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A TREATISE

ON

ELECTROLYSIS

AND

ITS APPLICATIONS TO THERAPEUTICAL AND SURGICAL TREATMENT IN DISEASE

BY

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PREFACE.

In presenting this short treatise on *Electrolysis* the author is well aware that the subject is by no means discussed with a view to the final determination of the causes under which this display of electrical energy performs its operations. Yet, he believes that many new facts and explanations of those previously recorded are not at variance.

It is difficult to understand the action of electricity in biological and physiological relations without first properly understanding the principles of chemistry and physics, which control the manifestations of this physical force. Neither can we expect to grasp the great truths which underlie the action of electricity upon living tissue, unless a comprehensive view be presented of the natural laws which affect the construction and destruction of these living tissues.

It would be presumptuous to assume that modern science has yet established the natural laws of the metabolism of the tissues of the animal organism, but we have every reason to believe that many of these laws have been recognized in nature, and it becomes the duty of the student to compare and contrast these recognized laws with the teachings of natural physics. An attempt has been made to represent these natural laws in such a manner that the medical profession may apply the results of science to the conditions of diseased or hypertrophied tissues. It is hoped that the limits of therapeutical application are suggested in the following pages, so that the physician may know how to apply electricity to the human structures in a rational way, with the expectation that the results of this application shall not be entirely empirical, and to withhold its application in those cases of diseased tissue which are not amenable to its favorable action.

In consequence of this view of the subject of the so-called action of electrolysis upon living tissues, it has been deemed wise to begin the treatment of our subject with a statement of the principles of physics as applicable to electrolysis, and afterwards to present these applications in the treatment of diseases. On this account much elementary matter is brought forward, which it is hoped will enable the reader to follow more clearly the train of thought as presented by the writer. We are well aware that very many of the principles of electricity have been omitted, but with the more general knowledge held by physicians of the modern day, it would be wearisome and useless to repeat those which are more clearly presented in many of the well-known treatises on this subject.

279 Beacon St., Boston,
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CHAPTER I.

INTRODUCTORY.

THE physician and surgeon are so accustomed to the use of material agents in the treatment of diseased tissues, that they can hardly be expected to take up the use of therapeutical agents which are apparently immaterial, unless they could obtain a clear understanding of the principles which govern their behavior.

Many of the books which treat of the general subject of electricity are too technical for the ordinary medical practitioner to glean that knowledge which may help him to apply, in a practical way, this immaterial agent to the treatment of diseases. Those treatises which are devoted to the subject of medical electricity mention the principle and practice of electrolysis in such a vague manner, that it would be wise to review in this introductory chapter the basis upon which electrolysis and its manifestations are founded.

What is known under the name of force, kinetic energy, or whatever else it may be called, is simply dependent upon properties existing in nature which enable one form of matter to transfer its latent, or stored up, energy to some other form of matter.

Among the bodies which exist among us, and which are recognizable by our senses, are some which seem to be arranged in definite forms and of definite structure, and whose particular organization has the property of renewing continuously, for a longer or shorter period, the materials of which they are composed; these bodies constitute what is called the Organic kingdom.

Other bodies which also exist about us, which are also recognizable by our senses—bodies which are not possessed with particular or individual properties of manufacturing the materials which constitute their form or structure—are comprised under the generic name of the Inorganic kingdom. It is true that some of the constituent members of this second class can be transformed into new bodies, which differ from the original form; in other words, these bodies are endowed with chemical phenomena.[1] While again others of this class are subject to receiving peculiar properties which may be imparted to them, and which may be called physical phenomena.

Observation shows us that every chemical phenomenon is accompanied with physical effects. Observation also teaches that every organic change is accompanied with physical or chemical effects.

Physical Laws.—Among the phenomena of nature which are about us, we see an uniformity of behavior that proves to us that there are fixed laws which govern these phenomena; an instance illustrative of the truth of this statement is the falling of an apple from its tree to the earth. It is well known that upon the observation of this fact Newton founded the universal law of Gravitation. The establishment of these laws is deduced from science, and these laws must be confirmed by the fact of their general uniformity. The circumstances and basis upon which a physical law is founded, will invariably reproduce the same manifestations by which this law is illustrated; for instance, when a ball rolls upon an inclined plane from a higher to a lower level, its movements are controlled by the attraction which the earth exercises upon it; these movements are also influenced by the resistance which the plane itself effects either by friction, or by the resistance of the air or other medium, in which the objects themselves are all immersed.

The phenomena which are regulated by physical laws may for convenience be separated into two classes,—those which transport an unchanged body without alteration of its composition, and those which transport the material of which the body may itself be composed. An illustration of the first-named class is reiterated in the fall of a body by the laws of gravitation to the earth, and an illustration of the second class is seen in the magnetization of a piece of iron around which an electrical current traverses in a coil of wire.

All physical phenomena being recognized as those of motion, the causes of these motions should be referred to as forces.

It is necessary in the purely physical discussion to stop at this point. It belongs to the domain of metaphysics to discuss the original causes, or creation, of these forces.

Matter is found in different conditions;—the ponderable and impon-

[1] Chemistry was originally the art of extracting juices from plants for medical purposes.

derable materials of which it is composed being associated in their elementary forms to constitute the substance itself:—the *solid* condition consists of a coherent form which is independent of the space which encloses the body; in other words, so long as the solid body is not subjected to any outside influence there is an equilibrium between the attracting and repelling forces, mutually inter-acting, which are inherent in the molecules of which the body is formed;—the *fluid* condition is that in which the molecules may take any arrangement of position, provided always that the relative distance of every two which are contiguous shall remain uniform; we may suppose in this condition that the attracting and repelling forces which act between the molecules of a fluid are *almost* in a state of equilibrium. In consequence of the property which the molecules possess, of altering their positions, the fluid will always assume the shape of the vessel in which it is contained, but the fluid condition will not assume any change of volume as long as the pressure upon all its surfaces is equal;—in the *gaseous* condition the body has the tendency of increasing its volume and of occupying all the space which is placed at its disposal.

The gaseous condition is therefore the direct opposite of the solid condition, and the power of expansion of the gaseous condition is in opposition to the power of cohesion which is inherent in the solid condition; consequently, the mutually attracting and repelling force of the molecules is overpowered by the repelling force which each molecule has upon the other. As the same body may exist in either the solid, fluid, or gaseous condition, it may be easily inferred that the molecules of which a body is composed will be nearest together in the solid condition and most widely separated in the gaseous condition. The action of heat, or of any other force, may change the solid condition to a fluid or gaseous condition; the volume, of course, will increase in changing from the solid to the fluid and gaseous condition. Upon the common theory, as above advanced, the ready inference may be drawn, that the mutually attracting forces of the ponderable atoms, which combine to form the individual molecules of a body, vary in proportion to the mutual contiguity of these molecules; then, when the same body becomes fluid these molecules must consequently occupy more space. Again, the molecules will become still more separated in the gaseous condition; moreover, when the molecules are more widely separated their mutual attraction will become more feeble; a very slight influence from an external source may entirely overcome in their latter state the mutual attraction of the molecules, in consequence of which they will separate or become attached to some other body which is ready to receive them.

This brief and concise review of the principles and conditions under which matter is found in nature, is essential to the comprehension of the subject of which this work will treat. Electricity is a force of nature, and its manifestation under the derived name of electrolysis in the structures met with in the organic kingdom, plays an important part in the decomposition and formation of these very structures. (*Ελεκτρον* amber, for electricity, and *λύσις*, a loosing).

Erb says, (Handbook of Electro-Therapeutics.) "Of effects of electrolytic processes produced within the economy we possess merely surmises. A beginning has been made by Drechsel, who succeeded in making urea from solutions of carbonate of ammonia by electrolysis with changing currents. It is at least probable that this process occurs also within the living organism."

The theory of the "Correlation of Forces" and the "Conservation of Energy," as well as its dissipation in the result of work accomplished, is one of the most important factors in the health and disease of the animal tissues. Empirical medicine has taught us many facts, the explanation of which upon scientific grounds has led modern physicians to achieve many triumphs over disease which in former times were not even thought of. Until the last few years electrolysis has been used in an empirical manner; it is only lately that the theory of its use in the production of changes in animal tissue has been studied; hence, achievements in the treatment of disease by this method have not formerly met with the success which it merits. A careful study of the empirical use of this agent in producing changes in living tissue should not be overlooked; the varying results from this experience should be compared with a scientific research and experiments upon organic structures. The difficulties formerly met with from an unstable knowledge of electrical phenomena are now replaced by more exact science. Sufficient information of many of the phases under which electricity is found in the organic as well as in the inorganic kingdom is now held, from which we may form the basis of a study of electrolysis in its effects on living and diseased tissue. The reader must bear patiently the details of this information, in order to learn something of the principles which underlie the therapeutical application of electrolysis; these principles are not more complicated than many others which have lent assistance in the practical application of valuable drugs to the treatment of diseases, and which are now so well known and used to good effect by the general practitioner of medicine.

No one will realize so much as the author of this treatise the difficulties which are encountered in unraveling the confusion and inconsistencies of clinical observations of those who have attempted to apply electrolysis to the cure of diseased tissue. It may be well understood that the enthusiasm of some physicians is in direct variance with the skeptical disbelief of others; and this may be true, even if votaries who belong to both classes have experimented with this method of treatment, and have conscientiously reported what each believed to be the correct result of his work.

