THE APPLICATION OF THE ELECTRIC LIGHT CURRENT IN ELECTRO-THERAPEUSIS.

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Read before the Brooklyn Gynæcological Society, April 7, 1892.

Electrical effects in therapeutics, as elsewhere, depend mainly upon the *current-strength* or volume of the circulating force. This in turn depends upon the *electro-motive force*, or the pressure under which the current moves, and the *resistance*, or the obstruction which opposes the passage of the force through the medium in which it circulates. A clear conception of the significance of these terms affords the key to a practical knowledge of electro-physics. Since, in the adaptation of the electric light current to office use, the doctor must be to a great extent his own electrician, a few words in elucidation of these rudimentary facts of electrical physics may not be amiss before taking up methods and appliances for our purpose.

ELECTRO-MOTIVE FORCE.

The electro-motive force of a current of electricity is the propelling power of the current. To borrow an illustration from mechanics, electro-motive force is to an electrical current what the driving force or pressure is to a current of water. As water tends to flow from a higher to a lower level, so electricity tends to move from higher to lower tension, in other words, to seek an electrical level. Just as the force of a waterfall is measured by the difference of water level above and below the fall, so the pressure of an electrical current is proportionate to the difference of electrical level or potential, in the body from which and that to which the current is due. Electro-motive force then depends on difference of electrical level or potential. It is frequently spoken of, therefore, as the difference of potential, or simply the potential. The term tension is also used synonymously with electro-motive force.

Definite units have been adopted for the measurement of each of the factors of electrical currents. The unit of electro-motive force is the *volt*. The potential or pressure of the current is, therefore, sometimes termed the voltage. The value of a volt is approximately the electro-motive force of a single Daniell cell in perfect working order. More definitely, it is the equivalent of a mechanical force capable of generating a velocity of one metre per second in a mass of one gramme.

ELECTRICAL RESISTANCE.

A column of water moving through a conducting pipe meets with a certain amount of resistance. So the circulation of electricity encounters more or less obstruction from the conducting medium in which it moves. This is termed electrical resistance. It varies with the nature of the conducting medium. It is least in metals which are consequently good conductors. In many substances, such as glass, hard rubber and dry wood the resistance is so great that these bodies are practically non-conductors. Again, electrical resistance, like that of the water column, will vary directly as the length of the conductor and inversely as its cross-section. Long wires, then, will offer proportionately more resistance than short ones of the same size and material, and fine wires more than coarse ones in the exact ratio of their sectional areas, and the same is true of all conducting media.

It must be borne in mind that in battery circuits the battery forms a part of the circuit, and the battery elements as well as the conducting wire offer resistance. The resistance within the battery is called the internal resistance in distinction from that without which is the external resistance of the circuit. The internal resistance varies greatly in different types of battery, and this fact has an important bearing in explaining the great difference in the performance of batteries of different construction.

The unit of resistance is the *ohm*, the value of an ohm being the resistance of a column of pure mercury whose cross-section is one square millimetre, length 106.25 cm., and the temperature zero centigrade (the temperature of melting ice).

CURRENT.

The term current technically stands for the current-strength, or the volume of electricity that flows in the circuit. The current-strength depends upon the resistance in the circuit and the electro-motive pressure under which the current is impelled. Remembering that the battery itself forms a part of the circuit, it is plain that a battery of high internal resistance, like most of those in common use, can yield but a limited volume of current, however small the resistance in the metallic or external portion of the circuit. On the other hand, storage batteries, in which the internal resistance is but a few thousandths of an ohm, yield current in enormous volume through small external resistance. The same is true of all batteries of low internal resistance. Since the internal resistance of a battery is due chiefly to the resistance of the fluid between the plates, it follows that batteries of large plates are capable of yielding more current than batteries of the same type having small plates, since the conducting power of the fluid column varies directly as the area of its cross-section. But it must not be forgotten that the current volume from large cells is greater than from small ones of the same type only when the external resistance is small. Where high external resistances are concerned, like those of the human body, the size of the cell makes practically no difference in the current-strength, as can readily be shown by Ohm's formula.

