Practical

Electro-Therapeutics.

UNIVERSITY OF MICHIGAN

PRACTICAL

ELECTRO-THERAPEUTICS

A

MANUAL

OF

LABORATORY EXPERIMENTATION

FOR

STUDENTS OF MEDICINE

BY

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PREFACE.

The successful use of electricity as a therapeutical agent requires upon the part of the physician a considerable knowledge of electricity as a pure science and more or less experience in the practical handling of electrical apparatus. This study of what may be called Electro-Physics must of necessity precede the study of Electro-Therapeutics proper. Unfortunately the subject of Physics has not heretofore received in our medical schools that attention which its importance demands and to this cause undoubtedly has been due in large measure the long delayed recognition by the medical profession of the importance of electricity as a means of treating disease.

Such recognition is now, however, no longer withheld by those who are abreast of the best medical practice of the day and the study of electricity as a science, and by the laboratory method, is rapidly becoming an absolute essential in the education of the general practitioner.

In recognition of these facts an optional laboratory course in electricity for professional students was several years ago established in the University of Michigan. The need of a suitable manual was quickly felt, and in 1884 Professor J. W. Langley, by whom the course was organized, published what may be called the pioneer work in this line of electrical study.

The natural expansion of the course and the experience acquired within the last six years calls for a new manual of experiments. The present book embodies, in substance, much that was contained in the former one but many changes and additions have been made. This does not profess to be a complete manual of laboratory electricity. It is designed for a special class of students who wish to acquire, in a short laboratory course, a knowledge of such portions of the science as shall be of the most value in the practical employment of electricity in medicine. Accordingly the briefest outline of only those facts and principles which conduce to this end has been given; while, as an aid to the student in filling in the outline, many references to two standard works—one upon electricity as a pure science, and the other upon electricity in its applications to medicine—have been made.

If this little manual shall assist in making the course in Electro-Therapeutics a source of still greater profit and pleasure than it has been in the past, the author will feel that his labor has not been unrewarded.

CHAS. K. McGEE.

Ann Arbor, March, 1890.

CONTENTS.

ABBREVIATIONS.

C—Current.

G—Galvanometer.

G (l. c.)—Galvanometer, lower coil.

G (u. c.)—Galvanometer, upper coil.

E—Electromotive force.

R—Battery Resistance.

r—Resistance outside of the battery.

m. a.—Coupled in multiple arc.

T.—Thompson's "Elementary Lessons in Electricity and Magnetism." Edition of 1888. Numbers refer to paragraphs.

B. R.—Beard and Rockwell's "Medical and Surgical Electricity." Seventh edition. Numbers refer to pages.

PRACTICAL ELECTRO-THERAPEUTICS.

1. **Galvanic Batteries.**—For the practicing physician the principal source of electricity is the galvanic battery. The one great fundamental fact of nature upon which nearly all forms of the galvanic cell depend is the following:

If any two metals, brought into electrical connection by simple contact or by a wire, be immersed in any acid, alkali or solution of a salt which is capable of corroding either of them a current of electricity will flow across the connection from the least to the most corrodible of the two metals. The current will traverse a *completely closed circle or circuit* consisting of the incorrodible metal, the wire, the corrodible metal and the corrosive fluid and continue to flow as long as any of the corrodible metal is left or until the corroding fluid is exhausted. "Opening the circuit" at any point, by cutting the connecting wire, for example, or by dividing the fluid into two portions by means of a non-conducting diaphragm, will cause an immediate cessation of the current.

Many different conditions influence the strength and constancy of the current and many different modifications of this simple arrangement of two metals in a corroding fluid have been made for the purpose of obtaining as constant and as strong a current as possible. Hence has arisen several hundred forms of the galvanic cell [See Niaudet's "Electric Batteries,"] each having its own peculiar advantages and disadvantages. A knowledge of only about half a dozen different forms is necessary to the physician. Read up on the following which are of importance for the reasons given:

This is a battery which any physician can easily make in a few hours in almost any village in the country and will serve admirably as an "emergency battery."

1. Volta's Cell.—Important as illustrating the simplest form of battery and the general principles of the galvanic cell. [T. 152, 154, 155, 157, 158, 159, 160, 166, 167, 168, 169.—B. R. 21, 22, 23, 26.]

2. Copper Sulphate Cells. [Daniell's, Gravity, Sawdust, Etc.]—Important as a standard of electro-motive force and for being almost absolutely non-polarizable. Not often used in therapeutical work. [T. 170, 176.—B. R. 32.]

3. Bunsen's Cell.—Heretofore the most widely known and used of all batteries. A powerful, constant, cheap, durable battery but not very portable. On account of the labor of setting it up and taking it down every time it is used the Bunsen is not as convenient a battery as the Bichromate. [T. 171, 172. B. R. 34.]

4. Sulphate of Mercury Cells.—Used to a considerable extent in small pocket induction coils. A quite powerful and a very compact battery, but the use of the mercury salt renders it expensive for any other purpose than to operate small induction coils. [T. 175.]

5. Bichromate of Potash Cells. [Chromic Acid, Grenet's Battery, Etc.]—A powerful and cheap battery giving a reasonably constant current if not placed upon "short circuit." The great point in favor of this cell is the readiness with which it can be set up and taken down—it being only necessary to lower the plates into the fluid before and to withdraw them again after using the battery. When the fluid is fresh this cell is fully equal to the Bunsen excepting upon circuits of very low resistance. Ten to twenty small Bichromate cells, each holding one or two ounces of fluid, make a most excellent battery for all kinds of therapeutical work excepting that requiring the electro-cautery or the induction coil. Special attention will be given to the practical understanding and use of this battery. [T. 165.—B. R. 35, 307.]

6. Sal Ammoniac Cells. [Leclanche, "Diamond Carbon," Etc.]—This is the only one of the various batteries to be

considered which can be left permanently set up. For this reason it is especially suitable for operating door and office bells, annunciators, call bells, etc. It polarizes quite rapidly if left upon closed circuit for more than a few moments (especially a circuit of low resistance) and for that reason, among others, is not as suitable for general therapeutical work as the Bichromate. However a battery of twenty to sixty cells arranged in a cabinet is sometimes employed by physicians for office practice. [T. 173.—B. R. 37.]

2. Electric Light Wires.—For the physician who thoroughly understands the principles of electricity there can be no more convenient and powerful source of electrical energy than that furnished in our larger cities by the cables of the Incandescent System of Electric Lighting. This source of electricity is especially suited to the electro-cautery being for this purpose far superior to the very best galvanic battery and vastly more convenient.

A special piece of apparatus to reduce the current strength is, however, necessary, and one of the objects of this course will be the explanation of the method by which the incandescent current can be adapted to the physician's use. Any attempt to use the electric light current by one who does not thoroughly understand what he is about is attended with great danger both to patient and operator.

The current of the Arc System cannot be readily employed as a source of therapeutical electricity as it is too strong to be easily managed by any one who is not an electrical expert.

3. Local Action and Amalgamation.—All batteries whose fluids contain *free acid* must have their zincs amalgamated on account of the "local action" which would otherwise quickly destroy them. It is not *necessary* to amalgamate the zincs of sal ammoniac batteries although such amalgamation is no detriment but rather an advantage. The same is true of any battery which does not contain a *free acid*. [T. 161, 162.—B. R. 25, 26.]

To amalgamate a zinc thoroughly clean it in dilute sulphuric acid and then pour upon it a little mercury. Rub the latter over the entire surface of zinc exposed to the battery fluid. Another method is to place the zinc in a solution of a mercury salt containing a little free sulphuric acid. A zinc must be so thoroughly covered with mercury that it will not effervesce when left in dilute sulphuric acid. Some battery zincs are so impure that it is almost or quite impossible to amalgamate them enough. This is especially true when the zinc contains little pieces of graphitic carbon. Such zincs should be discarded and new ones obtained.

EXPERIMENTS.

EXP. 1. Take pieces of any two metals which happen to be at hand (tin, lead, copper, nails, silver coins, zinc, gold ring, nickel five cent pieces), immerse them in dilute sulphuric acid (or any other dilute acid, alkali or solution of a salt) and connect them by short pieces of copper wire including a G in the circuit. Test several pairs of metals and notice that you get different deflections with different metals. In dilute acids the greatest deflection will be obtained with zinc in combination with some incorrodible metal like gold. Hence zinc is the metal which is almost universally used for the corrodible plate of batteries. [T. 72.—B. R. 24.]

EXP. 2. To prove that the current flows through the fluid as well as through the wire place a piece of zinc above and a piece of copper or silver below the tongue. Now connect them with a wire and notice the sharp metallic taste produced by the passage of the current through the tongue. In this Exp. the fluids of the mouth take the place of the dilute acid of the battery. By using different pairs of metals you can in this manner also easily detect the fact that the strength of the current varies with the metals employed, being greatest when one of the metals is zinc. Try it. Place a piece of zinc on the tongue and then bring it in contact with the gold or silver filling of your tooth. What do you notice? Explain the phenomenon.

EXP. 3. Make a Voltaic Pile [T. 150—B. R. 30] with a dozen zinc and copper plates separated by pieces of paper wet in strong brine. Place your finger on the lower plate and your tongue on the upper one. Pass the current through your G (u. c.) including a resistance coil of 100 ohms, and compare the deflection with that given by one or two Volta's cells through the same circuit. This Exp. illustrates the principle upon which electric belts, pads, etc., [B. R. 445] are constructed. The moisture of the body supplies the fluid, the belt itself containing, in some cases

at least, some hygroscopic salt which absorbs the moisture thus supplied. A well constructed belt will give a very fair current for a time, but it is liable to gradually fail on account of the corrosion of the plates and connections.

Exp. 4. Dip a piece of unamalgamated zinc in dilute sulphuric acid and notice the evolution of hydrogen from its surface. Now immerse a piece of copper in the acid and bring the upper ends of the two metals in contact. Notice that the hydrogen now comes from the copper instead of the zinc plate. Is the copper being corroded? Is the zinc? Bring the plates in contact at the bottom instead of the top and notice that the effect is the same. Separate the plates from each other, connect them by a wire and observe that the effect is still the same even when the wire is a very long one. [T. 160.] Notice that in this Exp. the hydrogen does not *entirely* cease to come from the zinc plate. Why? [T. 161.]

Exp. 5. Bend a piece of zinc back and forth several times and notice that it is quite tough. Now amalgamate it and bend it again. Notice how brittle it has become and remember that *amalgamated battery zincs are very brittle and must be handled with care.*

Caution.—*Remember that finger rings, watches, chains, etc., as well as battery zincs, may be amalgamated and perhaps injured thereby.* Mercury may be largely driven off from any piece of jewelry by slightly heating it over a lamp or gas burner. Great care must be used in this process if the piece happens to contain a setting.

Exp. 6. Repeat Exp. 4, using a piece of *amalgamated* zinc instead of the unamalgamated. The results obtained are different in *one* particular. What is it and why the difference?

Exp. 7. Read the next paragraph upon soldering and then make a Volta's cell like the model on side table. Amalgamate the zinc after everything else is done.

4. How to Solder.—It is quite desirable that one who handles electrical apparatus to any extent should know how to solder. The following suggestions are accordingly given:

1. Have the soldering iron hot enough to melt the solder about as readily as a warm knife blade melts butter. Do not let it get red hot as the "tinning" will be thereby burned off.

2. The parts to be united must be scraped clean with a knife or a piece of sandpaper.

3. A "soldering fluid" or flux must always be used. Rosin

is used for soldering tin or lead; zinc chloride (made by adding an excess of zinc to dilute muriatic acid) for soldering copper, brass, zinc, nickel, German silver, silver and gold; for soldering iron use zinc chloride solution to which some salammoniac has been added.

4. Small pieces of metal and wires may be soldered without the use of a soldering iron by clamping or twisting them together, laying a small piece of solder upon the joint, adding a drop of soldering fluid and heating over an alcohol lamp or gas burner. The melted solder will spread between the pieces by capillary action.

5. Rules and Memoranda.—The following rules for the use and care of batteries should be firmly fixed in the memory:

1. Dilute sulphuric acid for batteries is made by adding, *with constant stirring*, one volume of the commercial acid to fifteen volumes of cold water in a vessel not easily broken by heat. Never add the water to the acid. Why?

2. To make Bichromate Fluid add one volume of commercial sulphuric acid to twenty volumes of cold water, stirring constantly. Then saturate the solution with bichromate of potash. About four ounces of bichromate is required to saturate a quart of the dilute acid.

The following formula requires a little more work but furnishes a rather better fluid, especially for a cautery battery: To one pound of finely powdered bichromate of potash, in a porcelain dish, add *with constant stirring* two pounds of strong sulphuric acid. To this mixture add *carefully and with constant stirring* twelve pounds of cold water. When *cold* [B. R. 35] the solution is ready to use. It is convenient to remember that a pint of water weighs about one pound and a pint of sulphuric acid about one and three-fourths pounds.

It is a good plan to add about one ounce of a soluble mercury salt to the quart of Bichromate Fluid which is to be used in a *battery having carbon plates*. This will keep the zincs well amalgamated. Fluid containing mercury salts should not

be used in cells employing platinum plates as the action of the battery is liable to amalgamate the platinum.

Chromic acid (chromium trioxide) may be used in place of bichromate of potash in the proportion of three parts of chromic acid for every four parts of bichromate. It is preferable to bichromate—especially for cautery batteries.

3. Bichromate fluid is no longer good after it has become green. Why?

4. Battery cells should never be filled so full that the fluid comes in contact with the metal straps or connectors attached to the upper ends of the battery plates.

5. In batteries employing porous cups the fluid about the incorrodible plate should never be higher (nor, in fact, quite as high) as the fluid about the zincs. By observing this rule the diffusion of the oxidizing fluid towards the zinc is delayed.

6. No effervescence should occur in a battery cell which is working properly. It indicates local action and, consequently, incomplete amalgamation. Battery zincs must be occasionally re-amalgamated.

7. After being used, all batteries (excepting the sal-ammoniac and a few others which are intended to be left set up) should have their plates taken out of the fluids immediately, and in case of the two fluid batteries the fluids should be put into their respective bottles for preservation and not allowed to stand in the battery cells. Porous jars must be soaked in water for several days to remove from their pores the salts which, otherwise, are liable to crystallize and break the jars. See specimens of jars thus broken on the side table.

8. The carbon clamps and connections of Bunsen's battery should never be left clamped to the carbons as the acid gradually creeps up and corrodes them.

9. The evolution by Bunsen's battery of the disagreeable and poisonous fumes of nitric oxide may be largely prevented by adding to the nitric acid a little bichromate of potash.

6. The Galvanometer.—No one can successfully use electricity without understanding the principles of and at times using some form of galvanometer. Even a very simple and cheap instrument may be made, in the hands of a skilled operator, to yield valuable and comparatively accurate results. A galvanometer adapted to the currents employed in electro-therapeutics is called a "milliamperemeter;" and one adapted to the heavy currents used in electric lighting is often called an "ammeter" or an "amperemeter." A galvanometer may be used,

1. To determine whether or not any current is flowing.
2. To determine the direction of the current.
3. To measure the strength of the current.
4. To measure the resistance of a circuit.

The great fundamental phenomenon of electricity upon which the construction of the galvanometer depends is the following: *A freely suspended magnetic needle always tends to place itself at right angles to a wire through which a current is flowing.* [T. 185, 186, 187, 188, 189, 197, 198, 199.—B. R. 40.]

The galvanometer which you will use in the laboratory is a tangent galvanometer in which the needle is suspended above the coil of wire instead of within it. The instrument contains two coils, the lower one for very strong and the upper one for weak currents.

For deflections not greater than 10° or 15° the current is nearly proportioned to the deflection. [T. 198, 199.] In using these particular instruments the following table will be of considerable assistance. The table gives approximately the strength of the current in milliamperes for deflections, produced by the *upper coil*, not exceeding 24°. This table applies only to these particular galvanometers. In general every galvanometer must be calibrated by itself and its own table constructed from actual experiment. [T. 198.]

TABLE.

Giving the Current in Milliamperes, Corresponding to Various Deflections of the Galvanometer.

1°	1.8	9°	17.0	17°	35.0
2°	3.6	10°	19.0	18°	38.0
3°	5.4	11°	21.2	19°	41.5
4°	7.0	12°	23.4	20°	45.0
5°	9.0	13°	25.6	21°	49.0
6°	11.0	14°	27.8	22°	54.0
7°	13.0	15°	30.0	23°	60.0
8°	15.0	16°	32.5	24°	67.0

By thoroughly mastering the principles of the galvanometer a physician can easily construct one for himself (out of a good pocket compass and a few feet of insulated copper wire) which will serve all practical purposes in electro-therapeutics. In order to measure the current the instrument must be calibrated and a table like the above constructed. This can be easily done if one has a few resistance coils and knows how to apply Ohm's Law.

7. Rules for Using the Galvanometer.—The following precautions must be observed in using these galvanometers. Similar rules apply to all other instruments of like construction.

1. The galvanometer must be so placed on the table that the coil shall be parallel to the needle when no current is flowing.

2. On account of the danger of injuring the instrument (by fusing the wire or burning the insulation) no current should be sent through it which gives a greater deflection than 85°; nor should any current be allowed to flow longer than is necessary to take the reading.

3. Conducting wires must not be allowed to pass over or near the needle; and all resistance coils, magnets, pocket knives, pieces of iron, gas pipes, etc., must be kept at least two feet from the galvanometer.

4. The most accurate results are obtained when the deflections do not exceed 30° or 40°. Consequently use the upper or

lower coil according as the one or the other gives the most favorable deflection.

EXPERIMENTS.

Exp. 8. Magnetize a common sewing needle by rubbing it *in one direction only* with a horseshoe magnet. [T. 92—B. R. 6.] Then float the needle on a glass of water using a small piece of cork as a float. You now have a compass. [T. 83.] After the needle has come to rest in the magnetic meridian stretch a piece of copper wire above and parallel to it. No effect is noticed until a current be sent through the wire. What happens when a current from your Volta's cell is allowed to flow? This is Oerstedt's fundamental experiment. [T. 185.]

Exp. 9. Modify this Exp. 8 by using your G, which place on the table with its length pointing east and west. Now stretch the wire just above the needle and parallel to it. Notice carefully the effect; now place the wire *below* the needle and notice a slight difference in the result. What and why the difference? Wind the wire several times around the instrument and observe the marked increase in the deflection [T. 187, 189.]

Exp. 10. Modify the experiment in one other way. Notice how much deflection you get when only one strand of wire is held just above the needle. Now wind the wire into a coil of six or eight strands having a diameter of about two inches. Hold this coil (in a vertical position) just above and parallel to the needle and observe the deflection again. Why is it greater? This Exp. illustrates the construction of your galvanometer, in which, however, the coil is underneath instead of above the needle.

Exp. 11. Place your G on the table with its N to the west. Now pass the current of your Volta's cell. Why does not the needle move? This shows the necessity of observing the first rule under paragraph 7.

Exp. 12. A galvanometer may be used to determine which is the + pole of a battery or any other current generator. In other words it will indicate the direction in which a current is flowing. Connect your Volta's cell to the G and notice in which direction the needle turns (in the same direction as the hands of a watch or the opposite). Now reverse the connections and notice that the needle swings in the opposite direction. After having once determined in which direction the needle turns when one of its binding posts (distinguished from the other post by some sort of mark) is connected with the + pole of a battery whose polarity is known it is evident that the instrument can thereafter be used to distinguish between the poles of a battery which is out of sight (in a

cabinet or in the cellar for example) or to determine the polarity of the current derived from an electric light circuit. This is of importance because in surgical electrolysis different effects are produced at the different poles.

Let a student on the opposite side of the table pass the wires from his battery through a crack or over the top of the desk while you determine which is the + and which the — pole.

Take your G to the special piece of apparatus marked "Generator A," and determine the polarity of the wires which come from a battery in another part of the building.

Exp. 13. Pass the current of one bichromate cell through your G (l. c.) and notice the deflection. Then without breaking the connections bend one of the conducting wires over and near to the needle. Notice that you get a different deflection showing the necessity of the third precaution under paragraph 7. Bring a piece of iron, a coil carrying a current, a magnet, etc., near the needle and notice how they may change the true reading.

8. Battery Polarization.—Almost every known form of battery gives its maximum current immediately after the circuit is closed. A gradual decrease in the strength of the current is then observed with most batteries. This is called the "polarization of the battery," and, in most cases, results from both a decrease of the electromotive force and a slight increase of the battery resistance. In Volta's cell it occurs so quickly after the circuit is closed as to make its observation a matter of some difficulty while in the bichromate cell it may appear only after the lapse of several seconds or minutes. The *cause* of polarization is : (1) The deposition of a film of hydrogen gas upon the incorrodible plate; or, (2) The exhaustion in those batteries which do not evolve free hydrogen, of the thin layer of oxidizing fluid which is in immediate contact with the incorrodible plate. [T. 163, 164.—B. R. 30, 31.]

9. Prevention of Polarization.—Polarization due to a deposit of a film of hydrogen may be prevented:

First, by some mechanical device for brushing off the film as fast as it forms. This is not a satisfactory method as it does not completely prevent the difficulty.

Second, by using an oxidizing fluid about the incorrodible plate to burn up the hydrogen as fast as it forms. This is the most common method and effects a *nearly* complete prevention of polarization.

Third, by using a solution of some suitable metallic salt about the incorrodible plate. Copper sulphate is generally used. In this case metallic copper instead of hydrogen is liberated and no polarization whatsoever occurs. [T. 165.]

Polarization due to exhaustion of the oxidizing fluid about the positive plate cannot be entirely avoided. It is not appreciable when a battery is upon a high resistance circuit, but becomes quite troublesome upon a very low resistance which we always have with the galvano-cautery. It may be largely reduced by agitating the fluids of the battery so as to renew the film of fluid next to the plate more rapidly than by its simple diffusion and cautery batteries are generally made so that the plates can be rocked back and forth when the battery is in use. A battery quickly recovers from this kind of polarization by simply being allowed to stand on open circuit for a few minutes.

EXPERIMENTS.

Exp. 14. Connect your G with the sal-ammoniac battery on the side table and notice that in a few moments the deflection begins to grow less. This is due to "battery polarization." Allow the cell to stand on open circuit for ten minutes and again test it. Observe that it has nearly or quite regained its former strength. For what purpose are these batteries especially suited?

Exp. 15. Test a gravity cell for polarization. Notice that you may leave the current on almost indefinitely without any sign of decrease in its strength. No battery is freer from polarization than a well constructed and properly charged copper sulphate cell. Why, then, is not this cell used in practical electro-therapeutics?

Exp. 16. Make use of "Apparatus B." Read the directions attached thereto *carefully* and follow them exactly. Convince yourself of the following facts:

1. A bichromate battery polarizes considerably upon a circuit of *low resistance.*

2. This polarization is lessened by rocking the cell or by otherwise agitating the fluid so as to renew the oxidizing solution in immediate contact with the positive plate more rapidly than by simple diffusion.

3. Upon a circuit of very *high resistance* the bichromate battery shows no marked polarization.

10. What Determines the Strength of a Current: Ohm's Law.—In order to have a clear understanding of the conditions upon which the strength of the current, in any particular case, depends we must sharply distinguish between the three following electrical quantities:

1. The Current (C). Its unit of measurement is called Ampere.
2. Electro-motive Force (E). Its unit of measurement is called Volt.
3. Resistance (R or r). Its unit of measurement is called Ohm.

In the case of every current of electricity all three of these quantities are involved and the experimental study of electricity has shown that if we by any means know the value of any two of these quantities we can find out the value of the other by a simple calculation.