It will be seen in the pages which follow this introduction of our subject, that a large amount of physical, laboratory, and clinical work of electrolysis has been submitted to a careful scrutiny; but that the physiologists have not contributed their quota. In consequence of this omission of an important link, we are obliged to glean our physiological information in part from the results of chemical science and in part from pathology, and to make our physiological application from the general knowledge of the existing laws of physiology; and also to compare the teachings which are derived from these two sources with the operations of electrolysis in the treatment of diseased tissues of the body. Fortunately clinical experience is so rich in the materials offered to our study, that there is a fruitful source for speculation as well as theory. Theory should be supported by the facts of experiment, if we wish the theory to be proved—and herein lies the difficulty; for in chemical science we can prove a theory by physical analysis and synthesis; in physiology we can bring to bear the observations of the minute animal structures, whether these are seen in healthy tissue or after they have been the subject of disease. For our present study, on the other hand, we shall be obliged to take under consideration the results of chemical research, of physical phenomena, of physiological teachings, and of clinical observations as seen for the most part by partisan observers. With these data we shall be obliged to obtain our results by the method of deduction, and to test these by our own knowledge of their truth, which is derived from personal experience.

Owing to the difficulties which have been enumerated, the purposes of this treatise may perhaps be better understood if an attempt be made to sketch in advance the method of this arrangement.

To comprehend the details of electricity as also the laws which govern the various forces of nature a separate treatise would be required for each division; books on these subjects are already so numerous and well written, that the reader should consult them for the many omissions which necessarily will be found in these pages.

Electrolysis is considered by the physicists to be a manifestation of electricity displayed in fluid substances, so that they appear not to have thought it worth while to present a separate work on this effect of physical energy; again the writers on medical or physiological studies of electricity have incorporated the effects of electricity on the human body in a general, and not a special, view of the display of electricity in the nature of electrolysis; consequently a wide range of study is required to obtain a proper knowledge of special work in this line of enquiry. It will be noticed by those who have examined into this subject that electrolysis has been in use for a long time, and for the treatment of a large number of diseases; consequently we have a long list of its applications to study, if we wish to undertake this method of treatment.

The second chapter will be devoted to the physical action of electrolysis. In this portion of the study an attempt has been made to explain the causes and effects of electricity as shown in the general organism of nature; its relations to chemical analysis and chemical synthesis are also reviewed. It will there be seen that electricity, like heat, is a form of motion which is the result of the display of a force generated and transmitted by means of material substances. It is also attempted to show that the laboratory has revealed the fact that organic chemical compounds are endowed with those same properties of disengaging this force which are seen in the inorganic chemical compounds. A number of detailed chemical experiments are given, which have not to our knowledge been recorded in any text book, which show the laws under which the combinations and decompositions of several organic compounds are conducted and accompanied with the discharge of electrical force. It must be quite evident, if the results of these experiments are true, that similar chemical actions do proceed in the organic structures of which the human body is composed. If then the decompositions which take place in the inorganic compounds held in solution are accompanied by the display of chemical energy, it must also be true that disturbances resulting from the decompositions of the compounds held in solution in the human tissues will produce the display of some form of energy in the structures of this organism. It may be that this energy is not transformed into electricity, nor is it contended that such is the case, but some form of energy must result from the organic chemical decomposition, whether it is heat or cell formation or cell destruction, or the transmutation into another form of energy.

The third chapter will describe the method of generating electricity and delivering this force from the galvanic cell. A study of this subject will illustrate many of the principles and behavior of electrolysis in the presence of fluids and substances which are dissolved in these fluids. This exposition will serve a very good purpose in the explanation of the basis for the application of the use of electricity in producing decompositions of substances which are in the path of the electrical circuit.

In the fourth chapter the matter of conductors, or paths along which the electrical force is transmitted, is discussed. Here is an important part of our study, for the question of an easy or a difficult passage of electricity forms a very important matter in the application of electrolysis to the structures of the human body. The diffusion of the current of electricity depends upon this property of the conductivity or resistance of the conducting medium. It is also shown in this same chapter that the amount of electro-chemical action will depend largely upon the question of the conductivity of the circuit which is outside of the battery; upon this principle will depend also the character and strength of the current which reaches the point of the desired application of electrolysis. It will here be seen, too, that the action of the current is applicable to all parts of the conducting medium, and it will be shown that the electrical force will pass through the easiest channels; but that the strength of the current will be equal through all parts of the circuit both within and without the galvanic cell. It will also be shown that, no matter of what size may be the electrodes, the same amount of the current will pass in or out of the conducting medium; and, moreover, that the interpolar zone will be placed in a condition of polarization.

The fifth chapter will be devoted to the explanation of the destruction of the living tissues by means of electrolysis. This effect cannot be definitely stated, because physiology has not yet laid down in what physical condition the life or death of a structure consists. It is not improbable that at some future day the life or death of a cell may be explained by the clearer interpretation of the natural forces, but it cannot be expected that the student of medicine shall interpret what the physiologist does not understand, and perhaps what it was not intended that he should understand.

In the sixth chapter will be described the method of using electrolysis as a therapeutical agent. It will therein be shown that the benefit which may be derived from this use is, like all other therapeutical agents, dependent in a great measure upon the manner in which this method may be employed. As the manner of using electrolysis can be better understood by a knowledge of its practical application, it has been thought advisable to incorporate a practical description of the methods used by various operators in the treatment of certain diseases; these are described in the four following chapters.

The apparatus and the methods of measuring the strength are described in the eleventh chapter. This matter of using currents of a definite and measured strength has lately been considered by writers on electricity as of considerable importance, because unless these currents are used with a proper knowledge on the part of the operator, the results which may be obtained are not necessarily such as should be hoped for. It will, therefore, be of importance to clearly understand how the strength of the currents may be measured.

The twelfth chapter will be occupied with a description of the apparatus and instruments which are required for treatment of diseases by electrolysis. It will be noticed in this description that it is not possible to arrange for every form of instrument which may serve the purpose for the convenient manipulation of each form of disease; the operator will have to employ his ingenuity in devising suitable instruments for a given case, in the same way that surgeons practise in their applications to the cases which are brought under their observation from time to time.

The thirteenth chapter will be devoted to a general summary of the applications of electrolysis. It will also discuss the theory of the so-called electrolytical action of the tissues.

CHAPTER II.

PHYSICS OF ELECTROLYSIS.

It will be necessary to explain something of the behavior of electricity as experienced in nature before its manifestations as electrolysis can be mastered. Without undertaking to explain the details of electricity, or electrical force, as it should be called, the reader should become acquainted with the conditions under which electricity is recognized. Reference should be made for a fuller explanation of the theories and scientific bearings of this subject to elementary and technical treatises, such as that of —"Jenkins on Electricity and Magnetism."

It will be sufficient for our purposes here to remember that electricity in nature is known under two opposite conditions, that of positive and of negative character. Electricity accumulating upon an object may charge it with one of these characters, which will be developed by influence upon that part of the conducting medium which is nearest to the electricized body; this accumulation of electricity will be of a kind contrary to that of the inducing substance. When these two kinds of electricity meet together in a conducting medium they will neutralize each other, and the electrical condition of the body will be in equilibrium. This recombination of the two opposite kinds of electrical force, when brought suddenly together, combine by some manifestation of energy, which may not always be apparent to sight; oftentimes this forcible union produces an explosion and an electric spark. The following simple illustration is familiar to many of us:—when a person walks rapidly over a dry woolen carpet in dry air, and touches a stationary dry metallic object, or the dry skin of another person who is at rest, a spark passes between the two points of contact; the rapid motion of the walking person and the friction upon the woolen surface charges his body with active electricity of one kind, and which is suddenly discharged by the contact with another conducting medium charged with the opposite kind of electricity. If the second person would also keep in motion under similar circumstances, no spark will occur, because both conducting bodies are similarly charged. Again, if the surface of either body be moist, electricity, which is engendered by the moving body as the result of friction, will not accumulate, because it passes off through the conducting medium furnished by moisture. The spark in the above case is the dynamic result of the effort of the two forms of electricity to reunite, and to restore the lack of equilibrium between the bodies charged with opposite kinds of electricity.

Electricity may, on the other hand, pass continuously through appropriate conducting mediums from the place of its generation or accumulation, provided that the contact of the conducting medium be constant; in this case its transmission, or " flow," along the conducting medium will occur continuously from the point of origin, out and through them to the original source of electrical disturbance. To produce or set in motion this continuous flow, or transmission, we must have a generator of electrical force in which the electrical disturbance or excitement is excited in a continuous manner, and from which it can be transferred by a suitable circuit in a more or less uniform way.

Volta was the first to make such a generator, which may be called a battery of continuous current. This generator or battery was formed by making alternate layers of zinc and copper, and between them was interposed a layer of cloth or bibulous paper moistened with acidulated water. Any number of these layers of zinc, acidulated water, and copper may be piled one upon another, always with the precaution of having these layers placed in the same relative order, and to have each copper connected by solder joints with the succeeding zinc; the two end metallic layers were unconnected, and a copper wire was soldered to each, thus forming the two terminals of the voltaic pile or battery. These terminals are called RHEOPHORES, [from *ρυειν θερειν*, current carriers] or ELECTRODES [*ελεκτρον*, amber—*οδος*, way; path of electricity], and, when united together by contact, will complete or close the electrical circuit, as it is called; in this case the current will traverse from one pole to the other pole, and so on, through the voltaic pile. This apparatus is illustrated by Fig. 1.

This current, or flow, is set in motion from the zinc to the next copper, and so on, through the pile, by reason of the difference in potential energy, or that difference in electrical condition, which causes the transfer of the disturbance from one point to another; this motion resulting from disturbance is always accompanied by some form of energy, the effect of which may usually be made evident or exhibited to our senses. The explanation of this physical effect is rendered in the following law:

DIFFERENCE OF POTENTIALS IS A DIFFERENCE OF ELECTRICAL CONDITION IN VIRTUE OF WHICH WORK IS DONE BY POSITIVE ELECTRICITY IN MOVING FROM THE POINT AT A HIGHER POTENTIAL TO THAT AT A LOWER POTENTIAL, AND IT IS MEASURED BY THE WORK DONE BY THE UNIT QUANTITY OF POSITIVE ELECTRICITY WHEN THUS TRANSFERRED.

The Voltaic pile is not a convenient form of generator of electricity for continuous current, and hence may be substituted by a series of galvanic

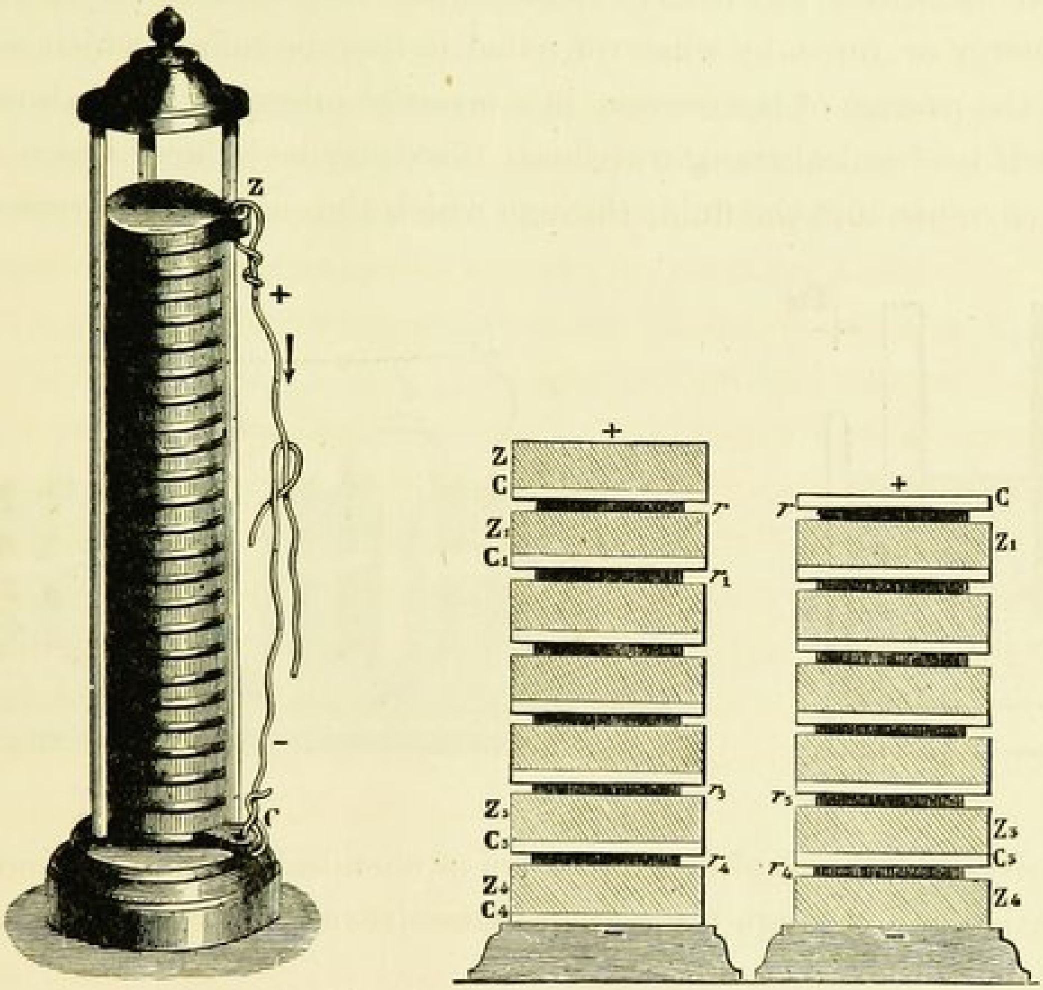
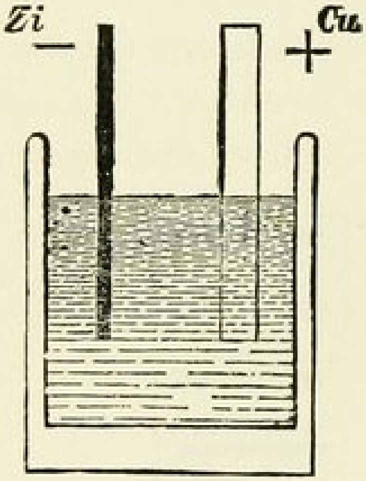


FIG. 1.—Z, zinc; C, copper; +, positive; —, negative elements.

cells, in which the two metallic elements, zinc and copper, are immersed in a solution of acidulated water. In this form of battery the copper in one cell is connected by copper wire with the zinc in the succeeding cell, or vessel; the last copper is the positive pole or terminal, and the first zinc is the negative pole or terminal of the battery, as shown in the accompanying illustration (Fig. 2). In the simple galvanic cell the copper metal may be substituted by the carbon metal, since the difference in the potential between zinc and carbon is as great, if not greater, than that between zinc and copper; and this form of generator also combines other advantages which it is unnecessary to mention in this place.

Such is the brief outline of the physical explanation of the cause of setting in action an electrical force, kinetic energy, or electricity as it is simply named and known to the general reader. It is hardly necessary to make a fuller explanation, but the principle may be better understood by applying the resulting laws of physics directly to the subject under discussion.

In the instance of dynamic effect first related, we see the manifestation in electric spark, or light, caused by the effort to reunite the two kinds of electricity which have caused molecular disturbance in matter. This energy or force, by whatever name it may be called, which accompanies the passage of the current in a material substance, may also manifest itself in chemical transformations; these may be induced by even very feeble currents, and the fluids through which the electricity traverses may



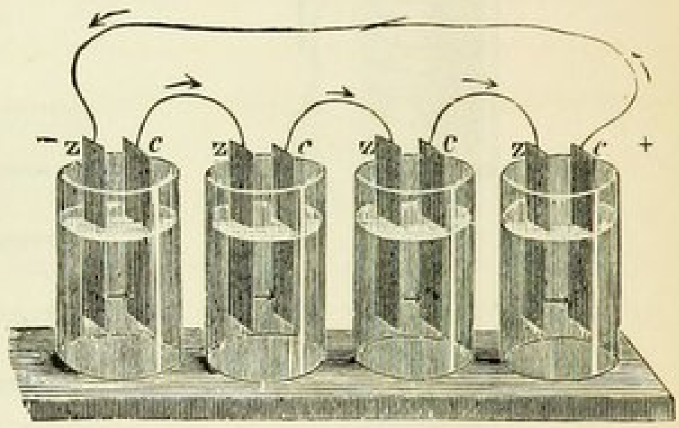


Fig. 2.

themselves be the seat of decomposition of chemical compounds contained in solution, even though these fluids themselves are non-conductors of the current.

As yet scientists have not agreed upon a physical basis upon which to explain the decomposition of chemical compounds by electricity. A Swede, by the name of Grotthüs, was the first to propose a theory. He suggested that the constituent elements of a binary compound, or of a compound acting as such, contained in its natural condition equal amounts of the two kinds of electricity (positive and negative). During the condition of combination the two atoms composing the water molecules, one of which was positive and the other negative, neutralized each other so as to produce a state of electrical equilibrium; for instance, the electro-positive hydrogen was combined with the electro-negative oxygen; but if an electrical current was excited by plunging a positive and negative electrode into the vessel which held the water, the atom of hydrogen nearest to the positive electrode, *a*, was attracted to it and became detached from its corresponding oxygen atom; the latter then would seek the adjacent electro-positive hydrogen, *b*, and this would send its hydrogen atom to combine with the next molecule, *c*, and so on; until the last oxygen would seek the positive electrode. This is illustrated in Fig. 3, in which the small dots marked + represent the hydrogen atom, and the larger circles marked — represent the oxygen atoms, there being two hydrogen atoms to one oxygen atom in each molecule of water which is formed by their combination.

This illustrates what is known by the name of the hypothesis of Grotthüs; by the establishment of this theory, electrolysis would consist of a series of decompositions and recombinations, and of a direct transfer of the elementary atoms from one pole to the opposite.

Grotthüs has applied this theory to the behavior of the metallic oxides, to the acids, and to the salts, when in solution, and acted upon by a current of electricity. Substances of a simple binary combination of atoms in

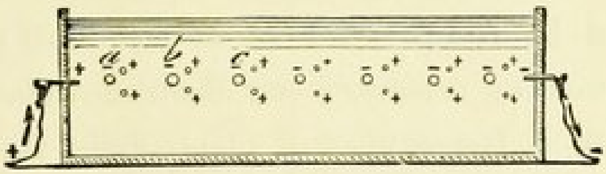


FIG. 3.—The Hypothesis of Grotthüs.

solution may be thus the seat of electrolysis, in which the electro-negative elements will become separated at the positive electrode, and the electro-positive elements will become separated at the negative electrode. The quantities of the substances, which are thus decomposed by the action of electrolysis, will agree with the quantities of their chemical equivalents, but not with their atomic weights; for every eighteen parts of water decomposed, two parts of hydrogen will be freed, and sixteen parts of oxygen, the combining equivalents of water molecules being in the ratio of one to eight.

As in the case of simple binary combinations in water, so also is the case of hydrate of potassa (K_2O,) $\overset{+}{K}$ being positive, $\overset{-}{O}$ being negative, and sodium chloride ($\overset{+}{Na}\ \overset{-}{Cl}$), etc.

An electro-negative element would also be united with a compound radical having the function of a simple electro-positive element, as for instance ammonium chloride ($\overset{+}{N}H4\overset{-}{C}l$). Finally the electro-positive element being simple and the electro-negative element being a compound radicle would behave in the same manner; thus sodic sulphate, $\overset{+}{Na_2}$ $(\overset{-}{SO_4})$, and sodic nitrate $\overset{+}{Na}$ $(\overset{-}{NO3})$.

Berzelius has carried the theory of Grotthüs into all chemical reactions. In fact, the chemical combinations of the atoms would be the effect of a mutual attraction of the electricities of opposite kinds. According to Berzelius, the order of simple bodies should be ranked in accordance with the intensity of their chemical affinities; and these would be identical with that of their electrical tensions; in other words,

THE QUANTITY OF A BODY DECOMPOSED IN A GIVEN TIME SHOULD BE PROPORTIONAL TO THE INTENSITY OR TENSION OF THE ELECTRICAL CURRENT.

The hypothesis of Grotthüs will not account for the migration of IONS which occurs, in a variable or unequal ratio.

Electrical Osmosis (cataphoric action, sometimes called) is another physical phenomenon. This name is applied to the phenomenon by which molecules are transferred through a porous medium which is induced or influenced by the presence of an electrical current within this fluid. When a porous cell separates two electrodes placed in a vessel containing a fluid which is the subject of electrolysis, the migration of the IONS is accompanied by a transfer of the fluid *en masse*. This effect is not apparent where there is no intervening porous cell, nor where the free surface of the fluid is sealed off from atmospheric pressure; because it is prevented by the laws of hydrostatic pressure. Electrical osmosis is a physical effect entirely distinct from electrolysis; the fluid is transferred from the positive to the negative pole, and consequently the height of the liquid will be increased at the negative pole and diminished at the positive pole. Where the resistance of the fluid is great, and the chemical action feeble, the increase in the action of electrical osmosis is proportionately greater; the reverse of this is also true.

To understand clearly the physical action in a galvanic cell, we may, for convenience, consider this as containing two fluids, one of which is a weak solution of sulphuric acid, and the other a solution of sulphate of copper; then we may consider that a strip of zinc is immersed in the former of these solutions, and a strip of copper in the latter; now, if we connect these two metals by a copper wire we will understand that the strip of zinc will represent the positive element,—that is, the pole by which an electrical current will enter a solution, and that the strip of copper will represent the negative element—that is the pole by which a current will pass out from a solution; consequently, the electrical current will go from the zinc to the copper within the solution, while in order to complete the circuit outside of the cell the direction of this current will be from the copper to the zinc. A portion of the zinc will also be dissolved while copper is being deposited upon the strip of zinc. It will be found that the weight of zinc dissolved in the solution is not equal in weight to that of the copper deposited upon the zinc; these two amounts will be, on the other hand, in proportion to the chemical combining equivalents of these two metals,—or that for each equivalent of zinc which is dissolved from the positive electrode one equivalent of copper is deposited upon the surface of the zinc. Faraday established the following law in respect to electro-chemical action:

"When the same current acts successively upon different compounds, the weight of the elements separated is in the same ratio as their chemical equivalents."

By the electrolytical decomposition of water, two parts by weight of hydrogen are found at the negative terminal (kathode), while sixteen parts, by weight, of oxygen are found at the positive terminal (anode). In the electrolysis of compounds in solution, the elementary substances which appear at either pole, or electrodes, are not necessarily simple chemical bodies, but may be composite or mixed elements. The same principle of decomposition, or separation into these bodies, holds equally with that of simple elements. Moreover, it is well established that, if the same electrical current be made to pass through a series of different solutions, the chemical actions in each solution are in the ratio of the chemical equivalents of the compounds which are dissolved. Professor Gore has illustrated this last fact by an experiment of which the details are given in his Text Book of Sciences.[1] He caused a voltaic current to pass through a solution of sulphate of copper from which only pure copper was deposited, and through a second solution from which pure antimony was deposited; he then found that the weight of the copper deposited was 31.7 grains and of the antimony deposited was 40.6; the latter number is equal to one atomic weight of copper, or 63.5 parts, which is the equivalent of 81.32 parts of antimony, or two-thirds of an atomic weight of that metal (121.98 being the full atomic weight of antimony).

[1] Electro-Metallurgy.

The Second or Subsidiary Effects of Electrolysis are of equal importance. Many of the elementary materials which appear at the electrodes are not those originally separated by the action of electricity, but some of these substances may be the result of the decomposition by the secondary chemical action of other elements; these latter are primarily set free by the action of electricity upon substances which were originally present. For instance biborate of soda [Na_2O, $2BO_3$] yields oxygen at the anode and boron at the kathode [Faraday]; yet, fused boracic acid is not subject to the action of electrolysis directly by the electrical current; the appearance of boron at the electrode is an indirect result of the decomposition of the solution of soda [Na_2O]. In this case, as the oxygen will appear at the positive electrode, and thus oblige the sodium to combine with the boracic acid, one portion of the boron will be liberated, secondarily, which will appear at the negative. In other words, electrolysis is the result of a discharge, in a fluid, of opposite kinds of electricity between two or more conductors which are at different potentials; this result is shown by the amount of chemical decomposition of the compounds which are in the solution, and which are the conductors of the electrical current.

Faraday considered the terminals through the union of which an electrical current forms a circuit, [as, for instance, carbon and platinum] merely the doors through which the electrical force enters and leaves the fluids; he named these doors electrodes. He likened the path of electricity to that of the terrestrial magnetism, namely, in the same direction with that of the apparent motion of the sun; the pole from which the current originated or left the fluid he called the anode, that is, from the carbon; and where it returned, or set, the kathode or the platinum. He named the decomposed substances, however complicated these might be, "IONS," those which went down, or set, in the direction towards the platinum the "kations" [κατὰ, down; ἴω, go], those which went up against the electrical current [from west to east] and which were the results of a chemical action at the anode he named "anions."[1] The substance which was in a state of decomposition he named an "electrolyte" and the process "electrolysis."

It has been previously mentioned that hydrogen gas will collect at the negative electrode (kathode), and that oxygen will collect at the positive electrode (anode); in these cases hydrogen will be the anion and oxygen the kation; [these words are simply correlative to each other, and they

[1] From ἀνὰ, up; ἰω, go.

are often spelt cathode and cation]. Inside of the galvanic cell the direction of the electro-chemical action is reversed to that outside of this cell, and consequently the hydrogen will collect at the copper, or carbon, battery-element, and oxygen at the zinc element, or positive pole; because the electrical current inside of the cell proceeds from the zinc to the copper or carbon, while out of the cell the current flows in the circuit from the copper back to the zinc. (See Fig. 4.)

A collection of either, or both, of these gases around the battery-elements *within* the solution will insulate these elements, and stop the display of electrical force, and the polarization of the battery will result—or in other words there will be two currents moving in the fluid in opposite directions. The chemical decomposition by an electrical motion in a fluid, or substance largely composed of a fluid, results, therefore, in electrolysis

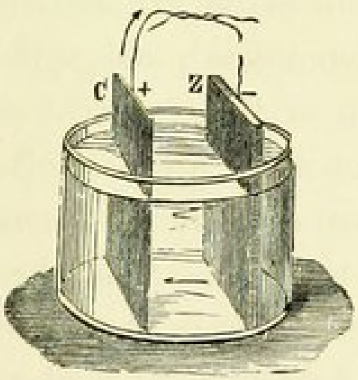


FIG. 4.

of the substances in solution; there are, also, subsidiary or secondary chemical decompositions which may be the result of a primary electrolysis. This action upon the surrounding mediums is complicated, and the limit of this action depends upon the exhaustion of the original electrical force, or upon the amount of interference caused by the polarization, or non-conduction, in these surrounding mediums. Thus, the ions will act upon the fluids surrounding the electrodes. This phenomena will occur unless the ions combine with the electrodes. Chlorides will become per-chlorides and chlorates will become per-chlorates at the anode. On the other hand, secondary actions which occur at the kathodes are those of reduction: thus, if iodide of potassium in solution be subjected to electrolysis, one equivalent of iodine will be liberated at the anode and will also have one equivalent of hydrate of potassium liberated at the kathode; this will show that the potassium set free from its combination with the iodine has combined with some of the surrounding water. Again, if chloride of ammonium in solution be decomposed, the chloride which is set free will react upon some of the remaining salt, and will produce nitrogen and chloride of nitrogen. A rise of temperature will favor the chemical decompositions and reformations resulting from electrolysis; this will promote at the same time a rapid mixture of the ions with the solutions. As the action will consequently be more rapidly performed under higher temperatures, the current density, or the capacity of the electrodes used, must be greater. It is not an accident which makes one substance an anion and another a kation. There are certain natural laws which govern this as all other physical relations; an electro-chemical element is not always one or the other of these, because anions and kations are merely relative to each other; for instance, iodine may act as an anion in certain solutions, while it may act as a kation in solutions of a different character; iodine combined with potassium in solution will become an anion, but in a solution containing iodine-bromide the iodine will become a kation. These actions, however, are pretty well generalized, and appear to be dependent upon the direction of the motion of the electrical current, or the path of the electrical transmission; the wider apart electro-chemical substances are placed in the list of chemical combining equivalence, the stronger is the chemical affinity between the two. "As the chemical equivalent proportions are either the same as their atomic weights, or are some simple submultiple of them, the following table of atomic weights is inserted for the purpose of reference:—

Aluminium,	27.5	Hydrogen,	1.	Rubidium,	85.
Antimony,	122.	Indium,	113.4	Ruthenium,	104.2
Arsenic,	75.	Iodine,	127.	Selenium,	79.5
Barium,	137.	Iridium,	197.	Silicon,	28.
Bismuth,	210.	Iron,	56.	Silver,	108.
Boron,	10.9	Lanthanum,	92.	Sodium,	23.
Bromine,	80.	Lead,	207.	Strontium,	87.5
Cadmium,	112.	Lithium,	7.	Sulphur,	32.
Caesium,	133.	Magnesium,	24.3	Tantalum,	138.
Calcium,	40.	Mercury,	200.	Tellurium,	129.
Carbon,	12.	Molybdenum,	96.	Thallium,	204.
Cerium,	92.	Nickel,	59.	Thorinum,	119.
Chlorine,	35.5	Niobium,	97.5	Tin,	118.
Chromium,	52.5	Nitrogen,	14.	Titanium,	50.
Cobalt,	59.	Osmium,	199.	Tungsten,	184.
Copper,	63.5	Oxygen,	16.	Uranium,	120.
Didymium,	96.	Palladium,	106.5	Vanadium,	137.
Erbium,	?	Phosphorus,	31.	Yttrium.	?
Fluorine,	19.	Platinum,	197.	Zinc,	65.
Glucinum,	9.3	Potassium,	39.1	Zirconium,	89.5
Gold,	196.6	Rhodium,	104.3		

When it is remembered that the union of chemical substances is a combination of elements in certain definite proportions by weight, we may readily understand that in the decomposition of a chemical compound into its component elements, the separation of the elements must be in definite proportion by weight also. In consequence of this law, when an electrical current passes through a conducting fluid, which contains chemical compounds in solution, the elementary substances liberated at the electrodes will be set free in their chemical equivalent proportions by weight.

"The same amount of electricity which will decompose one molecule or eighteen parts of water, setting free two parts by weight of hydrogen and sixteen parts of oxygen in one vessel, will decompose two molecules or seventy-three parts of hydrochloric acid, setting free two parts of hydrogen and seventy-one parts of chlorine in another. If we cause the same current to pass through a solution of cyanide of silver and potassium, then through one of sulphate of copper and finally through one of antimony, each solution being prepared and acted upon so as to yield only pure metal, we find that for every 108 parts of silver deposited in the first vessel 31.75 parts ($\frac{63.5}{2}$) of copper are set free in the second one; and 40.66 parts (or $\frac{122}{3}$) of antimony in the third one."[1]

The above truth was also discovered by Faraday, who first established the fact of equivalent proportional separations, as well as, also, that if the same current is made to traverse simultaneously various solutions in a series of vessels, the chemical actions in all of them are also in equivalent proportions; therefore, the resulting decomposition is produced by the same amount of electricity.

According to Professor Magnus, the separation and simultaneous deposit of substances, which takes place from the action of electrolysis in a mixed solution, will depend upon the following circumstances: — first, on the strength or density of the current; second, on the proportions in which the different substances exist in the fluid; third, on the nature of the electrodes; fourth, on the greater or less facility with which one or the other substance can be carried from stratum to stratum within the fluid, as well as upon the obstacles which stand in the way of this transmission, either in the shape of porous walls or in any other form.

Mention has already been made of the combination of atoms (elements)

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[1] Gore. op.

to form molecules. It must not be overlooked that, according to chemical science compounds are composed of atoms to form molecules, and that on the other hand molecules are chemically formed by the union of atoms in certain definite proportions. Now, when this union of atoms becomes separated, the separated matters must have definite proportions by weight, and these definite proportions are equivalent in a chemical sense:—a *monad* is an elementary substance, one atom of which possesses one equivalent of chemical power; a *dyad* is a substance which possesses two of such equivalents, and so on for the *tryad* and the *tetrad,* etc. Consequently one atomic weight of a dyad element is chemically equivalent to two of a monad element, and so on. It follows, moreover, that as a monad exerts one equivalent of chemical power, the elementary substances set free at the two electrodes are liberated in their corresponding chemically equivalent proportions, and that for each atomic weight of a dyad set free at one electrode two of a monad, or one of a dyad, are liberated at the other. For illustration, electrolysis of the compound hydochloric acid (HCl) causes one part by weight of hydrogen to be liberated at the kathode and 35.5 parts at the anode, because the atomic weight of hydrogen is 1. and that of chlorine is 35.5.

With these remarks upon the principles of electrolysis of inorganic bodies, we will consider the *electrolysis of organic and living tissues.*

The mode of action of *Electrolysis on living structures* can, à priori, be viewed as similar to its effects on saline fluids. Their power of conduction is (except epidermis and bone) like that of a weak saline solution. As the resistance of a saline solution is enormous compared with that of metals, only currents of great strength, *i.e.*, of many elements arranged as in Volta's pile, can traverse it, a fact that therapeutists have not sufficiently recognized. If a clean steel needle connected with a battery be placed on a spot deprived of epidermis and a current be transmitted through this needle, there will form around the positive pole brownish-black scales of peroxide of iron firmly adhering to the needle and fixing it in its position. The needle is oxidized by the oxygen of the tissues. The surrounding parts shrivel from the action of the acid developed. With strong currents bubbles of hydrogen are formed around the negative electrode and small drops of water; this shows the separation of hydrogen and its recombination with oxygen to form water; or else that the water contained in the tissues has been transferred *en masse* by electrical osmosis towards the negative electrode. The surrounding parts become slightly inflamed; pieces of muscle placed under the microscope show bubbles of gas between the muscle fibrillæ, paleness of the sarcolemma, and partial disappearance of the striæ, together with granular collections.[1]

It was formerly supposed that the positive pole alone could cause coagulation of the blood (Bruns and Heidenreich); but Dittel and Billroth deny that coagulation can be produced in this manner in aneurisms. So far it has not been possible to discover any change in the tissues between the poles, unless the needles be very close together, nor has the mechanical transmission of drugs through living tissues from one pole to the other been proven by experiment. It is easy to understand that the alteration of living tissues can with difficulty be studied on the living being. Many of these organic chemical changes may be inferred from the results of experiments upon organic chemical compounds which may be carried on in the laboratory. We have no right, of course, to assume that the same changes which are discovered from electrolysis of the chemical substances of dead tissue are the same as the electrolysis of living tissue. We may however assume that the truths of chemical science may be equally appropriate for chemical compounds which are contained in the structures of living tissues. The results of laboratory teaching in this department of science, electrolysis of organic chemical compounds, have been the subject of study from the time of Davy. Some of these researches, which were published in 1867 by Burgoin,[2] have an important bearing upon this subject. According to this writer, the phenomena of electrolysis are as simple, primarily, with the organic as with the inorganic salts; the metal, or basic, hydrogen will go over to the negative pole and the acid portion of the organic salt will appear at the positive pole. The reaction from the organic salt, potassium camphorate, will be the same as with the inorganic salt, potassium sulphate. These reactions are;

$$K_2S_2O_8 = S_2O_6 + O_2 \text{ (positive) and } K_2 \text{ (negative).}$$

Camphoric Acid ($C_{20}H_{14}K_2O_8$ = Camphor-Anhydride ($C_{20}H_{14}O_6 + O_2$) (positive) and K_2 (negative). The only difference between these two reactions will happen subsequently, from the fact that the nascent oxygen cannot produce further decompositions in one case, while it can in the

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[1] C. J. Zancopulos, of Greece. Ueber die electrolyt u. katalytschen Heilwirkungen des galvanischen Stroms. Arch. f. klin. Med., Band. X, p. 562, 1872.

[2] Comptes Rendus, 1867, pp. 987, 1144; also idem from Jour. de Pharm. et de Chimie, 1867.

other. This writer observes that the water of an electrolyte plays no part in the reaction but that of a solvent, and that the water is not decomposed. Burgoin presents a number of analyses which proves this fact; he then gives details of the electrolysis of sulphuric, nitric, and camphoric acids, and their corresponding salts. These results, as well as some other experiments with acetic and tartaric acids, differ in no respects from the foregoing analyses. This writer also states that, according to the earlier received theories, the decompositions which are caused by electrolysis of organic compounds varies with these compounds. These earlier authorities supposed this difference to be supported by the fact that many decompositions occurred, which set free organic radicles which polymerised (that is to say, form new bodies by a different arrangement of the same molecules) immediately as aldehydes, etc., Burgoin has, however, established that the same law governs both of these cases, and that the fundamental action in each is the appearance of the acid at the positive and that of the alkali at the negative pole.

The cause of the apparent dissimilarity is the difference in the compounds themselves. Thus with potassium sulphate (K_2SO_4) the K_2 appears at the negative and the SO_3 and O at the positive pole. Here the nascent oxygen can produce no further oxidation. But with organic acids it can oxidize and combine either with the carbon or the hydrogen or with both. Now the preference is for C (carbon) and the relation is such in organic acids that a very definite and easily formulated reaction takes place. This normal oxidation forms what may be termed the "characteristic reaction of organic acids." This, however, is a secondary action foreign to the action of the current.

Thus with acetic acid, $2C_4H_3O_3=2C_2O_4+C_4H_6$ (Kolb).

Succinic acid, $C_8H_4O_6=2C_2O_4+C_4H_4$ (Kekule).

Tartaric acid, $C_8H_4O_{10}=2C_2O_4+C_4H_4O_4$ (Bourgoin).

Other secondary decompositions may occur subsequently, greatly complicating the reaction. The following considerations will aid in the comprehension of these decompositions.

1. When an excess of alkali is present, this will act as a salt, and by its decomposition will increase the amount of nascent oxygen at the positive pole, and hence, the number of secondary products. The acid may be entirely consumed by oxidation.

Thus with succinic acid, $C_8H_4O_6+6O_2=2C_2O_4+C_4H_2+H_2O_2$.

These decompositions may occur simultaneously, and hence according to the conditions we may obtain one or another reaction.

1st or fundamental reaction. (Inorganic or organic salts).

Negative Pole.	Positive Pole.
Metal or basic hydrogen.	Acid anhydride and oxygen of acid or of salt.

2d. Organic acids and salts (secondary reaction).

Metal or basic hydrogen.	(a) anhydrous acid and oxygen.	(b) CO, aldehyde acids, hydrocarbons, etc.
3d. Metal or basic hydrogen.	(a) anhydrous acid and oxygen of acid or salt and of alkali.	(b) secondary products.

Apparatus:[1] One tube was placed within the other, the inner communicating with the outer by an orifice the diameter of which was 0.4mm. Both were filled with the electrolyte, potassium acetate, the solution of which was concentrated and had a neutral reaction. The decomposition began upon the closing of the current, and after five hours 5cc. were taken from around each electrode for analysis.

Free acid, in each cc., ...	0.0101
Free alkali, " "	0.0093

These are in the proportion of the chemical equivalents of KHO and acetic acid, and hence the fundamental action is shown.

Former analyses by Daniell and Miller show that the loss of salt is greatest at the negative pole with mineral salts. Hittorf showed the contrary to be true of organic salts.

2. Gas was collected at the positive electrode to amount of O, 87.4cc., CO 10.4, residue 2.2. This latter burned with a blue flame, indicating presence of CO. This showed that only a very small part of the acid is primarily destroyed by oxygen.

	Positive	Negative
Unaccounted for at the end of 6 hours,	0.008	0.004
" " " 24 "	Similar results.	
" " " 64 "	Similar results.	
" " end of operation,	0.166	0.008

[1] Idem, p. 998.

[These experiments upon organic chemical compounds, which were performed in the laboratory, prove conclusively that the separation of the elementary substances will follow electrolysis of organic chemical compounds which are partially or wholly in solution. We know also from experiments on dead and living tissue that the decomposition of chemical compounds in these structures will induce the display of electrical energy. We must therefore allow that there exists in our bodies, as the result of chemical formations and chemical decompositions, a continual discharge as well as storage of latent energy constantly going on in human tissues.

Some further experiments on organic chemical compounds have been detailed by Burgoin, which show that the chemical decomposition by electrolysis keeps on for a long time, and especially is this true of the compound hydrogen radicles.]

The result was the same with one equivalent of the acetate and one of the alkali, but very different with two equivalents of the acetate to one of the alkali, Kolb's reaction then preponderating.

ANALYTICAL TABLE OF GAS COLLECTED AT DIFFERENT PERIODS.

Hours.	12	18	24	30-36	48	56	60	64	72	80	96
O	15.5	6.	2.7	2.7	..	..	..	1.1	4.7	5.	8.2
C_2O_4	..	..	..	..	..	..	2.1	3.2	12.8	17.3	17.6
C_2O_2	5.3	5.1	4.3	4.3	3.7	2.4	3.8	5.1	3.6	3.4	3.
C_4H_6	79.2	88.9	92.2	95.5	96.3	97.6	94.1	92.	78.9	74.3	71.2

Kolb thinks ethyl acetate is produced, but Bourgoin has not confirmed its production. The blue flame is due to the presence of the oxide of carbon and not, as usually supposed, to the presence of hydro-carbons.

3. Free acetic acid.

This is the most difficult of all acids to electrolyse. It is impossible to decompose the concentrated, and with great difficulty the dilute, acid.

ANALYSIS OF GAS COLLECTED.

Gas at positive	3 days.	3 days.	4 days		
O	97.	95.8	92.2	Salt in 1 c.c. original liquid.	0.4309
CO_2	2.3	2.7	4.7	Positive pole.	0.4565
Residue.	0.7	2.5	3.1	Negative pole.	0.4252

The residue burns with a blue flame and a slight detonation.[1]

[1] Idem, p. 1144.

1. Concentrated and neutral solution of potassium tartrate. At the positive pole potassium bitartrate collected. There was no free acid, the faint acidity being due to some of the remaining bitartrate salt in solution.

Gas at positive electrode.	1 to 20 hours.	20 to 24 hours.
C_2O_4	61.2	80.7
O	7.8	7.2
C_2O_2	26.3	11.6
N	2.7	0.5

2. Analysis of liquids. At positive pole no free acid. Salt in 2 cc. 0.563, negative pole, very alkaline; 2 cc. contain of salt, 0.753; of free alkali 0.041. Loss at negative pole, 0.013, at positive, 0.120. The tartaric anhydride and water which collected at the positive pole formed tartaric acid, the result of which re-formation with the tartrate was the bitartrate, which was deposited on the bottom of the vessel. Some of the anhydride, however, was decomposed by the oxygen forming C_2O_4, C_2O_2, and H_2O_2, according to the following reaction: $C_8H_6O_{12}+3O_2=2C_2O_4+2C_2O_2+3H_2O_2$.

3. Alkaline solution, containing four equivalents of the tartrate and one equivalent of alkali.

Gas analysis.	in 24 hours.	in 72 hours.
C_2O_4	81.98	61.15
C_2O_2	9.60	18.47
O_2	6.68	18.18
C_4H_8	0.61	1.20
N	1.13	1.00

The origin of the hydride of ethylene seems to come from the large quantity of acetate of potassium produced. This ethylene compound was first obtained by Kolb.

Free tartaric acid.

Gas analysis.	1st day.	2d day.	3d day.	4th day.
C_2O_4	89.2	82.0	72.1	95.4
C_2O_2	6.9	10.6	19.1	4.1
O_2	2.2	6.6	8.2	4.1
N	1.7	0.9	0.6	0.5

On the 5th day C_2O_4 was almost uncontaminated by C_2O_2, thus, fundamental reaction at the positive pole, tartaric anhydride and O_2; the secondary reaction, $C_8H_4O_{10}+O_2=2C_2O_4+C_4H_4O_4$; at the negative, H_2.

From these laboratory experiments we pass on to the consideration of the views of others in regard to the action of electrolysis upon the living tissues. The preceding complicated decompositions of dead organic matter—that is, of organic matter without cell life—is interesting as showing the restricted limits of our knowledge of the chemical reactions.

Frommhold used for the purpose of obtaining electrolytical action on the living tissues a current from the coarse wire (primary) of an induction coil.[1] He produced the effects of electrolysis by the use of the bipolar rotation of an electro-magnet, as well as by the use of the primary induction apparatus. In other words, he used a dynamo machine; but he considers the only form of electricity, which is practically useful in electrolysis to be that of the constant current which is obtained from the galvanic-cell battery.

According to this writer, the variation in the action of the galvanic current will depend upon the size of the surface area of the plates, which serve as metallic elements of the cells, or upon the number of the couples which are connected in battery; when this area is more extensive, a great heat may be obtained in a proportionally poorer conductor, as in the case of the galvano-cautery. The high degree of heat, however, in this poor conductor, is due to resistance of the conducting medium, the platinum, and will be in proportion to the quantity and density of the original current. When the character of the original current is equalized by the resistance of the conducting medium, the resulting current will be the most favorable for use in the practice of electro-therapeutics.

The electro-chemical current, or action of electrolysis, is supposed by this writer to be favored by the coupling of a large number of small elements, because the internal resistance of the battery in such an arrangement would be more proportional to that of the external resistance of the circuit [the interpolar]. He supposed that a consolidation of the tissues would occur at the positive electrode, while their fluidization would take place at the negative electrode. Interpolar action would only be evident from the results in the treatment of a given disease. He attributed the pain caused by electrolysis to the tension of the current, and that this was produced on account of the resistance offered by the contact of the surface

[1] In K. Pest.Ofner Gesellch. d. Aerzte. Wien Med. Presse, XIV., 175-304.

segments of the electrolytical cylinder, which was placed upon the dry skin. In order to avoid this inconvenience of pain, Frommhold suggests that the form of this cylindrical segment should be changed into the linear shape, by means of flat arrow-pointed platinum needles, which should be inserted into the skin at intervals of two or more lines. In this way, the needles would penetrate into tissues which contain more water than the skin, and would produce deep and uniform electrolytical action, and not make partial and segmentary contact. He would restrict interpolar action to its destructive effects. He considered the use of this method as producing evil results in aneurisms. In these cases of aneurism he advised the use of one electrode, the negative, rapidly applied to the moistened surface of the skin, while the positive electrode was inserted into the aneurismal sac.

Frommhold supposed that there was a difference between electrolysis and electro-catalysis. The latter is an artificially prolonged action of the former. He attributed this to an increase of the quantity of the current as compared with its intensity; but, as will be seen later on, this difference is imaginary. He concluded that a current of intensity (the word "intensity" is often used for the word tension; tension is the more properly applied term) has a weak catalytic action, and that, as a considerable quantity should traverse the tissues, it was important that the electrodes should be covered with wet sponges or some other moistened layer. According to Frommhold, the explanation of the action of electrocatalysis should be attributed to electro-osmosis. (See page 14.) The phenomena of the latter would depend on the form, consistency and volume of the tissues, and upon the forces of polar decomposition and mechanical transportation. Frommhold suggested that a salt should be interposed in the path of the current; but it is extremely doubtful, in fact improbable, that such agents will traverse the tissue of the living organism. This author supposed that when the salts passed through the tissues they would be decomposed at the poles.

On the other hand, Dittel[1] has proved by experiment the impossibility of passing iodine or arsenic through the body by the action of electrolysis. These experiments were conducted on the lower animals. Iodine, which was applied to an electro-puncture in a pigeon, could not be found at the electrode of the opposite polar action; nor could it be found in the tissues

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[1] Oestreich Ztschr. f. prakt. Hlkde., No. 17, 1869.

under the positive electrode within the skin. He supposes that, in the few instances which have been reported of its supposed transportation through the tissues to the opposite pole, it was transported outside of the body by means of the fingers, or in some other accidental way; he cites a case to demonstrate the truth of this supposition:—in the case of a man with a cancer in the tongue, in which iodine was applied below the ear at the same point where the negative electrode was in contact, the current was passed during five minutes; the patient experienced a peculiar taste, which was explained by finding an iodine reaction in the saliva. As this patient had not been ingesting iodine, it was naturally supposed that the iodine had been absorbed by means of electrolysis; but on repeating the application of the current with twenty couples and for fifteen minutes, the same effect was reproduced, and it was then discovered that the patient's fingers had touched the electrode, and had thus transferred the iodine to his mouth.

Eulenberg discusses this same question of "the electrolytic conduction of iodine" which was advocated by Beer at Vienna in 1869; the theory was maintained of driving the iodine from the negative to the positive pole by means of the surface application of the electrodes. Eulenberg found in experiments, which were conducted by Brueckner, Benedikt, Ultzmann, Fieber, Ossikowski and himself, that it was impossible to conduct the iodine to great depths through the complex animal tissues. Eulenberg, however, states that the investigations of H. Munk on the galvanic introduction of different fluids into the uninjured human and animal organism deserve more serious attention. In these investigations Munk relied on the cataphoric action of electricity (electrical osmosis) to accomplish this absorption, which would be highly favored by the narrowness of the pores of the human body. In order to procure a sufficient cataphoric effect, the drug *must be brought in contact with the positive electrode or with both electrodes;* and a tolerably strong current should be employed during fifteen minutes, and alternately changing the direction of the path of the electricity, by reversing the poles. In this way Munk was able to produce the physiological effects of strychnine, and even death, in the rabbits submitted to the experiments, though the epidermis showed no evidences of injury. After application of concentrated solutions of sulphate of quinine, and of iodide of potassium, the quinine could be detected in the urine within the next twelve hours, and the iodine in thirty-six minutes after the beginning of the experiment, but in the greatest quantity after the lapse of five or six hours.[1]

Frommhold makes, and hardly with reason in our opinion, an unnecessary distinction between the two following instances:—first, when the iodide salt has been introduced by the action of the current alone; and, second, when the iodide has been absorbed previously to the application of the electrolysis. In his opinion the results of the treatment are different in these two cases; for instance, if the solution of iodide of potassium is placed upon the unimpaired skin at the point where the negative electrode is in contact, no presence of iodine can be demonstrated at the point of contact of the positive electrode, because the resistance of the skin is too great to allow of the transmission by electrolysis. If, however, the epidermis should be abraded at the point of application of both the drug and of the electrode, the salt will then be diffused by the action of the circulation, and not by the action of the electrolysis. In this latter case it would appear, in view of the experiments of Munk which have just been detailed, that the action of electrical osmosis would assist the usual process of imbibition and consequent absorption.

Frommhold very truly remarks that decomposition of the iodide is most rapidly accomplished in the case of vascular tissues. This is also true, according to the experience of the author of this treatise, in the result of resolution of vascular tumors when the iodide is not used; a fibroid tumor will not as rapidly be decreased after treatment by electrolysis as in the case of vascular enlargements, for instance, in the case of a nævus. Illustration of this view will be observed by the reader in the seventh chapter, in which are presented in detail quite a number of cases of the treatment of angiomata (nævi).

Frommhold states, moreover, that a solution of iodide of potassium may be advantageously injected in cases of isolated tumors previously to their treatment by electrolysis, taking the precaution to compress the veins so as to prevent its absorption; in this case the eschar will form more rapidly and will be larger, and the treatment will be more efficacious. According to this writer, electrolysis of small lymphatic tumors, of goitre and of articular inflammations, will be followed by better effects when the previous administration of iodide of potassium has been given. This

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[1] Handbook of General Therapeutics, Ziemssen, Vol. ii., p. 289. Wm. Wood & Co., New York, 1885.

opinion has not been borne out by the experience of other observers. When it is remembered that the use of iodide of potassium in the above-mentioned affections has not rarely been followed by an improvement, even in those cases in which treatment by electrolysis has not been attempted, it is reasonable to suppose that the above author may have met with some cases where the potassium medication might be in part responsible for the effects which he is disposed to attribute to combined action of electrolysis and iodide of potassium.

The action of electrolysis in its application to the cure of goitrous affections is more particularly discussed in a subsequent chapter, and therefore we will not continue this argument in further detail in this place,—since the reader can form a better judgment of the whole subject in the review of the pathogenesis and natural decadence of goitrous affections;—he will there see that the varieties of this disease are numerous, and that the benefits of their treatment will depend in great measure upon the pathological bearings of each variety.

The application of electrolysis in the cure or partial relief of aneurisms has occupied the careful attention of many physicians for a number of years, and it would be advisable before considering the practical bearing on these cases, to present some of the explanations of these observers in regard to the method of action, by which electrolysis can effect its beneficial action upon the tissues which are filled with blood or which convey this circulating fluid.

We owe to a very careful manipulator, as well as a close observer of this phase of our subject, some very useful hints. This authority has devoted twenty years of his experience in the treatment of aneurisms, and his opinions deserve a careful consideration in our discussion. This writer[1] states that the action of the electrical current is threefold: physiological, calorific and chemical. The two latter cannot be easily separated (probably they are transmutations of the same energy), and hence the term chemical action has not been specially applied. The current in traversing the living tissues produces its local effects at the points of contact of the electrodes; these will vary from that of rubefaction to that of cauterization, and are comparable only to the action of caustics of a chemical nature. These effects have no connection

[1] De l'action chimique de l'électricité. Ciniselli in Gazette des Hop., Paris, 1862, xxxv., p. 480. Resumé par Velpeau.

whatever with the physiological action; they are supposed to be the results of the chemical and calorific actions alone. The heat effect is obtained only by the use of a continuous metallic circuit with great resistance. The destructive effects may be obtained by the application of the rheophores separately, but in this case they simulate the alterations in the vitality of the tissues. The cauterization effected on the skin by the chemical action is supposed to be due to the development of acid at the positive and alkali at the negative pole. The alteration in the tissues is accompanied by signs of chemical action, the development of acid and gas at the positive, and of alkali at the negative pole. The application of two metal surfaces connected by a wire to the tissues is capable of producing similar effects, the tissues playing the part of the exciting fluid. Compared with other caustics the galvano-chemical is more easy, sure and extended; this is, also, (by means of electro-puncture,) more profound, and more easily controlled and finally more prompt, than other caustic applications. The use, however, of the galvano-cautery locally applied to the skin is hardly an instance of electrolysis, but would be more appropriately compared with the action of chemical caustics.[1]

Tripier (op. cit.) distinguishes the "chemical galvano-caustic" action from the "thermo-galvano-caustic" action. The former is due to the action of the acids and alkali at the points of contact, and the latter to the heat developed by a powerful current in an imperfect conductor. Davy was the first to show that electro-positive elements will collect at the negative pole, and vice versa; and that, if the well-washed fingers constitute the electrodes, the electrolyte gives the same reactions around the poles as with dead substances, thus showing that living acts like dead matter. A current traversing the living body therefore decomposes the salts, and the acids and alkalies appear at the terminal poles and will there act upon the electrodes, the tissues, or both. In order to produce cauterisation, the effect should not be influenced by the alterations of the electrodes, and hence these should be of platinum or other unoxidizable material. Ciniselli was the first to show (in a memoir to the Surgical Society of Paris, in 1860) and to explain fully the difference between the clots at the two poles, the clot at the positive pole being firm and unalterable, resembling exactly that formed by powerful acid caustics, while that at the negative resembles the action produced by alkalies. The cicatrices produced by

[1] De l'électrolyse. Par Dr. L. Ravacley, Thesis. Paris, 1876.

two kinds of caustics also differ; that produced by acid being hard and retracted, that by alkali being soft and not retracted. The microscopical characters also differ: the acid cicatrix shows much fibrous tissue and amorphous matter; the alkaline is soft, non-adherent to subjacent tissues, and shows much less fibrous tissue. Hence the negative pole is usually preferred except to close sinuses by adhesive inflammation.

Ciniselli in 1860 was the first to clearly enunciate and apply the theory of the chemical action of the current, but Mongiordo and Landoin, in 1803, noticed the same without applying it. Subsequently, according to the elder Becquerel,[1] Fabre-Palaprat had the idea of using the chemical action of electricity for its caustic effect, but he confounded this with the calorific effect. Crusell, of St. Petersburg, worked perseveringly on this same subject for seven or eight years, and addressed a memoir to the French Academy of Sciences. He suggested the use of the solvent action of the alkali, which would be generated, without producing eschars, in stricture of the urethra, etc. In 1849 he reported cases of the cure of cancer, ulcers, and two cases of cataract in which he used the galvano-puncture. The committee of the Academy, to whom his paper was referred, reported that the evidence presented was not sufficient to warrant the expression of an opinion concerning the merits of the method. Thus discouraged, Crusell subsequently limited himself to the study of the effects of the calorific action.

Lerché[2] applied Crusell's method,[3] and it was approved by Graefe.[4] One important result attained was the treatment of atonic ulcers by placing a voltaic couple on their surface.

LOCAL EFFECTS. After the application of a plate of copper and another of zinc, which were connected by a wire, there is produced under the zinc a redness of the skin and an abundant exudation of serum, while under the copper the skin appeared natural and there was no pain. The zinc should be placed upon the sound skin and over a wet compress. This is followed by rapid healing. It will be seen from the review of the work of the earlier experimenters, that the action of electricity applied locally to the skin was merely obtained from the effects which were apparent to the eye; it will also be seen that the electrolysis of organic compounds were

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[1] Traite de l'électricité et du magnetisme, Tome iv.

[2] Compt. Rend., xxviii.,1849.

[3] Med. Ztg. des Vereins, 1841.

[4] Deutsche Klinik, 1852.

studied from a chemical point of view. In the former case, the application of the negative electrode in contact with the moistened skin is followed by some of the signs of local inflammation. To all appearance this inflammation appeared like that which followed the application of ecsharotics or of rubefacients, but the chemical changes which occurred underneath the skin have not yet been examined. It has also been observed that an œdema of the tissues often accompanies the inflammatory action, that which is also true of the irritation produced by certain chemicals; yet, the œdema which follows the local application of the electrode is somewhat different, because, after the irritation produced by a chemical irritant, the œdema is succeeded by vesication. In this vesication a collection of serum occurs between the superficial and subcutaneous layers of skin; the œdema which follows the application of the negative electrode is an infiltration of the subcutaneous tissue; the action of a vesicant is followed by a denudation of the external layer of the skin, which is succeeded by a sort of sloughing, and the healing process is by means of a series of granulation; the œdematous infiltrations which follow the local action of electricity upon the skin is succeeded by a dry eschar, under which the process of healing proceeds without usually causing a secondary inflammation; when the dry scab falls off, a slight red mark shows its previous location. When an electrical current passes through the tissues between two poles applied to the skin, we may readily suppose that a transfer of liquids is made from cell to cell of the tissue, and this transference of liquids is probably due to the law of electrical osmosis, which has before been spoken of. This is, at least, the opinion of certain electrical students of physiology.[1] Electrical osmosis is very marked in the case of pure water, and diminishes upon conductivity imparted to the liquid by salts in solution. It is, furthermore, noticed that quite an appreciable amount of water will collect about the negative electro-needle, when inserted into the skin below the superficial layer. It may be argued perhaps that the accumulation of water is due entirely to the secondary formation, which is caused by the combination of hydrogen and oxygen, and which results from the decomposition of the organic compound. If this view is held, we must suppose that the destruction of organic compounds in the tissues is quite active; if the other view be held, the appearance of a large number of bubbles of gas will account for the chemical decompositions

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[1] DeWatteville.

of the organic compound in the tissues, while the water is transferred by electrical osmosis.

In short, it will be observed by the careful reader that some of the electro-chemical changes of organic compounds, which have been spoken of above, are very definite in character; and that many of them are mainly caused by the development of an alkaline reaction at the negative electrode, and of an acid reaction at the positive electrode; that, in addition to these specific reactions, there are many of a secondary character, which are influenced by the primary chemical changes at either pole. Professor W. N. Shaw (Article, Electrolysis, in the last edition of the Encyclopedia Britannica), in discussing these secondary electro-chemical decompositions, states that:—"The IONS appear in an abnormal molecular state; for instance, as before mentioned, oxygen is liberated as active or pure oxygen mixed with nascent oxygen (ozone). The molecular state of the deposit varies very much with the density of the current, which increases with the area of the electrodes." As a natural consequence from this mode of reasoning, many of the statements of those who have made practical application of electrolysis to the living tissues, which appear antagonistic, may and probably are reconcilable. The antagonism can be explained from the various circumstances in which the electrical current is carried through the organic structure, which may itself be the seat of the secondary electro-chemical decompositions.

Much that has been written by medical writers on the theory and application of electrolysis, and of so-called electro-catalysis, is obscure. Yet many of the facts and researches which are reported by the older writers are quite pertinent, and should not be overlooked.

Onimus and Blum,[1] in speaking of the uses of electricity in surgery, mention that the decomposition of living tissue is governed by the same laws of electrolysis as those of dead tissues. Electrolysis of muscle results in the development of sulphuric, nitric, phosphoric and hydrochloric acid at the positive, or anodal, terminal; while soda, potassa and ammonia collect at the negative, or kathodal, terminal from the battery. The decomposing action of the electrical current upon the animal tissues has been studied by Brugnatelli, Davy, Aldini, Prevost, Dumas, etc.

Blood, milk, muscles and other tissues which are largely composed of watery substances contain mineral salts, and the current acts especially

[1] Bull. Gen. de Therapeutique, Paris, Tome lxxxii., pp. 13 and 205.

upon these compound materials as well as upon the water contained in them; acids are carried, as above mentioned, to the positive pole, and alkalies to the negative pole. H. Davy immersed the ends of a piece of meat into vessels filled with distilled water, and connected these ends with the terminals of a strong battery. He found in the vessel at the negative pole potassa, soda, lime and ammonia; and in the vessel connected with the positive pole sulphuric, hydrochloric, phosphoric and nitric acids. The piece of meat subjected to this treatment for several days was entirely freed from its salts. He also immersed his fingers, as previously referred to by Tripier (p. 31), after they had been carefully washed, in two vessels containing distilled water, and connected them with the two poles of a battery. In the positive vessel he found the acids and in the negative vessel he found the alkalies, showing in this manner that living as well as dead tissue could be the seat of electrolysis. The resistance of the tissues to electro-chemical action is inversely to the proportion of fluids which these tissues contain. Thus dense tissues form

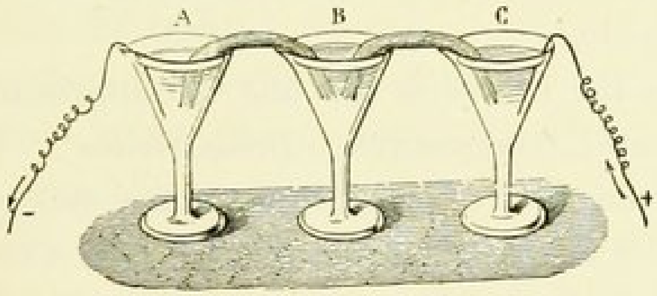

FIG. 5.

poor or feeble conductors. If the current be applied to the denuded surface of the body, its resistance is reduced one-third. Decomposition in the tissues occurs only at the electrodes. These writers illustrate this law by the following well-known experiment of Davy:

Fill three vessels: (A) with a solution of litmus and sulphate of soda or common salt, (B) with litmus and common water, and (C) with a solution of litmus, and place between the three vessels some wicking, whose ends are immersed in the solution; place these all in line, or in circuit, with an electric battery, as represented in Fig. 5. If the electric current be then made to traverse through the completed circuit, the litmus in vessel (C) will assume a red color (acid reaction at the positive electrode), and remain blue in vessel (A) (alkaline reaction at the negative electrode); the salt will be found to have passed from the first to the other two vessels, and the litmus solution in (B) will still remain blue (neutral). If the current be continued for a sufficient time the salt will be found to have been entirely decomposed, the acid being found in (C), and all the alkali in (A). If on the contrary the direction of the current be reversed, the alkali will be found in (C) and the acid in (A). The time requisite for the complete decomposition of the saline compound, will depend upon the strength of the electric current.

Onimus mentions that in dead tissue the blood will coagulate only at the positive pole, while in living tissue a coagulum will be formed at either electrode.

When dry electrodes are placed in contact with the skin upon the surface of the human body, eschars will be formed at the place of contact. These eschars partake of the acid or alkaline character (which is dependent upon which of the two poles is used) and are probably caused by the action of the escharotic upon the dry skin. This may be prevented by thoroughly moistening the parts to which the electrode is applied, or by the use of a weak solution of any acid, as tartaric, for instance, in the moistened negative electrode, and by a solution of carbonate of soda upon the positive electrode.[1]

Electrolysis in the tissues is not due to cauterization or to their destruction by elevated temperature. Broca writes[2] "It is certain that the portion between the poles is the seat of a molecular perturbation which begins and ends with the poles"; whereas Ciniselli states that, "The effect is not limited to area of cauterization (?), but extends to the interior of the tissues"; this is shown by the fact that the reduction in the size of pathological growths is out of all proportion to the local effects of cauterization, the decrease being continued after separation of the eschars.

[The use of the words catalysis and electrolysis occurs so frequently in the French and German writers that it would be well to discuss that question here. There is no occasion for the use of two different words to express the same physical effect. The word "electrolysis" at the present time, as may be gathered from the previous pages, is used for the convenient description of an artificial use of electricity to bring about certain chemical changes in fluid or semi-fluid bodies. Its effects are well known to chemists as forming an important factor for the production of

[1] Onimus et Legros. Traité de l'électricité medicale, 1872, p. 148 et seq.

[2] