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DEPARTMENT OF

GENERAL CHEMISTRY.

ELECTRO THERAPEUTICS

A SYNOPSIS OF

Lectures and Laboratory Work

IN

APPLIED ELECTRO THERAPEUTICS,

BY

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PREFACE.

This little Manual of Applied Electro-Therapeutics is intended primarily as a laboratory guide for Students of the University of Michigan. No appliances, used by the physician, are more liable to get out of order than electrical apparatus; and no physician can hope to successfully administer electricity without a thorough knowledge of those principles of physics which control the practical generation and application of electricity.

For a large part of the text and experiments in the following pages I am indebted to Mr. Chas. R. McGee, Instructor in Electro-Therapeutics.

JOHN W. LANGLEY.

Lectures and Laboratory Work

IN

APPLIED ELECTRO THERAPEUTICS.

Section I. Batteries.

If two different metals, connected by a wire, be immersed in a solution of a salt or an acid which is capable of corroding either of them, a current of electricity will flow through the wire from the least corrodible to the most corrodible metal. Such an arrangement is called a galvanic battery. The least corrodible metal is called the positive (+) plate, and the wire attached to it the positive pole of the battery. Similarily the most corrodible metal is called the negative (—) plate, and its wire the negative pole of the battery.

If the metals are immersed in only one salt or acid the battery is called a *simple* battery; if simultaneously immersed in two or more salts or acids, the battery is said to be compound. In compound batteries the two fluids are usually separated by some mechanical means, e. g. a porous earthenware cup, or shavings, the + plate being immersed in one and the — plate in the other.

Of the many hundred forms of batteries which have been invented the following are the most important to the physician.

Typical Simple Batteries.

1. VOLTA'S BATTERY consists of a piece of copper and a piece of zinc immersed in dilute sulphuric acid. Dilute sulphuric acid consists of one part (by volume) of com-

mercial H_2SO_4 and fifteen to twenty parts of water. The chemical reaction in this battery is as follows:

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

This H_2 attaches itself to the copper (+) plate of the battery and interferes with its action. The defect is spoken of as the *polarization* of the battery.

2. FROMMHOLD BATTERY. The polarization is partially obviated in the Frommhold by substituting for the copper plate a plate of lead which has been covered with a thin film of platinum black (metallic platinum very finely powdered). This deposit of platinum easily rubs off and the battery then becomes substantially a Volta's battery.

3. MERCURIC SULPHATE BATTERIES. The induction coils which are furnished by many instrument makers are provided with batteries which consist of a zinc and a carbon plate immersed in a solution of $Hg SO_4$. When placed in water this salt of mercury decomposes, one part going into solution and the other remaining as an insoluble yellow precipitate which may be thrown away after the battery has been used. The high price of the $Hg SO_4$ is the principal objection to these batteries, and they are therefore used only to operate the induction coil. If H_2SO_4 is added, the formation of the yellow precipitate is prevented.

Typical Compound Batteries.

1. DANIELL'S BATTERY is the oldest and for some purposes one of the best of the compound batteries. The two fluids are a saturated solution of $Cu SO_4$ and dil. H_2SO_4 ($Zn SO_4$ is sometimes used instead of dil H_2SO_4) and are separated by a porous cup of earthenware. A piece of zinc is immersed in H_2SO_4 and a piece of copper in the $Cu SO_4$. This battery does not polarize since no H is liberated, but instead the Cu of the $Cu SO_4$ is deposited upon the copper plate.

2. GRAVITY, SAND, AND SAWDUST BATTERIES. These are substantially Daniell's battery with the porous cup

replaced by sand, straw, shavings, sawdust, etc. The $Cu\ SO_4$ being the heavier solution is placed at the bottom of the jar and the $Zn\ SO_4$ (which is preferable to dil. $H_2\ SO_4$ in this form of battery) is on top and separated from the $Cu\ SO_4$ by the mere fact of its lesser specific gravity or by the materials just mentioned.

None of these batteries, of the Daniell type, are very suitable for therapeutical work.

3. Bunsen Battery. In this battery the zinc plate is immersed in dil. $H_2\ SO_4$ and the other plate (which is gas-coke—carbon) in strong nitric acid, the two fluids being separated by a porous cup.

This is a powerful, reliable battery, and suitable for all kinds of therapeutical work. It is not, however, very portable and requires to be set up and taken down for each operation. Cells of sufficient size for physicians' use cost from $2.00 to $3.00 each. In the long run it is doubtful whether any other battery would be found more durable and efficient than a dozen one or two quart Bunsen cells.

In place of the HNO_3 a solution of bichromate of potash is sometimes, and preferably used. The composition of this fluid *by weight* is as follows:

Bichromate of Potash,	3	parts.
Commercial $H_2\ SO_4$	4	"
Water	18	"

To aid in making this solution it may be remembered that a pint of water weighs 1 pound; a pint of H_2SO_4 about $1\frac{3}{4}$ lbs.

4. Grenet Battery. The plates are zinc and carbon and are immersed in a solution of

3 parts of	Bichromate of Potash	by weight.
8 " "	Commercial H_2SO_4	
24 " "	Water.	

The arrangement is usually such that the zinc can be lifted out of the solution when the battery is not in use.

This battery is especially suitable for the induction coil, as it contains no porous cup and is quite portable.

Plunge batteries of this type are very convenient, are furnished by dealers in a very compact form and work very satisfactorily for a time. Unless preserved with a good deal of care, however, they are liable to deteriorate rapidly and become practically useless.

Amalgamation.

The zincs of all batteries which employ free $H_2 SO_4$ should be amalgamated, i. e., covered with a film of mercury, so as to prevent waste of the zinc. This may be done in one of two ways:

1. Clean the zinc in dil. $H_2 SO_4$, and pour over it some mercury. Rub it over the entire surface with the fingers or a piece of cloth.

2. Dip the zinc into dilute $H_2 SO_4$, which contains a soluble salt of mercury, e. g.. corrosive sublimate. In a few moments the zinc will be completely amalgamated.

Battery zincs become very brittle after amalgamation and must be handled with great care.

Brief Practical Rules.

1. Never fill the cells so full that the fluid touches the copper strip attached to the zinc.

2. Let the fluid be of the same height in the inside and the outside cells.

3. In making dil. H_2SO_4 *add the acid to the water* (not the water to the acid) in a vessel not easily broken by heat. Stir constantly while adding the acid.

4. Bichromate fluid is no longer good after it has become *green.*

5. No effervescence should occur when a battery is working properly. Effervescence indicates a waste of zinc and a want of proper amalgamation. The evolution of H from the + plate of simple batteries is of course an exception to this general statement.

6. After use a battery should be taken down, all the parts rinsed thoroughly, and the porous cups left in a (non-metallic) pail of water for 2 or 3 days, or until again required for use. This is to prevent their becoming filled with salts, and perhaps broken thereby.

7. *All connections must be clean—free from dry salts, oxides, or grease.*

EXPERIMENTS.

1. Inspect the various batteries shown, and trace the path which the current takes when the circuit is closed. Compare the parts of a Bunsen cell with the corresponding parts of a Daniell's and a Gravity, and name the parts of each.

2. Select from the pieces on the table those parts which constitute a Bunsen cell; then a Gravity; a Daniells; a Grove; a Frommhold; a Bisulphate of Mercury.

3. Place a silver coin above and a copper or nickel coin below the tongue. Bring the edges of the coins together, and notice the peculiar taste which lasts during contact. This taste is due to a current of electricity. Almost any two metals may be used. Use a piece of zinc in place of the copper, and notice that the taste is sharper. This illustrates the general principle that a galvanic current may be obtained when any two metals, in contact with each other, are immersed in a fluid capable of acting upon one of them more than upon the other. It further shows that the strength of the current depends upon the nature of the metals used, being greater in case of silver and zinc than with silver and copper. This method of obtaining electricity for medical purposes is largely used in electric pads, belts, etc., in which the moisture of the body takes the place of the battery fluid.

4. Take a piece of zinc and bend it back and forth several times, and notice that it is quite tough. Now amalgamate it by first dipping into dilute H_2SO_4 and then into mercury, and rubbing with a rag. Bend the piece again, and notice that it has become brittle. This shows the necessity of handling battery zincs carefully, as amalgamation renders them quite brittle.

5. Dip one end of the zinc intended for your small battery into dilute H_2SO_4. Notice the effervescence. Amalgamate one

half of it and again immerse in acid, and notice that there is now no action. It is for the purpose of preventing this "local action" that battery zincs are amalgamated.

6. Write a list of the chemicals, and the quantities of each, which you would purchase of a druggist in order to set up the following batteries. Hand the list to the instructor for correction.

12 one quart Bunsen cells.
16 two " Gravity "
2 one pint Grenet "
6 " " Frommhold cells.

7. Make a Volta's battery like the model shown.

8. Set up the Volta's cell which you have just made, and notice the evolution of H from the copper plate when the wires are joined. Further notice that there is no action when the circuit is open.

Section II. Electrical Quantities and Measurements.

The intelligent use of electricity by the physician requires a knowledge of three electrical quantities and their relation to each other.

1. CURRENT [= C]. The first of these quantities is the *current.* It is that peculiar molecular activity which exists in a wire that connects the two poles of a battery. By general consent the current is said to flow from the + to the − pole. It is a fact of observation that the same wire under different conditions may exhibit this electrical activity in different degrees. Some particular degree is accordingly selected as a standard in terms of which we may describe all others. A wire which exhibits this standard degree of electrical excitement is said to be carrying a unit current of electricity. This unit current is called an *ampere*, and the strength of all currents is specified by stating how many amperes flow by a given point. In a closed circuit the strength of the current is the same at all points in that circuit.

2. ELECTROMOTIVE FORCE [= E. M. F., OR E.], is that force which maintains the electrical disturbance which we call the current. The unit of E. M. F. is called the *Volt*, and is practically the force of a Daniells cell set up with dil. H_2SO_4 instead of $ZnSO_4$.

3. RESISTANCE [=R]. It is an observed fact that a battery whose poles are connected by an iron wire will not give as great a current as when the poles are connected by a copper wire of the same size and length. Moreover it is found that less current flows through a long than through a short wire. This property of substances in virtue of which they hinder the passage of the electric current is called *resistance.* All substances offer resistance but

in different degrees. A certain piece of wire preserved in Kew Observatory, England, serves as the standard. The resistance of this wire is called an *Ohm* and we express the resistances of all substances in terms of this unit.

Ohm's Law.

The relation of these three quantities is such that when we know any two of them we can calculate the other. The equation expressing this relation is called Ohm's Law in honor of the German mathematician who discovered it. The quation is:

$$C = \frac{E}{R}$$

In this equation R stands for the whole resistance in the circuit. It is usually more convenient to think of the resistance as made up of two parts, namely, the resistance of the battery and the resistance of the patient or whatever else may be in the circuit besides the battery. The equation is accordingly better written thus:

$$C = \frac{E}{R + r}$$

in which R = resistance of the battery (and hence called internal or battery resistance); and r = the resistance of every thing else in circuit (and hence called external resistance.)

In order to apply this law to the practical use of batteries it will be necessary to remember the following

Facts and principles.

1. The E. M. F. of a cell is independent of its size and the height to which the cell is filled but is dependent upon the kind of metals and fluids employed. The E. M. F. of some of the leading batteries is as follows:

Volta's battery			=	.7 volt
Hg. SO_4	"		=	1.5 "
Daniell's	"	(with Z SO_4)	=	.9 "
"	"	(with H_2 SO_4)	=	1.0 "
Bunsen's	"	(with H N O_3)	=	1.8 "
"	"	(with Bichromate,	=	2.0 "
Grenet	"		=	1.8 "
"	"	(partly exhausted.)	=	.9 "

E. M. F. up to about eight volts can be easily measured by the sense of taste.

2. The resistance of a cell decreases as the size increases; the higher a cell is filled with the fluids the less is its resistance. The resistance of a cell is a very uncertain quantity and can only be determined by actual measurement in each particular case. In general it may be called ½ ohm to the cell, except in case of the gravity battery where it is more likely to be from 2 to 8 ohms.

3. For practical purposes it is convenient to remember that a copper wire 10 feet long and $\frac{1}{100}$ inch in diameter has a resistance of 1 ohm; and that the resistance of a wire increases directly as its length and inversely as its section. The resistance of a similar wire made of other materials is approximately as follows:

Brass	= 4 ohms	Mercury	= 60 ohms.
Platinum	= 6 "	Dil. H_2 SO_4	= 2,000,000 "
Iron	= 6 "	Water	= 40,000,000 "

The resistance of living tissue between two needles about one inch apart is about 500 ohms. The resistance of the body from hand to hand when the electrodes are firmly grasped with hands moistened with salt water is about 4,000 ohms.

4. If two or more cells are coupled in series (i. e. the + pole of one connected with the — pole of the second, the + pole of the second connected with the — pole of third, etc.), the whole series or battery will have an E. M.

F. equal to the sum of the E. M. F's. of all the cells in series.

The resistance of the battery will also be the sum of the resistances of the separate cells.

5. If two or more cells are connected in multiple arc (i. e. all the + poles connected by one wire and all the — poles connected by another) the E. M. F. of the whole will be only that of a single cell.

The resistance however will be equal to the resistance of one cell divided by the number of cells so connected.

6. If a number of batteries consisting of several cells in multiple arc (as in Prop. 5) be themselves connected in series we have a battery which is said to be connected both in series and in mult. arc.

The E. M. F. of such a battery will be equal to the sum of the E. M. F's. of the mult. arc. batteries which are thus connected in series and the resistance will also be equal to the sum of the resistances of the mult. arc. batteries thus connected.

7. A battery is doing its maximum rate of work when it is so connected that the internal and external resistances are equal.

It follows from this that for all therapeutical work, except that depending upon the use of galvano-cautery and the induction coil, a battery should be coupled in series.

8. The conductivity of a wire or other conductor is the reciprocal of its resistance.

$$\text{Conductivity} = \frac{1}{R}$$

9. When two different circuits are open to a current it divides and part follows one course and part follows the other. The currents in the two branches are proportioned to the *conductivities* of those branches.

EXPERIMENTS.

1. Taste the E. M. F. of the various batteries shown.

2. Introduce a resistance coil of 32 ohms into the circuit and taste again. Notice that there is no change in the taste as the E. M. F. is practically independent of the resistance of the circuit.

3. Practice the determination of E. M. F. with the Gravity battery as follows: Let one student with closed eyes put the wires to his own tongue while another student connects the wires alternately with 1, 2, 3, etc., cells. This will give an idea of the taste of 1, 2, 3, etc., volts. Now let the first student connect with one or more cells while the other tells by the taste the number.

4. Place a galvanometer so that its length points east and west. Now pass the current from your little cell. Why does not the needle move?

5. Now place it at right angles to its former position and send the current through it. The needle now moves. What general rule can you deduce from these last two experiments respecting the position of a galvanometer?

6. While still in the right position interchange the wires which come from the battery. Why does the needle swing in the opposite direction?

7. Notice in which direction your galvanometer needle swings when a current is sent through in a particular direction. Now let a student on the other side of the table put the wires of his battery through a crack while you discover by means of the galvanometer which is the positive and which the negative wire.

[*Note.* In the following experiments students will work in sections of four after first cleansing and setting up one Bunsen cell. Each student is expected to have the care of this one cell during the remainder of the course.

A record of the following experiments should be kept in a table like the following:

No. Cells in Series.	No. in M. A.	E.M.F.	Battery R.	External R.	Deflection.	Current
3 Bunsen, etc. etc.	1	5.4	1.5	10	20°	.47

The following precautions must be observed in order to secure success in the experiments:

a. All junctions of wires with battery or binding posts must be bright and clean.

b. Merely touching the carbons with a wire is not sufficient; it must be clamped on.

c. Keep all pocket knives and resistance coils at least 15 inches from the galvanometer. The coil is a magnet while the current is flowing through it and will disturb the needle.

d. So connect with the galvanometer that the needle shall deflect in that direction in which the numbers increase.]

8. Send the current of your Volta's battery through your galvanometer and take the reading as soon as the needle comes to rest. Allow the current to continue running a few minutes and notice that the needle slowly swings back towards zero instead of remaining at its first reading. Explain the phenomenon.

9. Repeat the experiment using the gravity battery instead of Volta's. Why does not the needle swing back as in the first experiment?

10. Through the galvanometer send the current of one Bunsen cell. Record the deflection. Now introduce in succession 32, 61, 109 and 570 ohms resistance and record the deflection obtained in each case. Do you understand why the deflections become smaller as the resistances become larger?

11. Through the galvanometer send the current of one Bunsen, then the current of two Bunsens in series, then three, and finally four. Notice that you get little or no more deflection with four cells than with one. Explain why by means of Ohm's Law.

12. Introduce a resistance of 32 or 61 ohms and repeat experiment (11). You now have a greater deflection with four cells than with one. Explain why, making the calculation of the current by Ohm's Law.

13. Pass through the galvanometer in succession the current from 1, 2, 3 and 4 Bunsens coupled in multiple arc. The deflections continually increase as the number of cells increase. Why should they?

14. Repeat experiment (13) with a resistance of 32 or 61 ohms in the circuit. Now the four cells give no more deflection than one. Why?

15. Prove that the E. M. F. of four cells coupled in multi-

ple arc is no greater than that of one cell by the means of the sense of taste.

16. The *E. M. F.* does not depend on the height to which the cells are filled. Prove by first tasting the E. when only about ½ inch of fluid is in the outer cell and then tasting again when the cell is as full as usual.

17. Prove the proposition of experiment (16) by using the galvanometer and a resistance of 61 or 109 ohms.

18. The *resistance* of a cell does depend on the height to which it is filled. Fill a Bunsen to the height of ½ inch and send the current through the galvanometer. Record the deflection. Now pour in about 1 inch more fluid and note the change in the needle. Add more fluid again and note result.

19. Close a battery of 4 Bunsens in series by 2 circuits one of which contains a resistance of 10 ohms, while the other has a resistance of 61 ohms. Now introduce your galvanomer in each of their circuits in turn and notice the deflection in each. Why should they be different when the battery remains the same.

Section III. Electrolysis

Whenever a current of electricity is sent through a liquid compound it decomposes the liquid into at least two parts, one of which collects around or upon the + electrode and the other upon the — electrode. This decomposition by electricity is called *electrolysis*, and the liquid decomposed is called the electrolyte. The quantity decomposed depends upon the quantity of the current. One ampere will decompose .00135 grains of water per second, and when expended in decomposing sodium salts will liberate .006 grain of caustic soda (NaHO).

When water or metallic salts are thus broken up, hydrogen and the metals collect at the — electrode, and oxygen and acids at the + electrode.

The products of electrolysis in connection with the electrodes *constitute a battery* which tends to drive a current in an opposite direction to that which produced the decomposition. The E. M. F. of this electrolyte battery is in general between one and two volts; in case of acidulated water it is about 1.5 volts. It follows as a necessary consequence that, if the decomposing battery employed have a less E. M. F. than 1.5 volts, the current will be stopped (after the first few seconds) by the reverse E. M. F. of the electrolyte. This reverse E. M. F. is spoken of as the *polarization of the electrodes.*

In calculating the current by Ohm's Law this reverse E. M. F. must be subtracted from the E. M. F. of the battery employed. Only the excess of the force of the battery over that (say 1.5 volts) of polarization is efficient in driving the current.

If a comparatively weak current is employed in electrolysis, only the soluble salts present will be decomposed; with a strong current, however, water also will be decom-

posed, with the evolution of oxygen and hydrogen gases. This fact is important, because in surgical electrolysis it is sometimes desirable to produce and sometimes to repress the evolution of gas.

EXPERIMENTS.

1. In surgical electrolysis it is generally necessary to confine the action of the current to some particular point, and in the treatment of vascular tumors to avoid evolving free acid or alkali within the cuticle. Insulated needles are furnished by instrument makers, but it is very desirable that a physician know how to make and insulate his own needles. The material used for insulating is a solution of shellac in alcohol, having a consistency a little less than that of glycerine. Spread a little of this varnish upon a slim darning-needle, leaving about one half inch of the point uncovered. Now hold it above a lamp or gas flame until the alcohol is entirely driven off (as will be proved by the needle no longer giving the odor of alcohol), and until the shellac fuses to a smooth, hard, glossy coating. Great care must be exercised not to burn the shellac. Repeat the experiment until you succeed in making a *smooth*, *even* insulation.

2. In this and the following experiments, which require more than one cell, work in sections of four.

Make a pad of paper about ⅛ inch thick and 2 inches square, and thoroughly wet it with water. Measure its resistance with the galv. and the resistance coils as follows: Place the wet pad between the two copper plates, which are furnished for the purpose, and send the current of 4 Bunsens through it and the galv. included in one circuit. Note the deflection of the needle. Now substitute for the paper the various R. coils until you find that one which gives the deflection that agrees most nearly with the deflection obtained with the paper. The resistance of this coil will not be far from the resistance of the wet paper.

3. Repeat the measurement of Exp. 2, using simply the copper wire, to make contact with the paper, instead of the copper plates. Notice that now the resistance is greater. Explain why.

4. Measure the R. of the sponge electrode, which is furnished for the purpose.

5. Wet your hand thoroughly with salt water, and measure its resistance between the copper plates.

6. Use 8 to 16 Bunsens, and measure in like way the R. of your body from hand to hand.

7. In electrolysis the acid set free at the + pole unites with the metal of the pole to form a salt. Chlorine will thus unite even with platinum and gold, so that needles made of these metals are no better than common steel sewing or darning needles for treating tumors, aneurisms, etc., by electricity. Electrolyze a solution of Na Cl, using first an iron wire and then a piece of carbon for the + pole. In the first case the liquid becomes colored with a salt of iron (Fe_2Cl_6), while in the second Cl comes off as a gas and may be detected by its odor.

8. Immerse the platinum strips which are furnished, in a beaker of pure water, and pass the current of 4 Bunsens. Then add a few drops of H_2SO_4, and notice the marked increase in electrolytic action. What are the gases evolved? Notice that a larger volume comes from the — than from the + pole. Why should that be the case?

9. Use 1 Bunsen instead of the 4, and notice the result. Now use your simple cell, and note that you obtain no decomposition, because there is not enough E. M. F. About 1½ volts are required to decompose H_2O.

10. Electrolyze a solution of $CuSO_4$ with 2 Bunsen cells. Notice that metallic copper is deposited on the negative pole, and that there is little or no gas evolved at that pole. This illustrates the general principle that metals are liberated at the negative pole.

11. Repeat with a solution of Na_2SO_4. In this case also the metal (Na) goes to the negative pole, but it is in combination with the water to form caustic soda. To prove that it does form caustic soda, wet a pad of paper with Na_2SO_4, and place on each side of the pad a small piece of litmus paper, and over the latter the strips of platinum. Now pass the current for two minutes, and then remove the platinum strips. The litmus under the — pole is blue, while the piece under the + pole is red. Now replace the platinum strips so that the — pole is over the red litmus; pass the current again for 3 minutes, and notice that the pieces of litmus have exchanged colors.

12. Wet the back of your hand, and lay upon it a piece of red litmus paper. Grasp in the palm of that hand the + pole of

a battery of 4 to 8 Bunsens. Place the — pole on the piece of litmus. Let the current run 3 or 4 minutes, and notice that the litmus becomes blue, because of free alkali from the salts of the tissues. Now repeat the experiment, but use a small *sponge electrode* instead of the — wire upon the piece of litmus. The litmus now does not change color, because the alkali is set free next to the metal back of the sponge electrode, and not at the surface of the skin as before. The same results may be obtained with the + pole, and lead to the following practical rule:

When employing the galvanic current as a therapeutical agent, never place metallic electrodes in direct contact with the skin, unless you desire to obtain the local effects of free acid or alkali.

13. In electrolysis the electrolyte and the electrodes constitute a battery which tends to drive a current in the opposite direction to the principal current; and if the principal current be suddenly removed, this reverse current will become evident. Prove this as follows: Use 4 Bunsens in series. Connect the + pole of this battery with the + binding post of a galvanometer. In the other binding post fasten the end of the wire which is attached to the small copper plate which was used in measuring resistances. Upon the copper plate lay a thick pad of paper thoroughly wet with a solution of Na_2SO_4, and upon the paper lay the other copper plate. Now hold the end of the wire, attached to the last plate, in contact with the — pole of the Bunsen battery for about 3 minutes. Then quickly transfer the end of the wire to the + pole of the galvanometer. You have thus "cut out" the Bunsen battery, and have connected the electrolyzed paper with the galvanometer. Notice that the needle now swings in the opposite direction from that in which it was moved by the battery.

This shows the necessity of using quite high E. M. F. in all electrolytic work, since a part of it must be expended in counteracting this reverse E. M. F., while the difference in the two E. M. F.s only, is engaged in driving the current.

14. With a battery of four cells extirpate two or three hairs from your hand. Thrust the *negative* electrode (consisting of a fine steel needle—not a pin) into the hair sheath about one-tenth of an inch. Grasp the + electrode (a metallic cylinder or sponge electrode) in the same hand, and allow the current to flow 10 or 20 seconds, or until the hair comes out at the slightest pull. Not more than half a dozen hairs should be removed at a single sitting.

15. Experiments on the electrolysis of blood, the treatment of artificial aneurism, and surgical electrolysis of tumors, etc., will occur on the day devoted to Section VI.

Section IV. Principles of the Induction Coil.

1. The essential parts of an Induction coil are:

(*a*) A "primary coil."

(*b*) A "secondary coil."

(*c*) A device for automatically making and breaking the current.

(*d*) A core of soft iron.

(*e*) A draw tube.

2. An induction coil will give the following currents:

(*a*) An "extra current."

(*b*) A "secondary current."

(*c*) Both *a* and *b* combined.

3. The battery [also called the primary] current flows only through the primary coil (which consists of about 50 feet of moderately large and insulated copper wire) and does two things:

(*a*) It makes a magnet of the soft iron core.

(*b*) It induces a current in the secondary coil.

4. The secondary coil, which is outside the primary, consists of 500 to 1,000 feet of quite fine insulated wire, and furnishes what is called the Secondary, Faradic, or Induced current. This current consists of a large number of short, intense currents or impulses, each one of which lasts no longer than the hundredth of a second.

One-half of these impulses are induced by the primary current just at the instant that it begins to flow through the primary coil, and they flow in a direction opposite to that of the primary.

The other half of the impulses are induced by the primary current, at the instant that it ceases to flow, and also by the magnetism which at the same instant is being lost by the soft iron core; and these impulses flow in the same direction as that of the primary current.

The secondary current is consequently not only an interrupted current but it is also an alternating current, and for that reason will not decompose water nor deflect a galvanometer needle. It has however a greater stimulating action than a current which does not alternate. There is no electrical connection between the secondary coil and the rest of the instrument, and the current which it gives does not come from the battery but is developed in the secondary coil by some process which is not very well understood, and which has received the name of "Induction."

5. The operation of the "break" or "interruptor" is as follows:

When the battery current commences to flow the soft iron core becomes a magnet and attracts the little piece of iron which is on the end of the vibrating spring. This attraction consequently draws the spring away from the adjusting screw and breaks the primary circuit at that point. Now since the primary current has been stopped, the soft iron core loses its magnetism and no longer exerts any attraction on the spring. In consequence of its elasticity the latter then flies back and touches the point of the adjusting screw. This establishes the current again and the same series of actions is repeated.

The adjusting screw is to regulate the rapidity of the interruptions. When the induction coil is used to allay pain the break should be made to vibrate very fast. Stimulation, on the contrary, is produced better with a somewhat slow vibration.

6. The core of soft iron has no electrical connection with the rest of the instrument, and serves two purposes:

(*a*) It stores up a certain quantity of electricity, in the form of magnetism, which it afterwards gives up again partly to the primary and partly to the secondary wire. This stored up electricity is stored at the expense of the battery current. The electricity does not pass to the core by any metallic conductor, but by the process of "induction" which takes place even across a vacuum.

(*b*) It serves to make and break the primary current by alternately attracting and releasing the vibrating spring.

7. The draw tube serves to reduce the intensity of the currents which the magnet induced in the two coils. The core, it is true, gives up its magnetism as if the tube were not present but the *tube* takes most of it and leaves very little for the coils. There is thus a current flowing round the draw tube and if it were split lengthwise it would not have the effect of reducing the extra and secondary currents.

8. A gradually increasing series of currents from the weakest to the strongest within the range of the instrument is obtained as follows:

(*a*). Attach handles to the posts for extra current and have draw tube in. This is the weakest current.

(*b*). Now pull out the draw tube and the current gradually increases.

(*c*). Push in the draw tube and transfer the handles to the posts of the secondary coil. This may not be any stronger that (*b*) but,

(*d*). When the tube is pulled out slowly the current becomes gradually very strong and stimulating.

(*e*). A still stronger current is obtained by connecting the second and third posts together by a wire and attaching the handles to the extreme parts. Now when the tube is out the current is the combined extra and secondary.

9. The extra current flows only during an exceedingly small fraction of a second immediately following the breaking of the primary circuit. It flows in the primary wire and causes the spark which is seen at the break. The extra current is caused almost entirely by the magnetism which the core loses when the battery current ceases.

The extra current is an interrupted, but not an alternating, current.

10. Measurements recently made in this laboratory by Mr. E. R. Wagner, show that an ordinary "Medical Induction Coil" gives for 36 ohms resistance in the external secondary circuit, about $\frac{1}{60}$ of an ampere per second when the draw tube is pushed in and $\frac{1}{40}$ of an ampere when it is out. For a patient whose resistance is 4000 ohms, the currents would be therefore about $\frac{1}{4000}$ and $\frac{1}{6000}$ amperes.

EXPERIMENTS.

1.* Examine the model of the induction coil and identify the following parts: Primary coil, iron core, break, path of battery current, path of extra current.

2. Explain fully, by means of the model, the action of the automatic break. Why does it continue to vibrate? What causes the spark when the break leaves the adjusting screw?

3. Using a battery of four Bunsen cells let each student take, through his arms, first the interrupted battery and then the extra current. Notice that the physiological effect of the latter is much greater than that of the former.

4. Prove that the extra current flows only at the instant of breaking the primary current by operating the break by hand.

5. Inspect the regular medical coils and repeat experiment 4 with them *using only one Bunsen cell.*

6. Work the break slowly by hand and thus prove that a current flows in the secondary at both "make" and "break" contacts.

7. Give shocks to each other using in turn both the extra current and the secondary. Now combine the two and observe the greater physiological effect. While taking a shock let someone move the draw tube in and out to illustrate the very marked influence which it has upon the current.

8. The secondary will not continuously decompose water or salts, nor will it deflect the galvanometer needle. Try it. Explain why it will not. This experiment shows that the secondary cannot be used in surgical electrolysis.

9. Examine the magneto-electric machine and decompose water with it, Why does the induced current of this machine decompose water when the induced current of an induction coil will not? Notice the very marked difference in the effect of the current upon the muscles when the current is interrupted by the spring and when it is not.

10. Set up all your Bunsens (15 to 20) in series and take the current through the arms. Notice the sensation of heat, and the fact that one pole is more marked in this respect than the other. If the current be rapidly made and broken the shock becomes almost intolerable.

Section V. Defects of Electrical Apparatus.

No one can long use electrical apparatus without at times experiencing difficulty in making it work satisfactorily. It occasionally happens that a battery refuses to give any current whatsoever or an induction coil fails to give the slightest sign of an induced current. Under such circumstances the difficulty is generally easily detected and corrected. A more common and at the same time a more serious trouble is experienced when a battery or coil, without utterly failing to work, nevertheless gives a much weaker current than it ought. The detection and correction of the defect in such a case is likely to test to the utmost a man's practical knowledge of electricity and electrical apparatus.

In this section will be mentioned the most common difficulties which a physician is likely to encounter in his practical use of electricity together with the means by which he can detect and correct them. For this purpose a graduated galvanometer and a separate Bunsen or other cell are indispensable. We shall hereafter speak of this independent battery as the "exploring battery" and the wires attached to it as the "exploring wires."

I. Defects of Batteries.

In general it may be said that the failure of a battery to give its accustomed current is due, either to a falling off of its E. M. F. or to an undue increase of resistance. To which of these two classes the difficulty belongs may be quickly determined by *tasting* the E. M. F. If upon trial this is found to be as high as it ought to be we are justified in concluding that the difficulty lies in an unusually high resistance somewhere in the circuit.

1. *Poor Connections.*—The most common trouble arises from imperfect contact between wires which are loosely twisted together or wrapped about a binding post. The current from such a battery as a physician uses can not jump over a space so small as the one-millionth of an inch, while wires which are separated from each other by many times this distance appear to touch each other perfectly. The only sure way to obtain perfect contact is to scrape the wires *bright* and to *twist them together.* Hooking them together is not enough. If any doubt still remains about a junction include it in a circuit with your galvanometer and note the behavior of the needle.

2. *Imperfect Carbon Connection.* This is a very common difficulty in Bunsen batteries and results in cutting down the current very greatly without entirely stopping it. The only safeguard is in scraping the carbon clean and *firmly clamping* to it a bright wire or "carbon strap." The contact is made still better by wetting the junction with water or a solution of a salt. Poor connections of this and of all other kinds become heated to a greater or less degree after the battery has been running for ten or fifteen minutes, and may then be quickly discovered by touching all the junctions in the circuit. The galvanometer and exploring battery may also be used as in (1.) The junction between the zinc plate and its copper strap sometimes becomes corroded and may be tested in a similar way.

1. *Defective Porous Cups.* It is very seldom that a battery entirely fails to work on account of poor porous jars. Such jars may, however, greatly decrease the usefulness of a battery by increasing the internal resistance to an unreasonable degree. A freshly charged battery will always have a very high resistance if the porous cups were perfectly dry before charging. It requires a little time for the fluids to penetrate the jar and thus to furnish a conducting medium for the current. It is accordingly a

good plan to soak the porous cups in acidulated water for two or three hours before using.

To test a porous cup stand it in a jar of dilute acid and fill it two-thirds full of the same. To the ends of your exploring wires fasten plates of copper about one inch square. Place one of them in the porous cup and the other in the acid outside. Have the galvanometer in the circuit and note its deflection in degrees. Now remove the cup and again place the copper plates in the acid and at the same distance from each other as before. If the deflection is much larger than before the porous cup has a very high resistance and is unfit for use. There is a great difference in porous cups in respect to their fitness for a battery and when a good one has been found it should be carefully preserved.

4. *Exhausted Fluids.* The normal action of a battery soon results in a consumption of the fluids. The $H_2 SO_4$ is converted into $Zn SO_4$, Bichromate fluid is changed into a Chromic salt while Copper sulphate and Mercuric sulphate are changed to $Z SO_4$ and the metals are deposited. The change is gradual and is attended by an increase in the internal resistance and a decrease of the E. M. F. To what extent this exhaustion of the fluids may be carried before they should be considered unfit for use must be determined by their cost and the character of the work which the battery is doing. For use with the galvano-cautery it is important that the battery be charged with fresh, or nearly fresh, fluid. In other work, however, this is less important and may be left to the judgment of the operator.

Dilute acid may be compared with fresh acid by its taste or its action upon unamalgamated zinc. Iron, zinc or copper may be used to test, $H N O_3$. Bichromate fluid should be red or black—not green. It always improves a battery that is working to shake the cells or to move the plates about so as to renew the fluid that is in immediate contact with them. For this purpose some Bichromate batteries are made to rock by the hand.

5. *Cross Connections.* In Bunsen batteries these can only occur when the carbon with its clamp inclines over so as to touch the zinc plate or its strap. Simple inspection will detect such a connection.

In the Grenet and other forms of battery take out the plates, wash them thoroughly and touch one exploring wire to the carbon and the other to the zinc plate. No current should be indicated by the included galvanometer if there is no cross connection. In some forms of Grenet cells the zincs are suspended by a flexible chain so that they *may* swing around and touch the carbons when let down into the fluid. The small Volta's battery which you have made may be rendered useless by the tacks touching each other inside the piece of wood to which the plates are fastened.

II. Defects of Induction Coils.

1. *Corroded platinum points.* Whenever a spark of electricity passes between two pieces of metal one or both of them become slightly corroded. For the purpose of reducing this evil to a minimum, platinum is used for the contact points of the break of the induction coil. But even platinum becomes corroded in time and the efficiency of the coil lessened. Accordingly the platinum points must be occasionally scraped or sand-papered.

2. *A break in the primary circuit* may be detected by means of the galvanometer and exploring batteries. Such breakage is rare and will generally be found to consist of a corroded junction rather than a severing of the wire.

3. *Defects in the secondary coil* may arise from two causes:

(*a*) The wire may have been broken in consequence of a fall or of having been hit by something. Look carefully for indications on the surface of the coil, and if such

exist carefully examine the strands of wire which are thus bent. Also follow carefully the ends of the secondary wire from the points where they leave the coil to their respective binding posts.

(*b*) There may be a cross connection in the coil arising from insufficient insulation or from the touching of different spirals of the wire. Such a defect cannot be readily detected without measuring the resistance of the coil. Again the cross connection may arise when the coil, or the base of the instrument, is *wet or even damp* with water or battery acid. Placing the instrument in a warm place for two or three days will correct the trouble in such a case.

4. The failure to obtain a current from a coil will sometimes be due to a break in the wire which runs through the insulated cords that instrument makers furnish with their apparatus. Test the cords with the galvanometer and exploring battery.

EXPERIMENTS.

The experiments to illustrate this section will consist of the examination of defective batteries, etc. Students will work in sections of four, and will keep a record of the number of the apparatus examined, its defect, and the method by which it was discovered.

No. 1. Defective connections in cells.
No. 2. " " in the external circuit.
No. 3. Cross connections and defective porous cups.
No. 4. Defective fluids and plates.
No. 5. " Induction coils.
No. 6. " Electrodes.

Section VI.—Therapeutical Application of Electricity.

The applications of electricity in medicine may be divided into two classes:

First, Surgical. Second, General.

The Surgical applications are, 1st, The treatment of vascular tumors and indolent ulcers by electrolysis, in order to produce chemical changes in circumscribed places.

2d. The treatment of aneurism by electrolysis in order to produce a blood clot.

3d. The galvano-cautery, to cause excision and destruction of morbid growth, etc.

The General applications are, 1st, To the nervous system, in whole or in part, in order to produce sedation, or stimulation.

2d. To the muscles, in order to produce exhaustion, or increased nutrition.

3d. To the whole body, in order to produce changes in nutrition, or in elimination.

4th. To the skin, in order to cause local stimulation.

Vascular Tumors.—In the treatment of vascular tumors by electrolysis, the object is to produce coagulation of the blood and also an alteration of the tissues by the chemical decompositions set up by the current. The electrodes are preferably steel needles insulated as described in Section III., and introduced into the body of the tumor. The positive electrode should be placed nearest to the centre of the circulation because the clot at this pole is firmer than the one formed at the negative pole. On account of polarization of the electrodes, and also to secure rapid action, an E. M. F. of not less than fifteen, nor more than twenty-five, Volts, should be employed. The pro-

gress of the action is determined by the resulting firmness and hardness of the tumor. The duration of the application will vary from three to ten minutes. The current which passes will vary from ¼ to 1 Ampere.

Aneurism.—In the treatment of aneurism the only object is to form a firm clot. All chemical action beyond that which is necessary to secure this is injurious. *Only one electrode, the positive, is passed into the aneurism.* The negative electrode is a sponge or wet cloth placed on the skin near the aneurism. The clot should be formed slowly. In general, fifteen Volts will be sufficient for the E. M. F.

Galvano-Cautery.—The use of the galvano-cautery can only be properly acquired in the laboratory. An entire day will be devoted to this subject. The cells must be joined both in series and in multiple arc. In general, a current from 10 to 20 Amperes will be necessary with an E. M. F. of 7 to 10 Volts.

General Application.—In the general application of electricity to the nervous system and to the muscles a great variety of electrodes are employed, including the bath, sponge electrodes, metallic buttons, catheters, needles and brushes. To cause sedation the galvanic is much more useful than the interrupted current. For allaying pain the currents stand in the order, galvanic, interrupted primary, secondary.

Principles.—The fundamental principles underlying this application are the following: 1st. If a galvanic current is applied to a motor nerve it will cause contraction of the corresponding muscle, only at the moment of making or breaking contact. 2nd. If the application be to a sensory nerve the sensation is much stronger at the moment of making or breaking contact. Neither of the above rules is quite universal. 3d. The direction in which the electric current traverses the nerve should be that of the proper nerve current, i. e., descending in a motor nerve. When the above condition is fulfilled the region of the nerve near the positive pole will have its irritability lessened; that near the negative pole will have its irritability increased. To allay pain therefore the positive pole should be placed over the seat of the irritation, and to prevent local action on the skin the electrode should be large and covered with a wet sponge or cloth.

Sedation.—In general, the galvanic current is employed without interruption and the E. M. F. will vary from seven to forty volts; the time of application from five to twenty minutes.

Stimulation.—For causing stimulation of a nerve or muscle, interrupted currents are indicated. The secondary is the most stimulating because it is alternating. *Currents which cause violent muscular contractions are generally injurious.* Those which cause a mild tingling are usually sufficient. The secondary current is applied by the various electrodes mentioned above. No attention need be paid to the supposed direction of the secondary current in the nerve or muscle. See section IV.

EXPERIMENTS.

1st. Electrolyze fresh blood. Observe the different nature of the clots formed at the + and — poles. Employ two Bunsens, using platinum electrodes. Now repeat using four Bunsens. The clots are more frothy and less firm. Why?

2nd. Find by trial the E. M. F. and the galvanometer reading, for the current which gives the firmest clot. Test with litmus paper the condition of the blood at each pole.

3rd. Electrolyse a muscle as directed for a vascular tumor. Notice the gradual hardening of the muscle. The + needle will adhere firmly and can be withdrawn with difficulty. The — needle will be quite loose. Why?

In actual practice the current should be reversed about ten seconds before withdrawing the needles from the patient. Why?

4th. Observe the difference between the effects of the galvanic and the secondary currents, when applied to an animal, in producing contraction and nerve exhaustion.

5th. Inspect the various electrodes and test on your hand the difference of sensation produced when you employ, 1st, a sponge covered electrode, 2nd, a moistened metal button. What is the cause of this ?

6th. Apply the scourge-brush to the back of your hand employing the secondary current. Grasp a sponge electrode in the palm of the hand and apply the brush to the dry cuticle on the back of the hand. Now moisten the back of the hand and apply the brush again. Notice the great difference in the effect produced. Why is this?

7th. The work with the galvanic cautery will be exhibited to the class by the instructor in charge.

8th. Form a clot in the artificial aneurism provided, and observe the manner in which the clot grows. By pouring water into the arterial end the effectiveness of the plugging can be tested.

QUESTIONS.

1. Describe a Bunsen cell.
2. What fluid is used in the porous cup ?
3. What is the composition of Bichromate fluid ?
4. What is the strength of the $H_2 SO_4$ used in batteries?
5. Are any precautions to be used in diluting $H_2 SO_4$?
6. What is the principal defect of a simple Z. + Cu. cell?
7. How is this polarization avoided in the Frommhold and in the Grenet ?
8. What are the materials consumed in a gravity cell?
9. Is the gravity battery suitable for galvano cautery?
10. Why are battery zincs amalgamated ?
11. The zinc of a gravity cell is not amalgamated. Why?
12. Describe the process of amalgamation.
13. How does amalgamation affect the physical properties of Zn?
14. Give Ohm's Law.
15. What is meant by E. M. F ?
16. What is the unit of E. M. F. called ?
17. Give the E. M. F. of Bunsen, Grenet, Bisulphate of Hg. Daniells.
18. What is the unit of current called ?
19. In what units do we measure R ?
20. What is the approximate R. of 30 feet Cu. wire .050 inch diam. ?
21. Is iron wire as good for connecting battery to a cautery as Cu. ?
22. What is the approximate R. of a piece of muscular tissue ?
23. What is the R. of body from hand to hand ?
24. In how many ways are batteries coupled ?

25. How does coupling in series affect E. M. F. How the R.?
26. What is the effect of coupling in M. arc. on E. M. F. and R.?
27. Does the size of a cell affect either its E. M. F. or R.?
28. When do we couple in M. arc. rather than in series?
29. What is the general principle of coupling so as to obtain the greatest effect?
30. What is the E. M. F. of a Bunsen battery of 3 in series and 5 in M. arc?
31. What is the Resistance of a Bunsen battery each cell being of ½ Ohm R?
32. How must a galvanometer be placed for use?
33. Under what conditions will 12 cells in series give no more than one cell?
34. Under what conditions will 12 in M. arc. give no more than 1 cell?
35. Under certain conditions a battery gives a current of 10 amperes through a total R. of 20 ohms. How much will flow if a R. of 20 ohms be introduced.
36. How does the height of the fluids affect the E. M. F. and R. of a cell?
37. What is Electrolysis?
38. What is the Anode? What the Kathode?
39. Why cannot water be decomposed with the Daniells cell?
40. How can the reverse E. M. F. of polarized electrodes be shown?
41. Mention two or three applications of Electrolysis to Surgery.
42. Describe fully the operation for removal of hair.
43. Describe fully the operation for removal of Aneurism.
44. Describe fully the operation for removal of Vascular tumor.
45. How are the needles to be prepared for an operation?
46. How many hairs may be removed at a sitting?

47. How would you treat facial neuralgia with electricity?
48. What advantage has the sponge electrode over metals?
49. Why is the carbon-back sponge better than metal-back?
50. How can the greatest stimulation be produced with the galvanic current.
51. How do you producé sedation with galv. current?
52. How many currents will an Induction Coil give?
53. Which is the weakest, and which the strongest?
54. How does the extra. differ from the induced, current?
55. Describe the Induction Coil.
56. Of what use is the soft iron core?
57. What is the purpose of the metal draw tube?
58. What causes the extra current?
59. Can the Faradic current be used in Electrolysis?
60. Explain why the break vibrates automatically.
61. Will an induction coil work if the core is completely insulated?
62. What do you understand by the word "Induction"?
63. What physiological symptoms indicate that the current should be discontinued?
64. Why should strong galvanic currents be cautiously used about the head?
65. How does the physiological action vary with the rapidity of the break?
66. Why is platinum used as the tip of the adjusting screw?
67. Of what material are cautery knives, scrapers, loops, etc., made?
68. What advantage has the cautery over the knife in amputation?
69. Name two or three of the most serious obstacles to the use of the cautery loop.
70. How are these difficulties met and overcome?