The formula which gives us the value of C when R and E are known is

$$C = \frac{E}{R + r} \qquad (1)$$

in which C is the current in amperes, E is the electro-motive force in volts, R is the battery resistance and r is the resistance of the rest of the circuit. This formula simply means that the strength of the current depends upon two things only; (1), the force or electrical pressure which is driving the electricity round the circuit, and (2), the resistance or friction of the entire circuit. It further states that the strength of the current in amperes is equal to the number of volts electro-motive force divided by the number of ohms resistance which we happen to have in any particular case.

This statement is true in every case of a current flowing in closed circuit and constitutes a great Law of Electricity known the world over as Ohm's Law in memory of the man who discovered it. [T. 155, 158, 179, 345.—B. R. Chap. VI, p. 65.]

This formula may be written in two other ways:

(2) $$E=C\,(R+r)$$

(3) $$(R+r)=\frac{E}{C}$$

The second formula gives us the value of E when we know the value of C and (R+r), while the third gives us the total resistance of a circuit when we know the values of E and C.

11. Useful Memoranda.—In applying the above formulae the following facts and constants should be borne in mind:

1. The E of a cell is independent of its size or shape and depends almost entirely upon the nature of the plates and fluids employed.

Each kind of cell has its own particular E. The following table gives the E of several of the more important batteries. These values are for freshly charged cells and are consequently too large for cells whose fluids are partially exhausted. [T. 178.—B. R. 68.]

Volta's cell,	.8 volt.
Copper Sulphate cells,	1.0 "
Sal-ammoniac cells,	1.4 "
Sulphate of Mercury cells,	1.5 "
Bunsen cells,	1.8 "
Bichromate of Potash cell,	1.9 "

2. Every battery cell offers more or less resistance to the passage of the current. This may be looked upon as *friction*—electrical friction, and varies from one-tenth to five or six ohms according to the size and kind of cell, depth of fluid, distance between plates, concentration of the fluids, temperature, etc.

In general the resistance of a one or two quart Bunsen or Bichromate cell may be taken to be one-third of an ohm. The resistance of a Gravity cell, like those upon the side table, is about three ohms. [T. 181—B. R. 75.]

3. Every part of a circuit outside of the battery also has

some resistance. In many cases this can be approximately known by remembering:

1. The resistance of any piece of wire is given by the formula

$$r = \frac{10\,a\,l}{d^2}$$

in which d = the diameter of the wire in thousandths of an inch.

l = the length of the wire in feet.

"a" = a number which varies with the material out of which the wire is made. The following table gives the value of "a" for the various substances named:

Copper,	1.
Brass,	4.
Iron,	6.
Platinum,	6.
German Silver,	14.
Mercury,	60.
Dilute Sulphuric Acid, $\frac{1}{12}$ acid,	2 000 000.
Water,	40 000 000.
Gutta Percha,	200 000 000 000 000 000 000.
Shellac,	4 000 000 000 000 000 000 000.

[T. 347].

2. The resistance of the body from hand to hand when cylindrical electrodes are firmly held in moist hands is about 4 000 ohms.

3. The resistance of living tissue between two needle electrodes about one inch apart is approximately 500 ohms.

4. There are three methods of coupling cells together:

First. Series. This is effected by connecting the positive plate of one cell with the negative plate of the next and so on through the whole number.

Second. Muliple Arc. This consists in connecting all the positive plates together to form one large multiple plate and all of the negative plates together to form one large multiple negative plate.

Third. Partly in series and partly in muliple arc. This consists in forming a number of groups coupled in m. a. which grougs are afterwards coupled in series exactly as if each group were a large cell instead of a muliple cell. Of course the number of cell required for this method is equal to the *product* of the number in series multiplied by the number in m. a.

5. The E of a number of cells coupled in series [T. 350] is equal to the sum of the electromotive forces of the several cells.

6. The E of a number of cells coupled in multiple arc is the same as that of one cell. [T. 350.]

7. The E of a battery composed of S cells in series and M cells in multiple arc (the total number of cells being S x M) is equal to S times the E of one cell.

8. The R of a number of cells coupled in series is equal to the sum of the resistances of the several cells.

9. The R of a number of cells coupled in the multiple arc is equal to the resistance of one cell divided by the number of cells thus coupled.

10. The R of a battery of S cells in series and M cells in multiple arc in equal to the resistance of one cell multiplied by $\frac{S}{M}$.

12. The Best Method of Coupling Cells.

As has just been stated there are three methods of coupling a number of cells together.

First. All in series.

Second. All in multiple arc.

Third. Partly in series and partly in multiple arc.

The question is often asked. "which one of these methods is the best—which one will give the largest current?"

Both theory and experience answers that no one of them is the best under all conditions. Sometimes one and sometimes another gives the maximum current *depending upon the value of the external resistance.* The one universal rule, which is a mathematical consequence of Ohm's Law and of the facts just given respecting the E and R of batteries, is the following:

That method of coupling which makes the battery resistance (*R*) *most nearly equal to the external resistance* (*r*) *will give in every case the maximum current of which the battery is capable* [T. 351.]

In accordance with this rule it follows that when the external resistance is large, say above 15 ohms, a battery should be coupled in series; if r is *very* small, say not more than one twenty-fifth of an ohm, the battery should be in m. a.; while if r is in the neighborhood of one ohm some arrangement in both s. and m. a. will give the best results.

EXPERIMENTS.

Exp. 17. A closed circuit is necessary to the existence of a current and in such a circuit *the strength of the current is the same at all points.*

Prove this proposition by putting in circuit four cells and several resistance coils of 500 to 1000 ohms total resistance. Now introduce your G (u. c.) at various points in the circuit—between any two of the cells, or any two of the coils, between the coils and the battery, etc.—and notice that you get exactly the same deflection at all points.

Exp. 18. *The E of a cell is independent of its size.* Prove this by putting in circuit with your G a resistance of about 200 ohms and then, *in turn,* the small bichromate cell on side table, the bichromate cell on your own table, and finally the large cell which is on the side table. Notice that you get no increase in the deflection as the size increases.

Exp. 19. *The E of a cell is independent of the depth of the fluid.* Prove by passing the current from one of your cells through the G and a 200 ohm coil. Gradually lift the plates out of the fluid and notice that the deflection does not change until just before the plates leave the fluid entirely.

Exp. 20. *The R of a cell increases as the immersed surface of the plates decreases.* Hence the larger and fuller a cell is the less will be its resistance.

Prove by sending through the lower coil of you G the current of one of your bichromate cells. Gradually raise the plates out of the fluid and observe the effect on the needle. Compare the currents given by the large and small cells on the side table and notice that the large cell gives the greatest current when connected with your G (l. c.)

Exp. 21. Use two cells in series and send the current through your G (l. c.) Take the reading. Now introduce in succession the following resistance: 1, 2, 5, 10, 25 ohms. In each case calculate the current by Ohm's Law and notice how the calculated currents agree in general with the deflections obtained.

Exp. 22. Use the l. c. of your G to measure the currents given by 1, 2, 3, 4 cells successively. Couple the cells in each case in series. Why do not the whole four cells give a greater current than one cell? Ohm's Law will explain it. Calculate the current in each case. The r of the G (l. c.) is practically zero.

Exp. 23. Repeat Exp. 22, using the u. c. of your G and including a r of 100 to 200 ohms in the circuit. There is now a gradual increase in the current as the number of cells increases. Why? Ohm's Law will answer the question.

Exp. 24. Again repeat Exp. 22 but in each case couple the cells in m. a. instead of s. You now get a greater C with four cells than with one. Why so in this case and not in Exp. 22?

Exp. 25. Use your G (u. c.) and a r of about 200 ohms. Measure in succession the currents of 1, 2, 3, 4 cells coupled in m. a. The whole four cells give no greater current than does one cell. Why? Ohm's Law will explain the mystery. Calculate the current in each case. The r of the G (u. c.) is about $\frac{1}{10}$ ohm.

13. Electrical Measurements.—A few experiments to illustrate the manner in which valuable approximate electrical measurements can be readily made with very simple apparatus will now be given.

EXPERIMENTS.

Exp. 26. *To measure E without using a galvanometer.*—Electromotive forces not exceeding about 8 volts can be easily measured with approximate accuracy by means of the tongue. Place the wires from various galvanic cells (the list given on page 14 will serve admirably) upon your tongue and notice the difference in the sharpness of the sensation. After a little practice this method of tasting the E will enable you to measure electromotive forces with tolerable accuracy and will furnish the readiest means of determining whether a battery is giving its due E.

Use the gravity battery and practice the determination of E as follows: Let one student turn his back to the battery and place the wires upon his tongue while another student shifts one of the wires at the battery so as to throw in circuit from 1 to 6 cells. A little practice will enable you to tell by taste the number of cells thrown in, and will give you an idea of the taste of from 1 to 6 volts.

By *comparing* the E to be measured with that of a standard battery like the gravity, this method can be made quite accurate.

Exp. 27. *To measure E by means of the galvanometer.*—Measure the E of three different cells as follows: Send the current of one gravity cell through your G (u. c.) and a r of 100 ohms. Now take the reading given by the cell whose E you wish to measure and call it B. Since in both cases the resistance is almost exactly the same, it follows from Ohm's Law that the deflections in the two cases are proportioned to the electromotive forces. Consequently if we let the force which we are measuring be represented by x the following proportion will give us its value:

$$1 : x :: A : B$$

$$\text{and } x = \frac{B}{A} \text{ volts.}$$

For quite high electromotive forces, say 5 to 25 volts, it will be necessary to use several gravity (or other standard) cells and such a resistance as will make the deflection about 10°. The number of cells used should be such as to give an E somewhere near that to be measured.

EXP. 28. *To measure R by using resistance coils.*—Put in circuit the resistance to be measured, your G (u. c.) and enough battery to give from 10° to 40° deflection. Take the reading. Now take out the unknown r and put in its place some of the r coils which are upon the side table. Try various coils and combinations of coils until you get the same deflection as before. When you have done this the total r of the coils is equal to the r which you are measuring.

By this method measure the r of coils "P" and "W" on side table.

EXP. 29. *To measure R without resistance coils.*—This requires a calibrated galvanometer. Your G (u. c.) has been calibrated and the table on page 9 give the current corresponding to various deflections.

Put in circuit the r to be determined, your G (u. c.) and enough battery to give 5° to 15° deflection. From the table take the value of C (in amperes—not milliamperes) corresponding to the deflection obtained. You know the value of E. Now substitute these values in the third form of Ohm's Law, $(R + r) = \frac{E}{C}$, and you will have the total resistance of the circuit. Substract R from this and you have left the resistance whose value you were seeking.

The accuracy of this method of measuring resistance depends upon the accuracy with which the G is calibrated and the precission with which you know the values of E and R. In general this method is more accurate for high than for low resistance, but it is always less reliable than the other method.

Measure the resistances of coils "P" and "W" and notice how the results agree with those obtained in Exp. 28.

EXP. 30. Measure the resistance of the body from hand to hand by the second method. Also the resistance of the hand from palm to back. In making these measurements the connection with the hand must be made by means of large copper plates or cylinders covered with paper or cloth wet with salt solution and firmly pressed upon the hand.

EXP. 31. Try to make the measurement of Exp. 30. by using *dry* wires or plates of copper pressed upon the *dry* skin. The resistance is now so great that you may be unable to get any appreciable deflection even with a large number of cells. This illustrates the necessity of using electrodes covered with wet sponge, cloth or buckskin when using electricity upon a patient. There is also another reason for using covered electrodes which we shall notice when we take up the subject of electrolysis.

14. Divided Currents.—If the poles of a battery be connected by two or more separate wires the current will always divide and each wire will carry a certain definite proportion of it. The two principal laws of divided currents are the following:

1. The sum of the currents in the several branches is equal to the main current.

2. Each branch carries such a proportion of the whole current as its conductivity bears to the sum of the conductivities of all the branches.

The conductivity of a conductor is the reciprocal of its resistance, i. e., conductivity $= \frac{1}{\text{resistance}}$. The conductivity of a number of strands, side by side, is equal to the sum of the conductivities of the several strands.

To find the *net resistance* of such a multiple-branch conductor add together the conductivities of the several branches and then take the reciprocal of this sum. [T. 353, 346.]

15. Shunts.—When any two points of a circuit are connected by a wire some of the current will be deflected from the main circuit and will pass through the wire. Such a wire is called a "shunt." A shunt is evidently one branch of a divided circuit and the laws governing the amount of current which it will deflect from the main circuit are evidently the same as those just given for divided currents.

The subject of divided currents is of importance as it shows us that we cannot confine the current to a single nerve or muscle when using electricity upon the human body. When, for example, one electrode is placed upon the back and the other upon the epigastrium the current will not be confined to the path traced by a straight line connecting the two points, but will spread out and traverse all parts of the trunk, the strength of the current, however, being less and less as the part is more and more remote from the straight line joining the electrodes. [B. R. Chap. X, p. 168]

EXPERIMENTS.

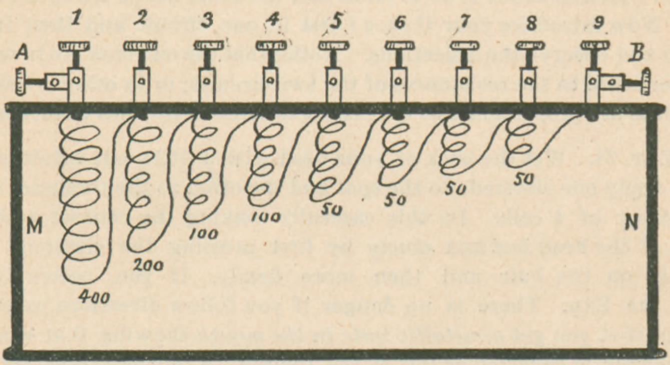
Exp. 32. Put in circuit your G (u. c.), a r of about 10 ohms and one cell of battery. Take the reading. Now without interrupting the current join the two poles of the battery by several feet of rather fine wire. Notice how the deflection drops but does not become zero. The wire is a "shunt" and is taking the principal part of the current. Now use a short, heavy wire and notice that the needle drops still more, or possibly remains at zero, showing that the less the resistance of the shunt the more of the current will it take.

Exp. 33. Connect the poles of your battery by two circuits one of which contains about 10 or 15 ohms and the other about 100 or 200 ohms res. Now introduce your G (u. c.) first in one circuit and then in the other and observe the deflections. Notice that the currents are inversely proportional to the resistances of the two circuits; or in other words the currents are proportional to the conductivities of the two branches.

Exp. 34. Wet the back of your head with a little salt solution and then apply one electrode to the spot and the other to the forehead using a battery of 4 cells. Do this carefully making the contact with the back of the head *last* and *slowly* by first pressing the electrode very lightly on the hair and then more firmly. If you become dizzy stop the Exp. There is no danger if you follow directions carefully. Notice that you get *a metallic taste in the mouth* showing that some of the current is deflected as low as the tongue. A current sent through the body from epigastrium to the back has been known to cause this metallic taste although the amount of current that reached the nerve of taste must have been almost infinitesimal.

16. How to Use the Electric Light Current.—It is by taking advantage of this property of the shunt to deflect a part of the current that we can adapt the electric light current to electro-therapeutics. As before stated a special piece of apparatus is necessary. This apparatus is in reality a shunt of peculiar construction, and the following diagram illustrates the method of using it:

M N represents a box containing a number of resistance coils having the values indicated by the numbers under each. These coils are connected with the binding posts on the top of the instrument as shown in the cut. The electric light cables are connected by leading wires to the horizontal portions of the end posts A and B. The electrode wires are then connected with any two of the posts—those two being selected which give the required electromotive force. What the E between any two posts is may be readily ascertained. The E between the two light cables is always about 100 volts. The E between the end binding posts is consequently 100 volts and that between any two posts taken at random is such a proportion of 100 volts as the resistance between those posts is to the total resistance of the instrument. For example, if the electrodes are attached to posts 4 and 6, the included resistance is 100 + 50 = 150 ohms;



the total resistance of the box is 1000 ohms; the E between 4 and 6 is consequently $\frac{150}{1000}$ of 100 volts, or 15 volts. Since in this expression ($\frac{150}{1000} \times 100$) the numerator is the only number which is changed in changing the electrodes from one set of posts to another we may write the expression for the E between any two posts thus:

$$E = \frac{B}{1000} \times 100 \qquad \text{or}$$

$$E = \frac{1}{10} B$$

in which B represents the resistance between the two posts employed. In other words the E at the electrodes which are attached to the instrument is in every case numerically equal to $\frac{1}{10}$ of the resistance included between the posts used.

These statements presuppose that the current is being sent

through living tissue which always offers a high resistance. If the current be employed on a *low resistance* the above statements must be somewhat modified; but in a general way they remain true and in any case the actual E could be calculated by means of Ohm's Law and the laws for divided currents already given.

17. Electrolysis.—(1) Every liquid compound or solution which is capable of conducting the current is called an *electrolyte.* Some liquids like bromine, kerosene and other oils generally, turpentine, etc., do not act as conductors and are not called electrolytes, nor are elements in the liquid state (e. g. melted lead, mercury, etc.,) called electrolytes.

(2) An electrolyte is always decomposed by the current which passes through it into at least two products, called ions, which are invariably liberated in immediate contact with the surface of the electrodes. The ion collecting at the + electrode (anode) is called the anion; that collecting at the — electrode (kathode) is called the kathion..

(3) The quantity of electrolyte decomposed is directly proportional to the quantity of electricity which is sent through it.

A current of one ampere will decompose a grain of water (equal to a large drop) in twelve minutes.

A one ampere current will deposit from a solution of copper sulphate $\frac{3}{10}$ of a grain of copper per minute.

(4) In most cases the ions are elements (or groups of elements) in the "nascent state"—i. e., a state of unusual chemical activity. In consequence of this fact it frequently happens that an ion, instead of being evolved as a free ion, combines chemically with the material constituting the electrode or with the electrolyte itself.

(5) It thus happens in many cases that the product actually appearing at the electrodes is not the original ion but a *secondary product* due to the chemical action of the true ion upon the electrode or upon the electrolyte. What the ions are in any particular case and whether or not secondary products are

formed must in every case be learned by reference to a standard work on chemistry or electricity.

In general it may be stated that in the electrolysis of salts of the alkalies free caustic alkali and hydrogen appear at the kathode while free acid and oxygen appear at the anode. Salts of the heavy metals usually give a deposit of that metal at the kathode and free acid and oxygen at the anode. [Read carefully T. 205 to 214.—B. R. Chap. IV, p. 45.]

18. Corrosion of the Electrodes.—Since acid radicles and the chemico-negative elements like chlorine, bromine, iodine, etc., are liberated at the anode and that too in the nascent state we would naturally expect to find the anode corroded by the process of electrolysis. Experience bears out the expectation, and only by employing some substance like gold, platinum or carbon can we avoid forming a solution of the + electrode. Even these substances (excepting the carbon) are corroded if the electrolyte contains a chloride. As a general thing the kathode is not corroded.

19. Surgical Electrolysis.—In surgical electrolysis the electrodes in the shape of common steel needles (or better the three-sided harness maker's needles) are thrust into the tissues which we wish to destroy, and the current allowed to flow for from one to ten minutes according to the necessity of the case. As might be anticipated from a knowledge of the general principles of electrolysis strongly alkaline products and some free hydrogen accumulate around the kathode while about the anode strongly acid products, a greater or less amount of dissolved electrode, and (if the current be a very strong one) some oxygen make their appearance. The gases usually escape through the opening made by the needle while the other products gradually diffuse away from the needles against which they are liberated, and in time impart their own acid or alkaline reaction to the tissues in the immediate vicinity of their respective electrodes.

Since all tissues of the body contain some chlorine in the form of chlorides a corrosion of the anode always occurs in sur-

gical electrolysis. The attempt to prevent it by using gilded or platinized needles is vain. *Some* corrosion will occur with any metal that can be used, and although the corrosion is less with platinum needles, it is doubtful whether this advantage offsets the difference in cost and convenience.

20. Polarization of Electrodes.—The products of electrolysis together with the electrodes constitute a kind of battery having in every case of surgical electrolysis an E of about $1\frac{1}{2}$ volts. This is in consequence of a tendency upon the part of the ions to recombine and reform the original electrolyte—which, indeed, in some cases they will actually do if the proper conditions be fulfilled. The E thus evoked in electrolysis is called the "*polarization of the electrodes*" and tends to send a current around the circuit in the opposite direction to that of the original electrolyzing current, and unless the latter has an E greater than $1\frac{1}{2}$ volts polarization will actually bring it to a stand still and thus prevent further electrolysis.

It follows as a practical consequence that in surgical electrolysis an E of more than $1\frac{1}{2}$ volts must be used in order to get *any* decomposition of the tissue fluids. In practice it is found that from 8 to 40 volts must be employed to secure satisfactory results. In applying Ohm's Law to the calculation of the current in electrolysis it is, of course, necessary to subtract $1\frac{1}{2}$ volts from the battery E in order to get the force which is effective in driving the current. [T. 413.]

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CAUTION.—*In performing the following experiments perfect cleanliness is absolutely necessary to success. Slight traces of acid upon the fingers or the table may entirely reverse the results of an experiment.*

EXP. 35. Attach your platinum electrodes to the poles of 4 cells in series, including your G (u. c.) in the circuit. Now immerse the electrodes (only the platinum part) in a beaker of *distilled* water. *Pure* water is a non-conductor, but you will obtain some decomposition probably, as even the distilled water of the laboratory is not absolutely pure.

It ought, however, to be quite small in amount. Now add sulphuric acid to the beaker, one drop at a time, stirring after each addition.

Notice the marked increase in the current as indicated both by the G and the increased volume of gases evolved.

Exp. 36. Repeat Exp. 35 using a strong solution of common salt instead of sulphuric acid. This Exp. illustrates the advantage of wetting sponge electrodes with a salt solution instead of pure water.

Exp. 37. Electrolyse a solution of copper sulphate using platinum electrodes and a battery of two cells. Observe the deposit of copper on the kathode. This illustrates the principle upon which electro-plating depends. You have electro-plated the electrode. If a solution of silver or gold had been used you would have obtained a deposit of these metals instead of copper. Remember that in electrolysis hydrogen and the metals always go to the kathode. Electrolysis, then, furnishes a ready method of distinguishing the poles of battery which is out of sight or the polarity of electric light wires.

Dissolve the copper off from the electrode by immersing it (only the platinum part) in the beaker of nitric acid on the side table.

Exp. 38 Determine the polarity of "Generator D" by means of electrolysis.

Exp. 39. Electrolyze a solution of copper sulphate; (1) with platinum electrodes; (2) with copper electrodes. In each case have your G (u. c.) in circuit and take the readings carefully. The copper electrodes must be of the same size as the platinum and held at the same distance apart. Notice that you get a stronger current with the copper than with the platinum electrodes. Why? Is the copper anode dissolved?

This illustrates the principle upon which the so-called non-polarizable electrodes are constructed. The anion is allowed to combine with the same kind of metal that is being deposited at the kathode and there is consequently no permanent decomposition of the salt. [T. 231.—B. R. 327.]

Exp. 40. To prove that copper is dissolved at the anode in the preceding Exp. use a slightly tarnished piece of copper for that electrode, and notice that it becomes clean and bright in consequence of the superficial corrosion which takes place.

Exp. 41. Electrolyze a solution of sodium sulphate, using four cells and platinum electrodes. The only *apparent* result is the evolution of hydrogen and oxygen. Is there any decomposition of the salt? Is the hydrogen a primary or secondary product? How about the oxygen? What has become of the sodium if the sodium sulphate has been decomposed?

Exp. 42. To prove the formation of free acid at the anode and of free alkali at the kathode in Exp. 41, add half an ounce of litmus solution to the electrolyte and hold the electrodes very still and as far apart as possible for a few moments. Notice that hydrogen and oxygen are evolved as before, but that in addition the solution turns blue about the kathode and red about the anode. Do you understand why? Be sure that you get a clear idea of what is going on in this Exp.

Exp. 43. Make sure that your hand is perfectly clean and free from acid. Lay a piece of blue litmus paper upon the palm and a piece of red litmus upon the back; wet both pieces with a neutral solution of sodium sulphate. Now press a *clean* copper anode upon the blue and a *clean* kathode upon the red paper and allow the current from four cells to flow for three or four minutes. Notice that the papers have changed color. Explain why.

Exp. 44. Repeat Exp. 43, but in this case cover the electrodes with six or eight thicknesses of *clean* paper or cloth wet in sodium sulphate solution. Now the litmus paper will not change color. Why not?

Prove that the acid and alkali in this case are liberated underneath the cloth or paper and in immediate contact with the copper by putting some pieces of litmus paper between the bare copper and its cloth covering. This Exp. illustrates the value of covered electrodes in a second particular (see Exp. 31 for the other point), and from it we may deduce the following practical rule:

A Rule Respecting Electrodes.—*When using the galvanic current never place bare metallic electrodes in contact with the skin or a mucous membrane unless you wish to obtain at the point of contact the caustic effects of free acid or alkali.*

Exp. 45. Remember that in all cases in which the current traverses a fluid, a wet cloth, sponge or paper, or the tissues of the body, it has a large resistance to overcome.

It is consequently of great importance that we make this resistance as low as possible by using *large* electrodes, *thoroughly wet* with a salt solution, and firmly held in position whenever we desire to obtain a strong current.

Fix these facts firmly in mind by measuring the current given by a battery of four cells under the following conditions:

(1) Use bare copper wires as electrodes, pressing them firmly upon opposite sides of the *dry* hand. You will probably get no appreciable current.

(2) Replace the wires with copper plates. Perhaps you now get a slight deflection.

(3) Wet the hand and hold the plates very *lightly* in place. A much stronger current now flows as your G indicates.

(4) Finally press the plates *firmly* upon the wet hand and observe the marked increase in the current.

Exp. 46. Electrolyze a solution of common salt with carbon electrodes. Notice that you get the odor of free chlorine. Now use iron wire electrodes and observe that there is less chlorine evolved (perhaps none) but that the anode is corroded, giving a light colored solution of iron close to the electrode. In a little while the alkali liberated at the kathode will diffuse over and cause a precipitate of ferrous and ferric hydrates.

A Caution. *Iron salts are liable to cause a more or less permanent discoloration of the tissues in which they may be formed. In minor electro-surgical operations, then, such as the removal of hair, moles, warts, etc., the kathode rather than the anode should be employed.*

Exp. 47. Electrolyze a solution of sodium sulphate, using platinum electrodes and one Volta's cell. Put the G (u. c.) in circuit and have the electrodes in the fluid before closing the circuit. When all is ready keep your eye on the needle and close the circuit. Notice that the needle gives a start but quickly comes to rest again at the zero mark. Explain why.

Now use a bichromate cell in place of Volta's and notice that now the needle remains slightly deflected after making the first jump. Explain the cause of this difference in the two cases.

Exp. 48. Polarized electrodes constitute a little independent battery which will send a current in the opposite direction to the polarizing current if permitted to do so by the removal of the primary battery. Prove this as follows: Put in circuit with your G (u. c.) four bichromate cells and a pair of large, *clean* copper electrodes between which is a thick pad of paper wet with a *neutral* solution of sodium sulphate. Allow the current to flow for four or five minutes and then quickly cut out the battery and bring together the wires which were in contact with the battery poles. This throws the G into circuit with the electrodes only. Observe that the needle swings in the opposite direction and then slowly falls back to the zero mark as the polarization gradually disappears.

Exp. 49. Remove one or two hairs from the back of your hand by electrolysis, using a very fine sewing needle as the kathode. (B. R. 516.) A steel needle, if it be made the kathode as it should be, is just as good as the irido-platinum needle recommended by B. R.

Exp. 50. In very many cases of electrolysis it is necessary to confine the action to a limited portion only of the tissues traversed by the

needle, and especially is it desirable in many cases to avoid the formation of any caustic products within the skin itself at the point of puncture. Needles which are insulated along a portion of their length must then be employed. Such needles can be purchased of dealers in electrical goods, but every physician can easily insulate his own needles and thus not only save considerable expense, but have just the right kind and size of needle for the operation in hand.

Insulate a common darning needle as follows: Stick it into the end of a match or lead pencil and then dip it, eye downward, into a solution of shellac in alcohol (wood alcohol is cheaper and better than common alcohol for this purpose) made about as thick as glycerine. Immerse as far as you wish the insulation to extend—say to within a half inch of the point—and then dry out the alcohol above a lamp or gas burner. Towards the last heat it sufficiently to *fuse* the shellac which will spread over the needle and form a smooth, and almost glass-hard coating if the operation has been successfully done. It may be necessary to put on a second coating of shellac. It is *absolutely necessary to drive off all the alcohol* in order to obtain a coating so hard that it will not peal up when the needle is thrust through the skin. Great care must be taken not to *burn* the shellac.

It is a good plan and much easier to insulate a variety of needles at a time by hanging them above a stove for several days or weeks. This will usually give a smoother coating, but it requires a long time for the shellac to dry sufficiently.

21. Galvano-Cautery.—No other means of producing the actual cautery is comparable, in point of convenience and efficiency, with the electric current. In this application of electricity to therapeutics the current is employed solely as a means of heating a piece of metal and does not to any appreciable extent enter the tissues which are operated upon. Our study of the Galvano-cautery then must be limited to the investigation of those principles which relate to the development of heat by the electric current.

Considerable difficulties beset this application of electricity to medicine and "no one can expect to succeed with the galvano-cautery who is not to some degree a master of electro-physics."

The great fundamental facts upon which the construction of the galvano-cautery depends are the following:

1. Every conductor through which a current is flowing is heated thereby.

2. The *amount of heat* developed in such a conductor (other conditions remaining constant) is proportional to its resistance.

3. It is also proportional to the *square* of the strength of the current.

4. The *temperature* to which a conductor will be heated depends upon

(1) The amount of heat developed within it.

(2) The rate at which it loses that heat by radiation, conduction, etc.

Ordinarily conducting wires, galvanometers and other instruments do not carry sufficiently heavy currents for the warming effects, which always exists to a greater or less degree, to become noticeable, but even these may become sensibly heated and even permanently injured by exceptionally strong currents.

The following is a brief outline of the conditions which must be fulfilled in order to secure success with the electric cautery:—

1. A very strong current is required, varying from three to fifty amperes, according to the size of the piece of metal to be heated.

Since in all cases the resistance of the cautery itself is very low this condition is best fulfilled by using a battery of *very low resistance.* Conducting cords, connections, etc., must also be heavy so as to possess as little resistance as possible.

2. This current must be under very complete control, so that its strength can be instantly modified to suit the changing resistance of the cautery. This may be done in one of two ways:

(1) By raising or lowering the plates in the fluid. This changes the battery resistance and consequently the strength of the current.

(2) By including some form of rheostat in the circuit by which the resistance can be quickly and gradually increased or diminished, as the necessity of the case requires. This method is not so economical as (1) but it involves less danger of melting the cautery and give a more constant temperature.

3. Changes in the strength of the current by polarization must be avoided as far as possible by rocking the plates or by using so large a brttery that it is not taxed to its utmost in furnishing the required current. This latter method of using an excess of battery power, cutting the current down to the requirements of the case by means of a rheostat as mentioned in (2), is preferable to all other means of securing a constant current.

The importance of having a current which is not continually varying in strength is apparent when we remember that the heat produced in the cautery varies as the *square* of the current. Slight changes, then, in current involve large changes in the temperature of the cautery.

Instead of using a galvanic battery the Incandescent light current may be employed. A special piece of apparatus to reduce and regulate the current is necessary. A shunt similar to the one described on page 22 may be used; or, what is better, a direct resistance may be put in circuit with the cautery. Whichever method be used the apparatus must admit of rapid and gradual adjustment. It is not advisable for one who is not something of an expert to attempt the manufacture of such a piece of apparatus. It is probable that in the near future suitable current regulators for medical purposes will be furnished by instrument dealers.

[In gaining a thorough understanding of the principle of the cautery a careful reading of the following references and a faithful carrying out of the experiments will be of great assistance. T. 366, 367, 369—B. R. Chap. III, p. 673. Also pp. 78, 79, 80. —Ganot's Physics, 10th edition, pp. 734, 735, 736.]

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EXP. 51. To show the necessity of a strong current in producing the cautery connect the poles of two cells in m. a. by a fine copper wire about twelve inches long. Have your G. (l. c.) in circuit. Notice to what extent the wire is warmed. Now slowly shorten the wire and observe the increase in temperature as the current increases in strength. In this Exp. you are changing only the current strength by reducing the total r of the circuit. If shortened sufficiently the wire may become red hot and even melt.

Exp. 52. Connect the poles of two cells in m. a. by a foot of medium sized wire, having G. (l. c.) in circuit. Notice the temperature produced and the deflection. Now open circuit and file the wire *nearly* in two. Again close the circuit and observe the deflection. It will be nearly the same as before. Observe the temperature of the filed notch. Notice that it is much greater than that of the rest of the wire. This shows that the heat developed at any point increases with an increase in the resistance. This fact is often taken advantage of in searching for imperfect connections in a circuit. By placing one's hand on the various junctions the poor one can often be found by its feeling warmer than the rest.

Exp. 53. The fact that the battery must have a low resistance is shown by connecting the poles of four cells in series by fifteen inches of medium sized wire, including the G (l. c.) in the circuit. Notice how warm the wire is and also the deflection. Now put the cells in m. a. and again make these observations. The wire is (perhaps) too hot to hold, and the G also indicates a much greater current. Calculate C in both cases by Ohm's Law.

Exp. 54. Show the necessity of low resistance battery by using (1) the small (2) the large cell on side table to drive the current through a few inches of copper wire. Use the G in both cases and notice how much more effective the large cell is.

Exp. 55. Twist together three wires nine inches long and connect the poles of four cells in m. a. (G in circuit):

1st. With this twisted strand.

2nd. With a single wire of same size as one of the strands and only three inches long.

The resistance of the strand is just the same as that of the single wire and the current will be the same in both cases; but notice how much hotter the single wire becomes. Explain why.

This illustrates the necessity of concentrating the resistance of the cautery in as small a piece of metal as possible, so as to avoid the cooling effect of a large exposed surface of metal. For this reason platinum is better than gold for a cautery as it has about six times the resistance of gold. The fact that it is less fusible is also important.

Exp. 56. Close the poles of two cells in M. A. with a short piece of polished fine iron wire. Gradually shorten the wire until it becomes red hot. Then disconnect it and examine the surface. It has turned black in consequence of oxidation by the atmospheric oxygen. Brighten it again with sand paper and again connect the poles of the battery. Shorten the wire this time until it fuses, apparently boils, and finally

burns in two. Iron is sometimes used for the "cautery loop" as it is very much cheaper than platinum. It is, however, much more liable to burn off during the operation. But *even platinum* will behave in almost exactly the same way if subjected to too strong a current. Remember this if you do not wish to have a very awkward accident happen during an important operation. Platinum can be as easily melted by the electric current as can lead by the blast lamp.

Exp. 57. Make a small cautery like the model shown. Be careful not to melt it the first time you attach it to the battery.

Exp. 58. Connect this little cautery with a battery of one or two cells and notice the effect of battery polarization. The wire first glows intensely and then becomes a dull red—perhaps even shows no glow after being a few moments on the closed circuit.

Exp. 59. Try to heat the little cautery with the six cells gravity battery. This battery has at least three times the E of two bichromate cells in m. a., and yet it fails to heat the cautery. Explain why.

Exp. 60. Observe the effect of raising or lowering the battery plates in the liquid by attaching the little cautery to one or two cells. Let one student raise and lower the plates while the other holds the cautery. This is one of the methods used to regulate the current of a cautery battery.

Exp. 61. Use enough battery to cause the cautery to glow brightly and note the reading of the G included in the circuit. Now immerse *one-half* of the cautery (say the right hand half) in water or press that half against very wet paper. Notice the cooling effect on the right hand half—the increase in the current as shown by the G—and the increased glow of the left hand half of the cautery in consequence of this increase in the strength of the current. Explain it. A similar effect attends the use of the cautery loop in surgery and constitutes one of the serious difficulties in the practical application of the galvano-cautery, as in some cases the uncooled half may even be melted as soon as the operation has begun. These effects are less marked when an excess of battery power is used and the current cut down by means of a rheostat, as recommended in the text, than when the regulation of the current is effected entirely by the raising and lowering of the plates. Why should it be so?

22. Magnetic Effects of the Current.—As many electrical instruments depend upon the power of the current to induce magnetism in soft iron a very brief outline of electromagnetism will here be given. The following are the most important laws:

1. A piece of untempered iron, surrounded by a helix of wire, becomes a magnet while a current is flowing through the helix.

2. The strength of this electro-magnet is proportioned to the number of turns in the helix and to the strength of the current. This law only hold while the magnet is still *unsaturated.*

3. Upon interrupting the current the induced magnetism instantly disappears. All ordinary iron, however, retains a slight trace of permanent magnetism which often causes the armature or vibrating hammer of automatic interruptors to "stick" even after the current has been stopped. This sticking may be prevented by pasting a little piece of paper upon the end of the magnet so as to prevent contact between magnet and armature.

4. If the iron be removed from the helix the latter will still act, when the current is flowing, like an electro-magnet, but its magnetism will be many times less than when the iron core is present. [T. 326 to 330—B. R. 52, 53.—Upon the use of electro-magnets in removing pieces of iron from the eye, etc., see B. R. 736.]

EXPERIMENTS.

EXP. 62. Cover a piece of soft iron rod about 4 inches long with paper. Then wind upon it a single layer of copper wire, not allowing the coils to touch each other. Using a few nails as an indicator, convince yourself of the following facts:

1. The magnetism appears *instantly* upon the closing of the circuit.
2. It disappears *instantly* upon the interruption of the current.
3. A slight trace of magnetism, called the "residual magnetism," remains. You may have to balance a nail on a knife edge or suspend it by a thread in order to prove this fact.

EXP. 63. The induced magnetism is proportional to the number of turns of wire in the helix. Prove by placing the iron in an east and west direction upon the table and far enough away from the G to cause a deflection of 45° when the current is flowing round the helix. The G, of course, is not to be in circuit. Now shift the wire from the battery along the coils of the helix and notice the gradual diminution of magnetism as the number of coils in circuit is lessened.

Exp. 64. With the G and the electro-magnet in the same relative position as in Exp. 63, change the strength of the current by using 1, 2 and 3 cells in m. a. or by inserting a resistance coil in the circuit. Notice the change in magnetism due to changes in current. Also observe the fact that *strong* currents are needed to produce strong electromagnets. If a strong current is not used the helix must be made of a *very large number* of turns of fine wire, i. e., we must compensate for the weakness of the current by greatly increasing the number of turns in the helix.

Exp. 65. With the same relative arrangement of G and magnet as in Exp. 63, prove the magnetic character of a helix by carefully withdrawing the core of iron from the coil. Observe how much weaker the magnetism has become by the removal of the iron. You may even have to bring the helix a little nearer the needle in order to get any evidence of its magnetic properties.

23. The Induction Coil.—It lies beyond the purpose of this book to describe fully the construction and theory of the induction coil nor is such description necessary as quite full accounts of the instrument will be found in the works mentioned in the following references. Moreover an actual inspection of the coils in the laboratory will give a far better idea of their construction than can any written description. [T. 398, 404.—B. R., especially recommended, 54 to 60; 292 to 304.—Jenkin's "Electricity and Magnetism," p. 289.—Larden's "Electricity," p. 268.]

A short account of the various currents furnished by the coil will here be given.

There are three quite distinct classes of induction coils.

Class I.—This is the coil usually described in text books upon electricity and is intended for scientific researches requiring the exceedingly high electro-motive force which is furnished by static electric machines. The celebrated English coil, made by Apps of London, which gives a spark forty-two inches in length is the most striking example of this class.

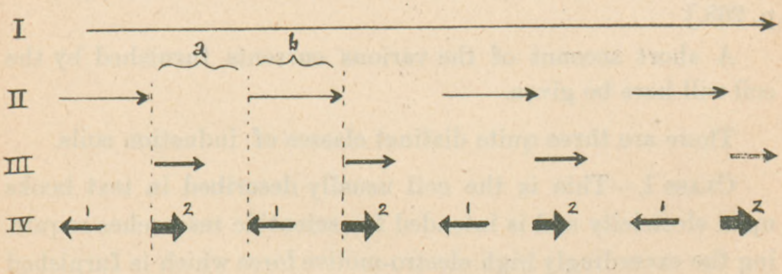
Class II.—To this class belong the coils employed in Physiological research. They give almost no spark but admit of a wide range of adjustments for modifying the strength and character of the current.

Class III.—This class is represented by the common Medical Induction Coil. The current is practically the same as that of Class II, but does not, as a rule, admit of so gradual and wide a change in strength and character. The instrument is, however, much more portable, being mounted in a neat case containing battery, electrodes, conducting cords, etc., and it is to this class especially that the following remarks apply.

The Induction Coil gives two different currents known respectively as the Primary (also called Extra) Current and the Secondary current. These two currents are sometimes combined, giving what might be called a third current which, however, does not differ sufficiently from the Secondary to entitle it to a separate consideration.

Besides the Primary and Secondary currents there is of course the current from the one or two galvanic cells which are used to operate the coil. This battery current is not administered to the patient but serves only to generate the other two.

The character of these three currents, namely, the Battery current, the Primary, the Secondary, may be graphically represented by the following diagram:



I is the graphical representation of a perfectly continuous galvanic current such as is used in electrolysis.

II represents the current from the battery which operates the coil. It is an interrupted current and all of the momentary currents are flowing in the same direction round the primary

coil of the instrument. "b" shows the state of things during the fraction of a second in which the primary circuit is closed by the contact of the vibrating hammer and the adjusting screw of the interrupter. "a" represents the state of affairs during the fraction of a second in which the current from the battery is interrupted.

III shows the character of the "Primary" or "Extra current." This current is generated in the primary wire just at the instant of cutting off the battery current. It is this current which causes the spark between the hammer and adjusting screw of the interrupter. It is always produced when an electro-magnet loses its magnetism upon the interruption of the magnetizing current. Electric bells, dental mallets, in fact every piece of apparatus in which an eléctro-magnet is rapidly made and unmade gives this extra current as a matter of necessity and in case of emergency an electric bell might be employed as an induction coil by one who thoroughly understands the principles of the instrument. In most pieces of apparatus this extra-current is an evil since it tends to burn out the platinum contact points of the automatic make and break, but in the Medical Induction Coil it is turned to account and constitutes the weakest current which the instrument will give. Notice that it is an interrupted current in which all the little impulses are *flowing in the same direction.* It has a higher electromotive force that has the battery which works the coil *but it does not represent any more electrical energy* nor, indeed, as much since something is always lost in *electrical friction.* What is gained in *electromotive force* is lost in *time.* The induction coil does not create energy, it simply transforms a certain amount of electricity of low electromotive force into an equivalent amount of electricity of high electromotive force, and what is gained in E is always lost in time. The total time during which the extra current is *actually flowing*, is probably twenty-five or fifty times less than the apparent time, i. e. a half hours' or an hours' use of the extra current represents only about one minute of *continuous* current. Hence it is, among other reasons, that the extra current (more commonly called primary current) is not suitable for surgical electrolysis, although it *will* to a slight extent discompose fluids and produce the other effects of the galvanic current.

IV is intended to show the character of the secondary current. It is an interrupted, *alternating* current. The width of the arrows in the diagram is intended to represent the electromotive force, and their length the duration of the successive impulses which go to make up the current.

An inspection of the figure shows that the secondary current is composed of two sets of impulses which are flowing in opposite directions. These two sets differ in electromotive force, those which are produced at the *break* of the battery current having a higher E than those produced at the *make*. The latter, however, have a slightly longer duration, so that the *total amount of energy* represented by the two sets is practically the same. It follows, then, that this current will not electrolyze fluids, magnetise iron nor deflect the galvanometer needle, since the effect of one little impulse is immediately counteracted by the next one flowing in the opposite direction.

On account of the alternating character of the secondary current, it has, properly speaking, no such thing as a positive or negative pole. If one set of the little impulses could be suppressed (say, for example, the ones marked 1), then there would be a true polarity of the secondary current. In the large coils of Class I such a suppression actually occurs, but in the coils of Classes II and III this is not the case except in a *very slight degree*. In consequence of this very slight suppression, and because one set of impulses has a higher E than the other, most medical coils possess a slight differential action at the two poles of the secondary. This can be observed by taking the electrodes in the hands, when in most cases one wrist will experience a rather stronger sensation than the other. The stronger sensation is produced by the negative pole of that set of impulses which has the higher electromotive force.

The characteristics of the two currents of the induction coil may be summarized as follows:

1. Both currents are intermittent but only the S is alternating.

2. The P has a true polarity and will produce in general the effects of the continuous current but in a much less degree; while the secondary has only a pseudo-polarity and will not produce the effects of a continuous current.

3. The electromotive force of the S is much greater than that of the P which itself has many times the force of the battery used in working the coil.

4. The actual amount of energy of the P and S is rather less than that of the battery cell which works the coil so that the *physical* effects of these currents is less than those produced by one galvanic cell.

5. The *physiological* effects, however, are vastly greater than those produced by a single galvanic cell, since in this case the current is employed to call into action the forces of the animal organism and does not itself supply the energy which is actually called forth.

EXPERIMENTS.

Exp. 66. Examine the model induction coil. This model is intended to show only the primary circuit and the automatic interrupter. It has no draw tube and no secondary coil and consequently gives only the primary (or extra) current. Trace the path of the battery current and also that of the primary. Study the construction and theory of the interrupter. Finally take the primary current through your arms, using only one cell to operate the coil.

Exp. 67. Examine the electric bell and notice the general similarity of its construction to that of the interrupter of the coil. Notice the spark produced by the extra current. Study out how you can attach the electrodes to the bell so as to take this extra current through your arms. Use only one cell to work it.

Exp. 68. Using the model coil prove that the primary current is felt only at the *break* of the battery current by carefully working the hammer back and forth by hand.

Exp. 69. The draw tube weakens the induced currents by itself absorbing the inductive influence. A current is induced around the tube instead of in the coils of wire. A tube split along its length will not reduce the strength of the induced currents. Prove this by slipping over the model coil first a complete tube and then a split tube. Notice that it is not necessary to have the draw tube *next to the core*. Even when placed *outside* of the primary wire it will reduce the strength of the primary current. In general, any continuous metallic conductor surrounding an induction coil, whether such conductor be next to the core or outside of both the coils, will reduce the strength of both the induced currents. Ignorance or disregard of this fact upon the part of some manufacturers renders several instruments in the market less powerful than they would otherwise be. In some coils the draw tube is very large and incloses both the primary and secondary wires as well as the core.

EXP. 70. Examine a regular medical coil and take the various currents which it gives. Prove that the secondary current is induced at both the make and break contacts by working the interrupter by hand. Notice how much the stronger the *break* impulse is. Observe, furthermore, the difference in the two poles of the secondary—the negative giving the most painful sensation. By changing the electrodes from one hand to the other this will be brought out more plainly.

EXP. 71. Prove that the secondary will not deflect the G (be careful that the coil is not so near the G as to exert a magnetic influence upon the needle) by sending it through the upper coil of the instrument.

EXP. 72. The secondary will not decompose electrolytes. Try it with a solution of copper sulphate, using the platinum electrodes.

EXP. 73. Using the large dissected coil, study the effect of slowly removing the secondary wire. Observe the gradual diminution of the current—which nevertheless is still appreciable after the coil has been entirely drawn off from the primary. This method of modifying the induced current is much used in instruments intended for physiological research.

24. Magneto-Electric Machines.—The essential thing in an induction coil is the rapid making and unmaking of an electro-magnet within a coil of wire. Any mechanical or electrical arrangement in which this is done will furnish an induced current in all respects similar to the secondary current of the regular medical induction coil. A magneto-electric machine is an instrument in which the core of soft iron is alternately magnetized and de-magnetized by the approach and recession of a powerful permanent steel magnet. In the usual form

in which this instrument is made there are *two* cores with their surrounding coils, instead of only one as in the induction coil, and these coils rather than the permanent magnet are movable. The principle, however, is the same—the cores are alternately rapidly magnetized and de-magnetized, thereby inducing a current in the surrounding wires. This induced current is an interrupted, alternating current but the successive impulses do not begin and end as *suddenly* as they do in the induction coil. Now the stimulating effect of the current depends upon the suddenness with which these impulses begin and cease and accordingly all magneto-electric machines are provided with commutators or with some other mechanical device for interrupting or short-circuiting the induced current at least once in every revolution of the coils. This gives the necessary suddenness to the make and break of the little component impulses and renders the current powerfully stimulating when the machine is driven rapidly. The commutator of some of these machines is sometimes so constructed as to turn all the little impulses (which are actually alternating in direction in the coils) *into the same general direction in the outside circuit.* This renders the current quite similar to (but not so smooth as) the simple galvanic current. The large magneto machine upon the side table is one of this kind and will decompose water and produce the other effects of the continuous current.

Magneto-electric machines require no battery with its ever-liable-to-be-spilled-fluid and in this respect is superior to an induction coil. In all other particulars however they are much inferior to the coil. They do not give as steady a current nor can the current be as gradually tempered in strength from the weakest up to the strongest which the instrument will furnish. Moreover an assistant must always be at hand to turn the machine while the operator himself attends to the electrodes. The machine, too, is more liable than the induction coil to get out of order—in consequence probably of the necessity of a *friction contact* between the revolving coils and the outside circuit.

EXPERIMENTS.

Exp. 74. Examine the two magneto-machines and trace the circuit traversed by the induced current. Be sure that you understand the manner in which the commutator of the large machine turns all the little alternating impulses into one common direction *in the outside circuit*. Notice, too, the method of interrupting the current in the two machines so as to render it stimulating.

Exp. 75. Adjust the larger instrument so that the current is not interrupted and then take the current through your arms. You scarcely feel it. Now put on the interrupter and notice that the current is too painful to be taken if the machine be turned rapidly *although the quantity of electricity is very much less in this case than when the interrupter was not used.*

Exp. 76. The large machine will decompose water, copper sulphate etc. Try it. This machine *might* accordingly be used in surgical electrolysis, although it would not be nearly as effective as a battery of a dozen two-ounce bichromate cells.

Exp. 77. The small machine gives an alternating current and will not decompose electrolytes. Try it. Notice how the current is modified by means of the movable armature. No special provision is made in the large machine for modifying the strength of the current.

In all magneto-electric machines the strength of the current increases with the speed.

25. Electrical Testing.—Any defect in electrical apparatus which prevents its working properly is known, in technical language, as a "fault." Some knowledge of the nature of the faults most liable to occur and of the methods by which their presence and location can be determined is absolutely indispensable to one who expects to make a practical use of electricity. A few suggestions upon the subject of electrical testing will accordingly be given.

Whenever a piece of electrical apparatus fails to work satisfactorily, some one of the following faults is probably the cause. In testing for some of these faults it is necessary to use an independent battery and galvanometer which are known to be in good working order. One cell of any reliable battery is sufficient. Connect one of its poles with one of the binding screws of the G, and to the other pole of the battery and

binding screw of the G attach two rather small flexible wires To the free ends of these wires fasten securely (by soldering or by carefully twisting the cleaned wires about the eye ends) two medium sized needles. These needles will be called "exploring needles" in the following directions. When they are made to touch any two pieces of metal which are in electrical connection with each other, a deflection of the G will evidently occur. Needles are better than the free ends of the wire because they enable us to make assured contact with the wire of silk and cotton covered conductors and with those metallic parts of an instrument which are covered with lacquer or varnish without injuring or removing these insulating materials.

1. *Imperfect Carbon Connection.*—This is a very common cause of an insufficient current when using a Bunsen battery, and is readily corrected by rubbing together the carbon and its connector so as to secure clean surfaces of contact. Wetting the carbon slightly often improves the contact.

In bichromate cells the carbons are usually fastened permanently to a metal mounting which in time may become corroded by the creeping up of the acid. In a well made battery this is prevented by thoroughly soaking the upper end of the carbon in *hot* paraffin and by carefully covering the whole joint with some acid-proof varnish or wax.

To test a carbon connection place both the exploring needles firmly upon the carbon and note the G reading. Then press one of the needles on the metal to which the carbon is fastened. The deflection should be as great or even greater than before.

2. *Exhausted Fluids.*—In Bunsen's battery the nitric acid is more likely to be at fault, and may be tested with a little piece of zinc. Strong acid will attack zinc almost instantly with very copious evolution of red fumes. Bichromate fluid is good as long as it retains a trace of red or brown color. That which has become entirely *green* is exhausted and works no better than dilute sulphuric acid.

The fluid of sal-ammoniac batteries is best tested by replacing it with fresh fluid.

Dilute sulphuric acid may be tested with a piece of zinc. Strong effervescence should take place after two minutes' immersion.

3. *Poor Porous Cup.*—A porous jar may cause high battery resistance if it is not sufficiently porous. A good jar filled with water should lose at least one-sixth of it in 24 hours by leakage. Another test is to replace a suspected jar with one which is known to be right.

4. *Imperfect Contact at Binding Screws, Line Connectors, or between wires carelessly twisted together.*—A fault of this kind is generally quickly dectected and corrected by tightening all the binding screws and connectors in the circuit. Before wires are twisted together they should be rubbed bright with a piece of sand or emery paper. *Simply laying one wire upon another should never be depended upon as a means of contact.* To make the connection sure the wires *must* be freshly scraped and *firmly twisted together.* The use of line connectors is far preferable to the twisting together of wires.

5. *A Complete Interruption of the Circuit in consequence of a break in the wire or soldered connections.*—A fault of this character is best detected by testing the whole circuit, section by section, with the exploring needles. This can be very quickly done with an exploring battery arranged as described above.

6. *Binding Posts sometimes become insulated from the underneath wires.*—This is frequently caused by the binding post turning a little in its hole and thereby breaking the wire or pushing it out of position. Test by putting one exploring needle against the post and the other against the wire underneath.

7. *Broken Strands of Wire in the silk-covered cords attached to electrodes* are often an unsuspected cause of trouble. In a fault of this kind the current is frequently intermittent, sometimes flowing normally and then suddenly ceasing without any apparent cause. Such breakage is especially apt to occur close up to the little metal tips, which are attached to the cords, in consequence of the frequent bending of the cord at these points.

A loose attachment of the cords to the tips may also result in a break in the circuit. Test by placing the needles in contact with the tips or with the middle of the suspected cord and each tip in turn.

8. *A Cross-connection or Short Circuit.*—This may happen in Grenet cells in consequence of the zincs swinging around into contact with the carbon plates. A Gravity or Daniell's cell may become short circuited by a deposited thread of copper running from one plate to the other.

A partial short circuit may occur in those batteries in which the plates are fastened permanently to a cap or cover on top of the jar in consequence of the cap becoming covered or soaked with battery fluid or water.

Test by taking the plates out of the fluid and touching the exploring needles to the two plates of the suspected cell; a deflection of the G indicates an imperfect insulation of the positive and negative plates.

This difficulty is corrected by thoroughly drying the parts and soaking them in hot paraffin.

9. *Corroded (oxidized) Platinum Points.*—This is the most common cause of the stopping of an induction coil, electric bell, mallet, etc., etc., and is both detected and corrected by rubbing the points *very slightly* with a *fine file.* Fine sand or emery paper will also do, but a thin fine file is better, in that it does not leave a fine grit imbedded in the metal to be subsequently fused, by the extra current spark, into a thin insulating coating of glass.

10. *Corroded Surfaces in Switches and Commutatators: or between sliding contacts of any kind.*—Some forms of the Grenet cell depend upon the friction contact of a brass rod with its surrounding sleeve for a zinc connection. Such a contact is very uncertain. In general the larger the surfaces in contact the less certain is the connection. Test all such suspected connections by putting the exploring needles upon the two pieces of metal which are supposed to be in electrical contact. If no current flows the contact is not complete and the

metals must be cleaned with a little fine sand or emery paper. This is a very common fault and must be carefully watched for.

11. Bichromate Batteries sometimes refuse to give a good current for several minutes after the plates have been lowered, in consequence of a deposit of crystals upon the surface of the plates. Hot water will remove such a deposit immediately. Such a deposit indicates too strong a battery fluid. Add more water or rinse off the plates after using the battery.

Sal-ammoniac Cells sometimes fail from a similar deposit upon the zinc rods. The zinc rods of these cells are frequently eaten off just at the surface of the fluid. A coat of paraffin at this point will prevent this difficulty.

12. A frequent cause of failure in using electrical apparatus arises from the attempt to employ *an insufficient battery power* for the particular instrument or work in hand. This is not strictly a fault, and can be discovered only by making certain that there is no other cause present capable of accounting for the failure. Failure from this cause is most liable to happen with the galvano-cautery and electric motors of various kinds.

EXPERIMENTS.

EXP. 78. Convince yourself of the unreliability of the contact obtained by simply laying two wires across each other, by watching the needle of your G when such a contact is made. Notice that the needle is almost constantly on the move, sometimes dropping back to zero and then suddenly starting up and perhaps revolving several times around as the contact is alternately made and broken.

EXPS. 79 to 91. In order to give some practice in electrical testing a series of defective batteries and other instruments has been prepared. Each student is expected to take one of them to his desk and make a *systematic* examination in order to find out the exact character and location of the fault. Keep a record of the number of the apparatus and of the nature of the fault, but *do not correct the defect.* After completing the examination, return the apparatus to the side table in the same condition in which you found it. Examine as many as you have time for during the afternoon. Fit up your exploring battery the first thing according to the directions in the text. Your Volta's cell will serve admirably for this purpose.

26. Problems.

—In order to fix some of the fundamental principles and facts more firmly in the memory and to give facility in applying them to particular cases, a few general problems will here be given.

As these problems are given out from day to day by the instructor, numerical values will be assigned to the letters used in the text.

PROBLEMS.

PROB. 1. A certain battery consists of s cells coupled in series. Each cell has an E of t volts and a R of u ohms. The external resistance is v ohms. What is the strength of the current in amperes?

PROB. 2. A battery of s cells in m. a. sends its current through an external resistance of t ohms. Each cell has an E of u volts and a R of v ohms.

(1) What is the R of the battery?
(2) What is its E?
(3) What is the strength of the current?

PROB. 3. A certain battery is coupled s in series and t in m. a. Each cell has a R of u ohms and an E of v volts. The external circuit has a resistance of w ohms.

(1) How many cells does the battery contain?
(2) What is the E of the battery?
(3) What is its R?
(4) What is the current in amperes?
(5) What is the current flowing through *each cell?*

PROB. 4. A battery of s cells in series and t cells in m. a. sends its entire current through an electrolytic cell containing acidulated water. The resistance of the electrolyte and conducting wires is u ohms. The inverse E due to polarization is $1\frac{5}{10}$ volts. The E and R of each battery cell is v volts and w ohms respectively.

(1) What is the C, in milliamperes, which flows through the electrolyte?
(2) What is the C in each battery cell?
(3) How many grains of water will be decomposed in one hour?

PROB. 5. Each cell of a certain battery, coupled in series, has an E of s volts and a R of t ohms. The external resistance is a piece of iron wire u feet long and v inch in diameter. The current is w milliamperes. How many cells are there in the battery?

PROB. 6. A battery of s gravity cells is coupled t in series and u in m. a. The E of each cell is two volts and its R is one ohm.

The current passes from the battery through v feet of brass wire having a diameter of w inch. Then through an electrolyte of copper sulphate having an inverse E of $\frac{5}{10}$ volt and a resistance of x ohms. The current then returns to the battery upon a platinum wire y inches long and z inch diameter.

(1) What C flows through the copper sulphate?

(2) How long will it take to deposit a troy ounce of pure copper?

(3) How many ounces of copper will be deposited upon the copper plates of the battery during the deposition of one ounce of copper in the electrolytic cell.

(4) How can the inverse E of $\frac{5}{10}$ volt in the copper sulphate cell be avoided, without taking the electrolytic cell out of the circuit?

(5) How much zinc and how much copper sulphate (crystallized) would be consumed in the battery during the deposition of one pound of pure copper in the electrolytic cell.

PROB. 7. A battery of s cells in series sends its current through a telegraph line of iron wire having a diameter of t inch. A non-polarizable voltameter, having a resistance of u ohms, when placed in the circuit, deposits v grains of copper in one hour. Each battery cell has an E of w volts and a R of x ohms. From these data find

(1) The strength of the current.

(2) The length of the telegraph wire.

PROB. 8. A battery of s cells in m. a. has its poles connected by three wires of the following material and dimensions:

1st. t yards of copper wire u inch in diameter.

2nd. v feet of German silver wire w inch in diameter.

3rd. x inches of platinum wire y inch in diameter.

These wires are laid *in parallel*, *i. e.*, they form a divided circuit of three branches. The E and R of each battery cell is $1\frac{5}{10}$ volts and $\frac{5}{10}$ ohm respectively.

(1) What is the total current?

(2) What is the current in each of the above wires?

PROB. 9. One Leclanche cell, having an E of $1\frac{4}{10}$ volts and an R of $\frac{3}{10}$ ohm, is just strong enough to work a call bell of s ohms resistance when connected to the bell by wires of no appreciable resistance. I wish to put the bell in a stable situated one mile from my office. The wire running to the stable is made of iron and is t inch in diameter. The return circuit is the earth and has no appreciable resistance.

(1) How many Leclanche cells must I use to work the bell?

(2) What size copper wire, put up in place of the iron wire, will enable me to work the bell with two Leclanche cells?

(3) What size iron wire, stretched beside the first one and used in parallel with it will enable me to work the bell with two Leclanche cells?

(4) How many gravity cells, each having a R of two ohms and an E of one volt would work the bell over the line wire already up?

PROB. 10. A battery of twenty gravity cells, each cell having an E of one volt and a R of two ohms, is coupled ten in series and two in m. a. The current passes from the battery through a galvanometer of five ohms resistance and then divides and passes through a divided circuit, one branch of which consists of x feet of iron wire having a diameter of $\frac{1}{50}$ of an inch. The other branch contains an electrolytic cell, filled with a solution of copper sulphate, having a resistance of five ohms and electrodes which are non-polarizable. Upon closing the circuit the galvanometer indicates a current of .5333 + ampere, and a pennyweight of pure copper is deposited in the electrolytic cell in three hours and twenty minutes. What is the length of the iron wire which forms one branch of the circuit?

QUESTIONS.

1. What materials are consumed in Volta's battery?
2. What chemical products are formed in Volta's cell?
3. What connection is there between the amount of zinc consumed in a battery and the strength of the current?
4. What is the strength of battery sulphuric acid?
5. What is the cause of inconstancy in the currents of some batteries?
6. What is the "local action" of a battery and what harm does it do? How is local action prevented?
7. Why are the zincs of some batteries amalgamated and those of others not?
8. How can a zinc be amalgamated without using metallic mercury?
9. What is "polarization" of the battery?
10. How is it prevented in Bunsen's cell? In the gravity cell? In the Bichromate of Potash cell?
11. Which of the batteries mentioned in the text is least apt to polarize?
12. Give the formula for making Bichromate fluid.
13. For what purpose is the Leclanche battery especially fitted, and why?
14. What fluid is used in the Leclanche cell?
15. What materials are consumed and products formed in the Daniell's cell? In Bunsen's cell?
16. Why is Bichromate fliud which has become green no longer good?
17. What is the purpose of the porous jars used in some batteries?
18. What is soldering fluid?

19. What soldering fluid is used is soldering iron to brass?

20. Why ought every trace of soldering fluid to be washed off after soldering?

21. Why is a gravity battery unsuitable for the galvano-cautery? Why is the Leclanche also unsuitable?

22. What do you understand by the term "electromotive force?"

23. Give the E of the following cells: Bunsen's, Volta's, Leclanche's, Gravity, Bichromate of Potash.

24. Why should not the clamps and connections be left fastened to Bunsen carbons?

25. What causes the cracking of porous cups, and how may such cracking be avoided?

26. Will it do to add a mercury salt to *every* form of battery for the purpose of keeping the zinc well amalgamated? What battery is an exception?

27. Mention three important precautions to be observed in using a galvanometer.

28. What is the approximate resistance of a medium sized Bunsen cell? Bichromate cell? Gravity cell?

29. How does a large cell differ from a small one in its electrical properties?

30. Does the depth of fluid in a cell in any way affect its power?

31. Some cells have two carbon plates instead of one. Why is this an advantage?

32. Some large sized cells contain several carbons and several zincs. Does such a cell have any more E than a common cell? For what purpose are such cells employed and why are so many plates used?

33. Are there any conceivable conditions under which a cell no larger than a thimble would give as good a current as a cell as large as a barrel? What are those conditions?

34. When are large cells much to be preferred to small ones and when are they no better than small ones?

35. What are the three general ways in which battery cells may be coupled together?

36. Under what circumstances would a battery of 1,000 cells in series give no greater a current than one cell?

37. Under what circumstances would 1,000 cells in m. a. give no greater a current than one cell?

38. Which is the best method of coupling cells?

39. How does coupling in series affect electromotive power? How the resistance of the battery?

40. How are electromotive force and resistance affected by coupling in m. a.?

41. How would you couple a battery of eight cells to treat a case of facial neuralgia?

42. When would you couple a battery in m. a. instead of in series?

43. What general rule have we for coupling a battery so as to obtain the maximum current which it will give?

44. Under what circumstances does a Bichromate cell show a good deal of polarization?

45. How may this polarization be lessened?

46. Upon what conditions does the strength of a current depend?

47. When does the battery resistance play an important part in determining the strength of the current and when does it not?

48. Give Ohm's Law in its three most important forms.

49. What is a calibrated galvanometer?

50. What connection is there between the strength of the current and the deflection of the needle in a tangent galvanometer?

51. What is a milliampere? A milliamperemeter ?

52. What would be called a "moderate current" as currents go in the therapeutical uses of electricity?

53. What is the approximate resistance of the human body from hand to hand?

54. What is the approximate resistance between the needles in an ordinary case of surgical electrolysis?

55. What is a divided circuit?

56. According to what law does a current divide itself in passing over a divided circuit?

57. What is the relation between resistance and conductivity?

58. What is the equivalent resistance of a multiple conductor consisting of four strands of wire having respectively the resistance 1, 3, 5 and 20 ohms.

59. If a total current of 100 milliamperes were flowing though this multiple conductor what would be the number of milliamperes flowing in each of the four strands.

60. What is a shunt?

61. How may the Incandescent Light current be adapted to a physician's work?

62. A certain galvanometer has a resistance of 15 ohms. What resistance must a shunt have in order that only $\frac{1}{10}$ of the entire current shall go through the galvanometer when the latter is used in electrical measurements.

63. Why cannot a current be confined to a muscle or nerve in using electricity therapeutically?

64. Are all liquids electrolytes?

65. Does *pure* water conduct electricity?

66. What is an Anode? A Kathode?

67. What are the ions in the electrolysis of acidulated water?

68. At which electrode does oxygen appear?

69. What is the relation between the amount of electrolysis and the strength of the current?

70. How much water will a current of 10 milliamperes decompose in an hour?

71. How strong a current would be required to deposit one ounce of electrolytic copper, from copper sulphate, in ten hours?

72. At which electrode are the metals liberated?

73. What are "secondary products" in electrolysis?

74. What are the primary products in the electrolysis of common salt solution?

75. What secondary products occur in the electrolysis of salt solution?

76. Explain why electrodes are corroded.

77. Which electrode is corroded most? Does either electrode escape corrosion entirely?

78. Is the resistance of an electrolytic cell affected by the size of the electrodes or by the distance between them?

79. What is "polarization of the electrodes"?

80. What is the value of electrode polarization in surgical electrolysis?

81. What is the principle upon which electrodes are made non-polarizable?

82. In surgical electrolysis have large battery cells any marked advantage over small ones?

83. How should a battery be coupled for surgical electrolysis.

84. At which electrode are acid products formed?

85. Why is the kathode preferable to the anode in the extirpation of hairs by electrolysis?

86. Why should sponge or cloth covered electrodes be employed when using the galvanic current upon a patient?

87. Why should electrodes be wet in salt solution?

88. Which pole of a galvanic battery causes the sharpest sensation or the most pain?

89. With what material are electrolytic needles insulated and how is it put on so as not to peel off when the needles are used?

90. Have platinum or gilded needles any great advantage over plain steel needles?

91. What would be the effect of bringing the two needles used in a case of surgical electrolysis into contact within the tissues?

92. How does the resistance of a wire vary with variations in its diameter?

93. A certain bell circuit has a resistance of 25 ohms. The wire has a diameter of $\frac{1}{40}$ of an inch. What diameter of wire must be used to reduce the resistance to one ohm.

94. In which of the following cases should quite heavy circuit wires be used and in which will quite small ones do as well as large:

1st. Electric door bell of low resistance.
2d. Surgical electrolysis.
3d. Galvano-cautery.
4th. Telegraph "Sounder" of very high resistance.
5th. Electric Dental Mallet.
6th. Electric fuse in blasting operations.
7th. Electro-magnet with coils of large size wire.
8th. "General Galvanization" of a patient with a battery of 10 cells.

95. Give some approximate estimate of the strength of current required to heat a cautery.

96. Why must a low resistance battery be used with the galvano-cautery?

97. What are some of the important conditions to be fulfilled in making a galvano-cautery?

98. What is the connection between the heat developed in a conductor and its resistance? What between the heat and the strength of the current?

99. Why is platinum used in the cautery rather than iron?

100. Mention two kinds of battery which are *not* suitable for heating the cautery, and in each case tell why the battery is not suitable.

101. How does the strength of an electro-magnet vary with changes in the strength of the current?

102. How with changes in the number of coils of wire surrounding the magnet?

103. How many currents does the induction coil furnish and what are they called?

104. What is the character of the primary current? What is the difference between primary current and extra current?

105. Has the primary current a positive and negative polarity?

106. Will the secondary current decompose water or produce surgical electrolysis?

107. Is there a difference in the poles of the secondary current?

108. How does the quantity of electricity furnished by the induction coil compare with the quantity of the battery current?

109. In respect to what quality is the induced current of the coil stronger than the battery current?

110. What causes the spark at the end of the adjusting screw?

111. Why does the draw tube modify the strength of the current?

112. Why do the cores of some induction coils consist of a bundle of iron wires instead of a solid iron rod?

113. If the secondary coil is entirely insulated from the rest of the instrument explain how the electricity gets into it.

114. Explain how the interrupter of the coil works.

115. Why is the secondary coil made of a much finer wire than the primary coil?

116. Why is the tip of the adjusting screw made of platinum? What is the little piece of metal upon the spring opposite the screw?

117. What is the character of the current given by a common medical magneto-electric machine?

118. Why is an induction coil better than an magneto-electric machine?

119. How is the current of the machine regulated?

120. A Bunsen battery fails to give its due current. Mention two or three possible reasons for the failure.

121. How can the corrosion of the metal fittings, to which the carbon is fastened in bichromate cells, be prevented?

122. A call bell circuit suddenly ceases to work. Mention some of the more *probable* reasons why it has ceased.

123. An induction coil with which you are working suddenly stops. What is the probable cause and how is it removed?

124. Draw a diagram of the working parts of a call bell, showing the path of the current. Explain why the hammer keeps vibrating automatically.

125. Upon attaching a cautery to its battery you fail to get more than a very dull red temperature. How would you attempt to remedy matters?