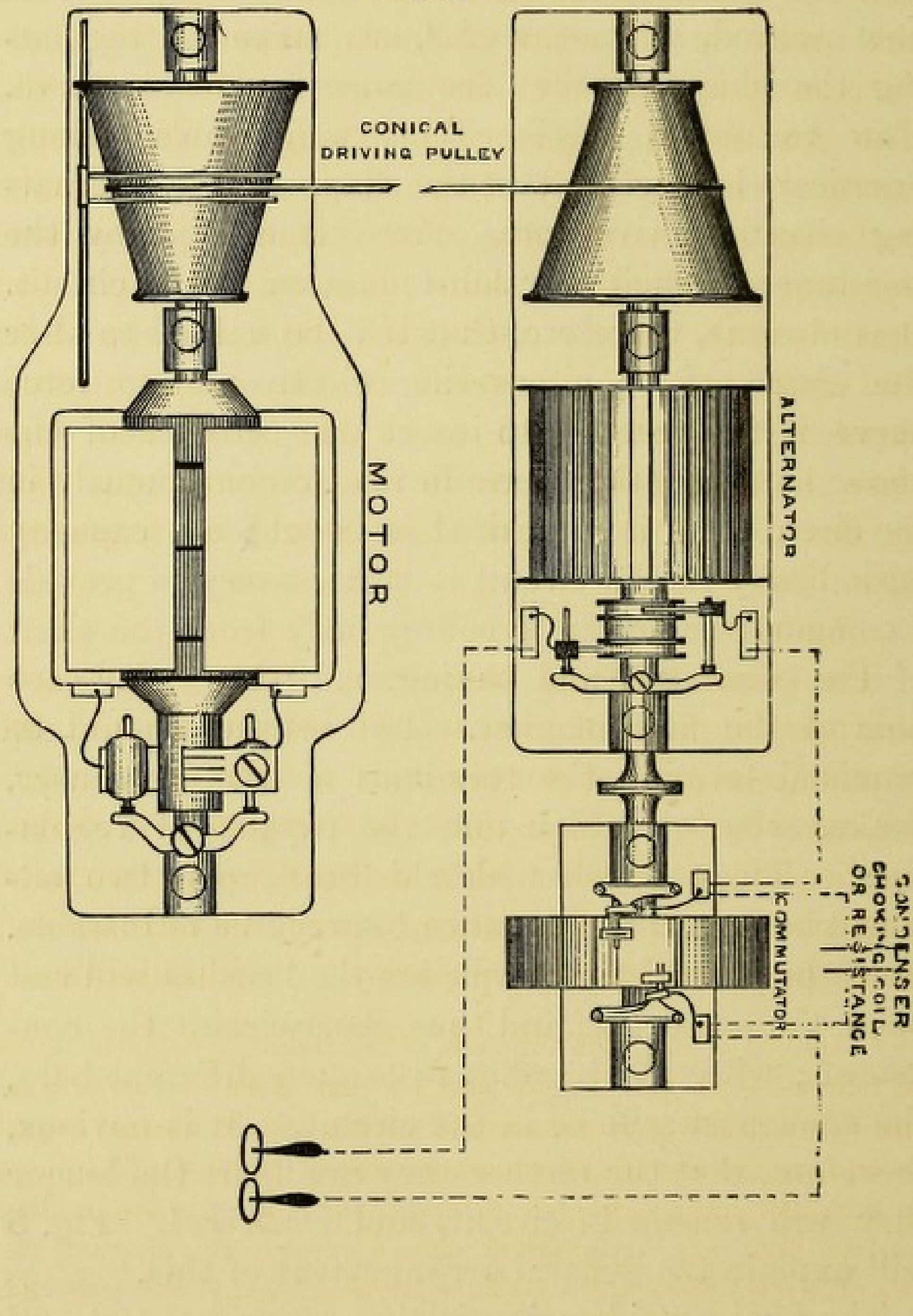


contact with the top portion only of the switch end. Attached to the sliding contact is a metal bar, which is shown projecting through the switch end and the ebonite base of the switch. This bar forms the locking arrangement, and it will be seen that, unless the traversing contact is quite " home " and the bar thereby withdrawn, the switch cannot pass this point, and therefore cannot be placed either " on " or " off." An ebonite blocking-piece is fixed to the radial arm of the switch to prevent electrical contact between the switch and bar.

While this instrument forms a ready means of utilising lighting currents (when not transformed) there still remain to be provided for those occasions when currents of sinusoidal or allied forms are required. These occasions are, as already stated, of fast increasing frequency in modern practice. Currents of this order may readily be obtained by the use of a small motor driving an alternating current-generator. Even if the supply be an alternating one this arrangement might be preferable to simply using the current through a transformer, inasmuch as both the electro motive force and " frequency " of the useful circuit could thus be accurately controlled. It will be convenient to drive the generator by means of a band running over two " reversed cone " pulleys fitted with a guide; the ratio of the speeds can then be regulated at will. The magnetic field of the generator, which must be excited by continuous current, should either be " commuted " from the generator or derived from a separate source. If the supply be a " continuous current " one, the first-named arrangement can be readily carried out; otherwise a small battery should be used. A regulator, either a rheostat or cell collector, must in any case be placed in this circuit. Control of electro-motive force and frequency is now secured, but not, so far, any means of regulating the shape of the electro-motive force curve. How to obtain this? It is well-known among practical electricians that the shape of the alternating electro-motive force curve is altered by the resistance, capacity, or self-induction of the circuit. It is obvious, therefore, that if it be wished to alter the shape of an alternating electro-motive force curve it is necessary to insert one or other of the above factors, either periodically or continuously in the circuit. If it be desired to insert (say) capacity periodically in the circuit it is necessary to provide a commutator driven synchronously from the shaft of the generator, and having one "bar" for each pole of the field magnet. Two brushes should be provided forming the terminals of the condenser, the capacity of which must be capable of regulation. These brushes should bear upon two adjacent bars, and the distance between be adjustable. For a portion of the revolution the brushes will rest upon the same bar, and thus short-circuit the condenser; while the brushes rest upon different bars, the condenser will be in the circuit. It is obvious, therefore, that the further they are apart the longer they will remain in circuit, and *vice-versâ*. Fig. 5 will explain the general arrangement of this.

The final consideration is that of prime cost and maintenance. If a comparison be made between

FIG. 5


CONICAL
DRIVING PULLEY
MOTOR
ALTERNATOR
KOMMUTATOR
CONDENSER
CHOKING COIL
OR RESISTANCE

the system here explained and the number and cost of the apparatus required to obtain the same effects (if indeed such effects be possible) by the old battery and coil methods, it needs little showing to prove that even on the score of initial expense the comparison is in favour of the more modern methods. The cost of maintenance in using public supply currents is certainly less than when ordinary batteries are employed. For instance, if the traversing interlocking shunt rheostat be used, the current in the main circuit (with 100 volts) would be 100 m.a. plus the current in the shunt circuit. Assume this latter also to be 100 m.a., and suppose the apparatus to be in use for one hour, then in Board of Trade units there would be consumed

$$\frac{\cdot 2 \times 100 \times 1}{1{,}000} = \cdot 02 \text{ unit.}^*$$

The ideal system, therefore, from an electro-therapeutic point of view would seem to be a direct continuous current supply with a traversing interlocked shunt rheostat for the purposes of direct application, together with a motor-driven alternator and arrangements for varying speed, field excitation, and the insertion of "capacity," "self-induction,"

* Applied to Brighton the basis of calculation is supplied to me as follows :—At the present time a sliding scale of charge is in use by which all current consumed after a certain amount (equal to burning the average maximum number of lamps for 183 hours in each half year) is charged for at 3d. per unit. As the lighting current used in a house almost always exceeds this amount, the use of electro-therapeutic instruments would come under the 3d. charge. In that case and under the circumstances above given, the cost per hour would be ·06d.

or "resistance" periodically or continuously into the circuit. With these arrangements and with the safety devices previously recommended any form of current can be obtained with a wide range of electromotive force and periodicity ("frequency"), and at the same time with an absolute absence of risk. The time ought to be approaching when electricity will be prescribed and administered not only in measured units of intensity, density, and time, but with definite ideas of the shape of the electromotive force curve, and of the therapeutic indications that a given curve may be expected to fulfil.

(Since the above was written it has become evident that a change is imminent in the official definition of "low pressure."* The committee of experts appointed to advise the Board of Trade on this point recommend that "when the conditions of the supply are such that the pressure may at any time exceed 500 volts if continuous, or 250 volts if alternating . . . the supply shall be deemed a "high-pressure supply." The limit of low pressure is thus raised to the figures named. It is further provided that "the pressure of a supply delivered to any consumer shall not exceed 250 volts at any pair of terminals." Thus, on the multiple wire system a 500 volt shock would be obtainable across the outer mains. If the neutral wire be not earthed it becomes in the highest degree probable that the negative pole will get to earth by electrolysis; in such a case a 500 volt shock could be got from the

* This change has now been adopted.

positive pole to earth. If this higher standard of voltage be adopted it would appear (1) that, in the interests of safety, the earthing of the neutral pole ought to be not only "allowed" for one class of main, but insisted upon for every class; (2) that, regarded from the standpoint of the present paper, it is evident that, for medical employment, the safeguards already recommended *—viz., the placing of the patient on the neutral pole and his effective insulation from earth—would become absolutely imperative; (3) that a still higher resistance (between the mains) would become necessary in the sliding shunt rheostat †; and (4) that with "the neutral" earthed and the above precautions taken safety is secured even with the increased voltage. In connexion with this report other questions of medical interest arise. Of these, one of the most important is the relative danger to life of continuous and alternating currents. The committee seem to consider that the latter are just twice as dangerous as the former. It would be interesting to know the nature of the evidence on which this opinion is based. The question has already been referred to in *The Lancet* and cannot be entered upon now, but certainly it is one about which the last word has not yet been said.)

* *The Lancet*, Dec. 21st, 1895, p. 1571.

† This could easily be done by using an eight candle-power (or smaller) lamp in series with it, taking care that full incandescence is attained under working conditions.

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