No matter what the volume of current a given battery is capable of yielding, the current which actually flows in the circuit will be limited by the external resistance. Resistance, however, is partially overcome by increased pressure, therefore whatever the external resistance, so long as there is any current at all, its volume will become greater and greater in proportion as the electro-motive force is higher. The current, therefore, varies directly as the potential or electro-motive force under which it moves and inversely as the total resistance. This fact is known as Ohm's law, and is expressed mathematically by the formula $C = E \div R$. It is evident from this formula that if the resistance were zero, the current would be infinitely great, even from a single cell of battery. If the resistance were infinitely great, the current would be zero, no matter how powerful the generator. It will be found in practice that the amount of resistance in the circuit is a very important factor in determining the volume of current. When the external resistance is reduced to an amount so small as to be inappreciable, when, in other words, the battery or dynamo is short-circuited, it yields its full volume of current. On the other hand, if the resistance is very great the current may be insignificant even from a generator of great power.

The unit of current is the *ampère,* the value of which is the volume of current that flows in a circuit, under a potential of one volt through one ohm of resistance. In medicine, however, where we have to do with small quantities only, the *milliampère* or thousandth of an ampère is the unit commonly employed.

We are now prepared to understand the difference between battery currents and the current of the Edison light system. Currents from batteries of the ordinary type are currents of small volume, owing in part to the high internal resistance of these batteries. Moreover, since only about fifty elements are ordinarily used, the voltage is lower than that of the incandescent light current, and the drop in current-strength under high external resistance is greater. A battery of fifty of the latest pattern of Law cells, for example, in good order, is capable of giving on short circuit a current of about four ampères, with a voltage of 74. The Edison current, on the other hand, has a voltage of 115, and will yield a current, therefore, of 115 ampères, through a resistance of one ohm.

Two terms, *multiple arc* and *series*, here require explanation. Instruments are said to be arranged in series when they are so connected in circuit that the current runs through them successively, as in Fig. 1. An instrument is in series when it is placed in one side of the circuit. Instruments are said to be arranged in multiple arc

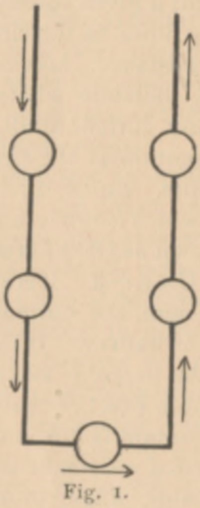

Fig. 1.

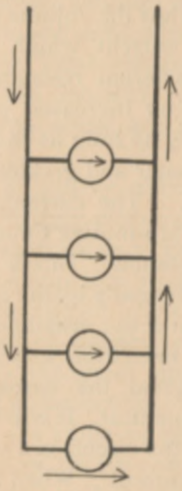

Fig. 2.

when two or more are so connected as to form bridges or arcs between the two sides of the circuit. This latter arrangement is shown in Fig. 2.

The ordinary applications of electricity in a doctor's office fall under three heads: galvanism, faradism, cautery. Each requires a somewhat different adaptation of the incandescent current, which we will now proceed to consider.

Galvanism. This I assume, and not electrolysis, is the proper term for the application of the smooth or interrupted galvanic current as used in gynæcology and in general medicine. It will naturally be feared that more or less danger may attach to the use of therapeutic currents from so powerful a source as the Edison dynamos. There is no difficulty, however, in using the direct current from the Edison mains with entire safety. The whole secret lies in the use of plenty of resistance. The volume of current which flows into the office is limited first by the size of the conducting wire. Again, at the point where the circuit enters the house, safety fuses of limited capacity are intercalated in both sides of the circuit. These fuses, which consist of thin lead or copper wire, act as safety valves, since they melt or "blow out" and break the circuit if the current by any accident exceeds the capacity of the fuse, which may be fixed at any amount required by varying the size of the fuse-wire. If now the current thus controlled is passed through a 16 c.p. lamp, connected in series as shown in Fig. 3, the volume of current which flows through the lamp, and, therefore, in the entire loop in which the lamp is connected, is about one-half an ampère. The lamp acts as a water-

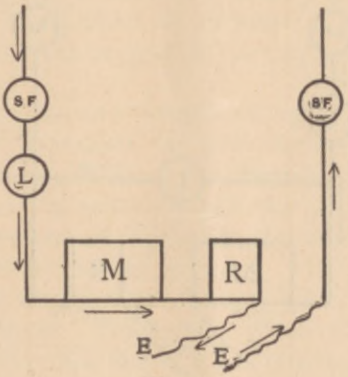

Fig. 3.

S. F. Safety fuses at the Edison terminals; L. 16 c.p. lamp; M. milammeter; R. Rheostat or current regulator.

gate does in a water-main, with this important difference, however, that if the lamp breaks the entire circuit is instantly arrested. A larger or smaller current may be had by substituting for the 16 c.p. lamp another of higher or lower capacity. The half ampère current, however, is a good stock current from which to draw for most gynæcological and medical purposes. By means of a suitable rheostat this current can be controlled as the flow of water is by a tap, and may be varied from zero to any number of milliampères required.

On first undertaking the adaptation of the Edison current to office uses I shared the opinion of Dr. Piffard that the high voltage of the current from the street mains would render it more painful than the currents of lower pressure we have been accustomed to use. Further examination of the subject has convinced me of the error of this assumption. Electro-motive pressure has no influence except to overcome resistance. The physiological effects of a smooth current depend upon the volume and quantity of current. With a given ampèrage actually flowing through the tissues, the effects are the same whatever the electro motive pressure. The current does the work, the pressure pushes it through the tissues. Since these views are somewhat at variance with a commonly accepted opinion among medical writers, I may say that they are endorsed by my friend, Prof. Robert Spice, of the Cooper Union, a physicist of recognized authority.

Under the belief that the high voltage of the Edison current is painful, Piffard and others make use of a shunt circuit for the

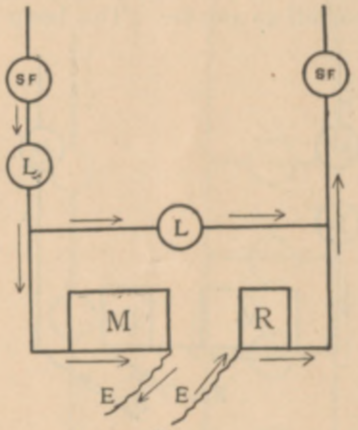

Fig. 4.

purpose of reducing the potential. This plan may be understood by referring to Fig. 4.

L and L[1] are lamps connected in series in the main circuit. A secondary loop is led from points of the main circuit on either side of the lamp L. The patient is placed in this secondary or shunt circuit, which also includes the milammeter and the regulator, and both lamps are turned on. This arrangement is not only unnecessary, but it does not even accomplish what it is supposed to do. On short circuit the voltage in the shunt drops more or less, and may be varied, according to the resistance in the shunting lamp, from three or four to seventy volts. With the patient in circuit, however, the voltage is practically the same for a given current whether the patient is in the direct or the shunt circuit.

For determining the polarity of the electrodes the milammeter affords the most convenient method, provided the direction in which the needle turns with an up-current has once been determined. In most instruments the needle is deflected in the direction in which the current flows. If, therefore, in the arrangement shown in Fig. 3, the needle of the milammeter turns to the right, E is the positive, E^1 the negative electrode. The polarity may also be determined by the electrolytic action of the current. If the copper terminals are dipped at a short distance apart in a glass of water and a half ampère current turned on, hydrogen bubbles will be given off at the negative pole, while no visible action occurs at the opposite pole. Or if platinum terminals be used and dipped in a solution of iodide of potassium, a brownish discoloration will be noted about the positive electrode from the liberation of iodine.

Faradism. For Faradism a coil may be operated by a switch from the main circuit. The current required may best be obtained by a separate loop with a 16 or 32 c.p. lamp, connected in series. The milammeter should not be included in this circuit; it is desirable that a rheostat should be, for regulation of the primary current.

No little misapprehension obtains in regard to the construction required in Faradic apparatus. It is a common error to assume that galvanic, Faradic and Franklinic electricity are different kinds of force. They are, in fact, one and the same. The essential differences in their physical or physiological effects is due to difference in the character of the currents. Galvanic currents as ordinarily used are smooth, continuous currents. Faradic currents are alternating currents. The peculiar effects of a Faradic current are mainly due to the fact that it is an interrupted current. The current from the secondary coil is at the same time an alternating current. Yet the impulses in one direction are so much feebler (about 13 times) than those in the other, that little importance can be attached to the alternating character of the Faradic current. The physiological effects, too, vary with the rate of interruptions—the number of periods per second. While the current-strength on short circuit is very small, the drop, even under great resistance, is comparatively little owing to the high electro-motive pressure. There can be no important physical difference, then, between a Faradic current and a direct interrupted galvanic current of the same volume and tension and number of periods per second. The tension of secondary Faradic currents as commonly used in medicine I have estimated at from 50 to 100 volts or more, and the current, on short circuit, averages about a half milliampère, does not often exceed a milliampère. A current of this strength and tension obtained from the Edison mains by the interposition of suitable resistance and with the use of an adjustable rheotome, would answer all the purposes of Faradic electricity. With a milammeter capable of registering fractions of a milliampère, precision of measurement would be possible by this method, and that at present is out of the question with Faradic instruments. Having rheostat, milammeter, rheotome and patient in circuit, the required current could be turned on and broken at the required rate of interruption. With suitable metric apparatus the current-strength and the number of impulses per unit of time could always be accurately known and recorded. The Faradic coil, however, is practically indispensable as a simple and convenient source of interrupted currents of infinitesimal volume and high tension. Precision of measurement in the use of Faradism is not yet possible.

The requirements of a Faradic instrument may be met by a very simple construction. All that is needed is an induction apparatus with a secondary coil of long, fine wire and a rheotome or rheotomes adjustable to give from 2 to 200 interruptions per second. An instrument thus simple will accomplish all that is possible with the multiple coils of Engelmann and others. It is a fallacy to assume, as certain writers on this subject have done, that a secondary coil, wound with a given length and fineness of wire, ensures a current of fixed volume and tension, even with the same primary. Current-strength, as we have seen, depends upon the resistance in the circuit and the electro-motive force. Resistance varies with the moisture of the electrodes, their area and firmness of contact, the thickness and dryness of the skin at the point of contact, and other conditions. Electro-motive force, and therefore the current in the secondary circuit, varies with the strength of the primary current, the rate of interruptions, and the extent to which the outer covers the inner coil. Hence, an induction coil wound to give the highest electro-motive force that can be required for any use will answer for all uses. The tension, and therefore the current, can be graduated from this maximum to zero by moving the outer coil so as to gradually uncover the inner one, or by regulating the strength of the primary current by means of the current controller. A still simpler method of regulating the secondary current is by means of a current controller placed in the secondary circuit. The entire range of tension (and therefore volume) of which the coil is capable is thus at command without moving the outer coil or changing the strength of the primary current.

More or less importance is attached to the so-called primary current from induction apparatus by many writers on electro-therapeutics. This current is nothing more than a series of impulses all moving in one direction, and the result of self-induction in the primary coil. It has no properties that distinguish it in any essential particulars from induced currents obtainable from the necessary coil, or an interrupted direct current of equal volume and tension.

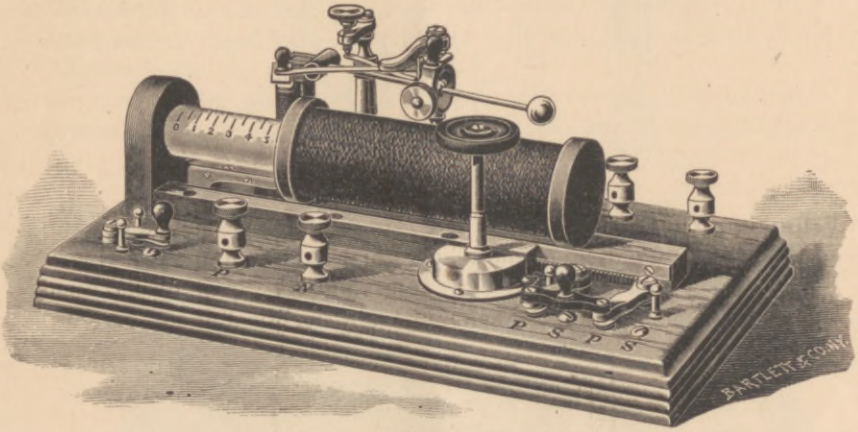

Fig .5.

The most approved Faradic apparatus is that constructed on the Du Bois-Reymond principle. An excellent Faradic instrument in point of both mechanical construction and physical performance is made by the Law Battery Co., of New York, and is

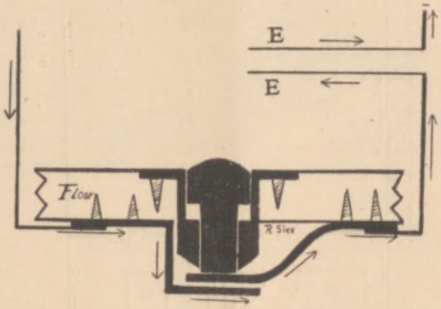

Fig. 6.

shown in Fig. 5. Its secondary coil is wound with 1,200 feet of No. 32 wire, giving a wide range of tension, and it is provided with two rheotomes for slow and rapid interruptions. The outer coil is movable over the inner by means of a rack and pinion.

Cautery. A convenient plan for cautery currents is shown in the right-hand section of Fig. 8. A is a bank of lamps arranged in parallel multiple-arc. Two of the lamps are 16 c.p. lamps, each carrying a little less than a half ampère (0.43 ampère)*

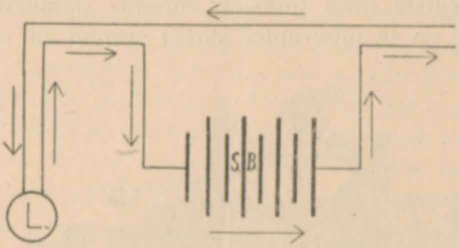

Fig. 7.

current. The others are 50 c.p. lamps, having each a current capacity of not quite one-and-a-half ampères (1.36 ampères). Each lamp turned on adds to the current an amount equal to its own capacity. Such a bank is suitable for a twenty ampère current,

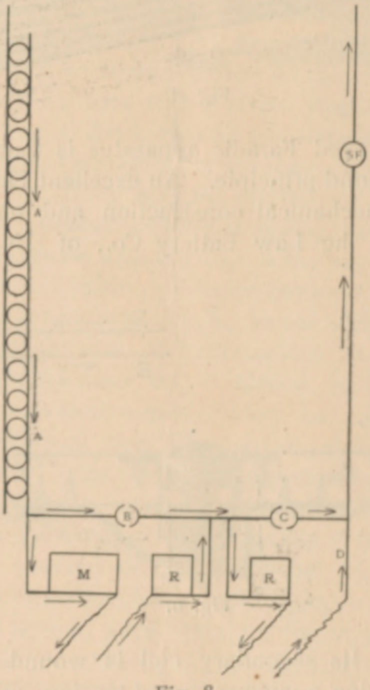

Fig. 8.

which is an average cautery current. The system may be easily extended to give thirty or forty ampères for heavier work. If a

*Edison lamps.

switch-plug is placed in B, the right-hand section is ready for cautery; if in C, the left-hand section may be used for galvanism.

The conducting wires in the handles of most cautery electrodes are made too light, and are liable to become heated. The contact points are especially apt to suffer, and for this reason it is well to close the contacts of the electrode handles permanently, and to make and break circuit by a heavy floor push-button such as is shown in Fig. 6.

The simple plan above described will be found far more convenient and satisfactory for cautery currents than the cumbersome

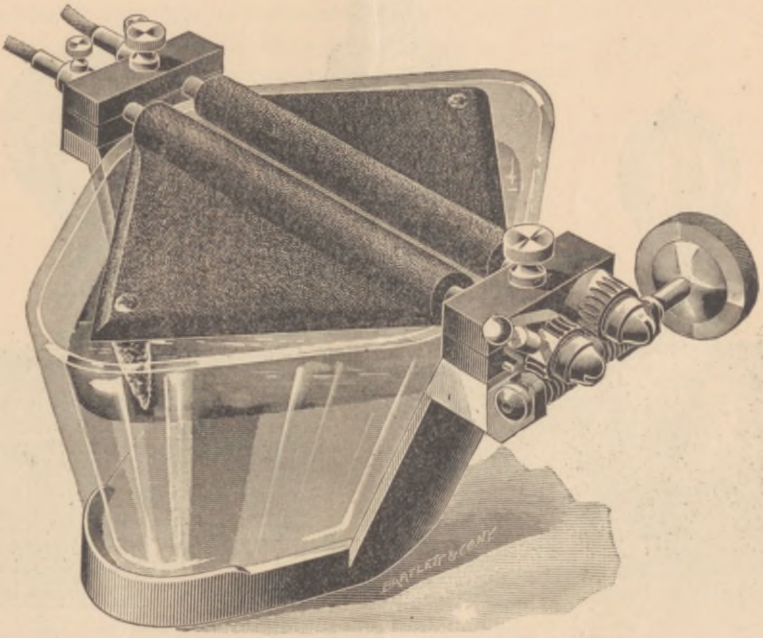

Fig. 9.

and costly motor-dynamo-transformer. The latter apparatus is wholly unnecessary for the purpose.

For a portable cautery plant the storage battery has practically supplanted all others. A storage battery, however, to be kept in good condition must be used daily, must be recharged as often as used, and its charge must never be more than one-third exhausted. It is advisable, therefore, to make the portable storage battery do duty also for office purposes. Most of the annoyance which attaches to the use of storage batteries that require to be sent out at short intervals to be recharged may be obviated when the charging current can be had on tap in the office. If the battery is kept well charged, and the charging current allowed to run through it daily, very little additional attention will be needed to keep it at all times in perfect working order. For charging, the positive terminal of the charging wire must be connected with the positive pole of the battery, and the negative with the negative pole. Moreover, the volume of the charging current must be regulated according to the size or

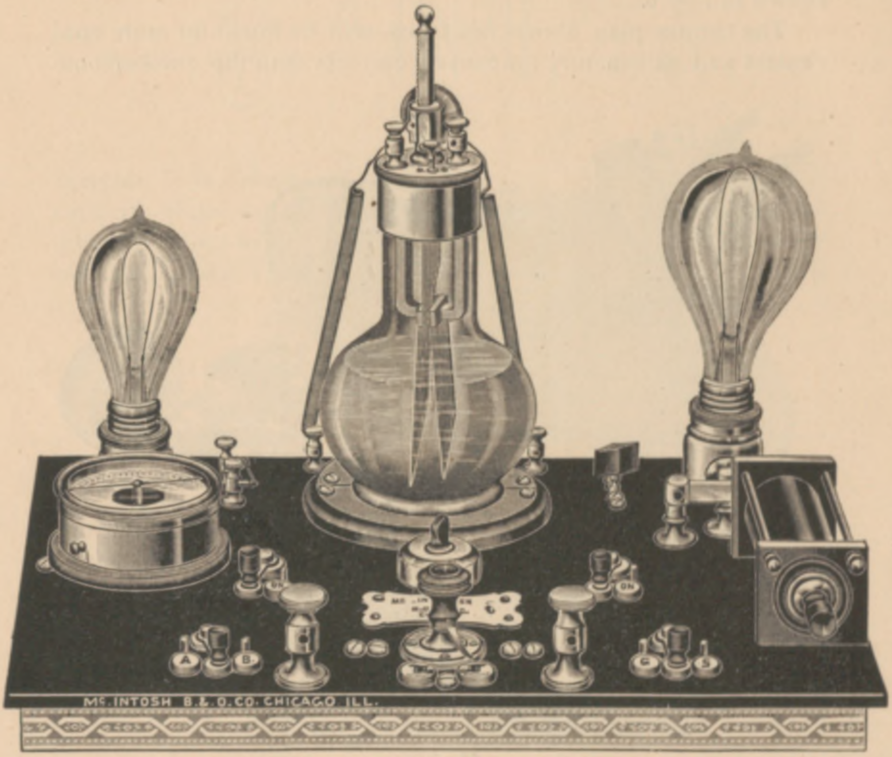

Fig. 10.

capacity of the battery. It may be just enough so that the fluid does not boil perceptibly. The battery will be injured or destroyed if these precautions are not observed. A safe charging rate is three ampères for every square foot of anode surface in the battery plates. A more convenient rule, however, is about one ampère for every twenty ampère-hours of battery capacity. For the usual medical battery a half ampère current answers sufficiently well. A simple and economical method of charging is shown in Fig. 7. The battery is connected by a loop with a single 16 c.p. lamp circuit, which is used for ordinary illumination. When the lamp is turned on the battery is being charged. Frequent charging and the maintenance of a full charge are thus secured without special attention.

A search-lamp may be operated by the storage battery or by connecting it with the terminals of the cautery plant represented in the right-hand section of Fig. 8. The current required by the miniature lamps usually employed for this purpose is about two or two-and-a-half ampères. Turning on two of the 50 c.p. lamps in the bank the current may then be turned up by the regulator till the search-lamp burns to full incandescence.

Rheostats or current regulators. After careful comparison of a number of rheostats, I have found nothing better for use with the Edison current than the Bailey water rheostat. In the old instrument, however, the aluminum wire should be replaced with plati-

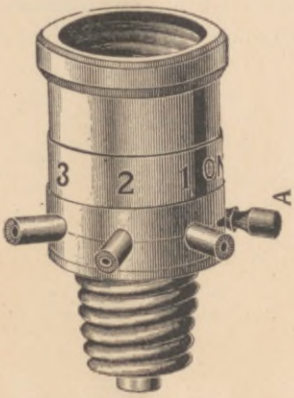

Fig. 11.

num to prevent corrosion at the contacts. The new Bailey regulator (see Fig. 9), made by the Law Battery Co., of New York, is in many respects an improvement on the old one. A good dry rheostat for the purpose is the Willms. The Vetter regulator is suitable for use only with currents of half an ampère or less. Where currents of large volume are required, as for charging storage batteries, a single lamp of large capacity may be used. A still more convenient regulator for large currents is a bank of lamps arranged in parallel multiple-arc, as shown in Fig. 8.

Milammeters. The milammeters sold by most instrument makers are inaccurate, unreliable, and otherwise imperfect. Absolute accuracy of measurement, while not indispensable for medical use, is certainly desirable. The only accurate milammeter at present made is that of the Weston Electrical Instrument Company, of Newark, N. J. The instruments of this company are universally recognized as standard Another advantage of the Weston meter is the fact that it is absolutely "dead beat"—in other words, the needle moves to the reading and stops instantly. Unfortunately this instrument is a costly one. The next best milammeters that I have tested are the Vetter and the New Barrett meters.

For those who prefer to purchase a switch-board fully equipped for use with the electric illuminating current, a suitable apparatus may be had of the W. F. Ford Surgical Instrument Company, of New York. A switch-board sold by the McIntosh Battery & Optical Company, of Chicago, is shown in Fig. 10.

A simple and inexpensive adapter intended for use with galvanic and Faradic apparatus only is made by J. C. Vetter & Co., of New York. It is a lamp socket with connecting posts for conducting cords. It may be screwed into any lamp socket or wall receptacle. The apparatus is shown in Fig. 11.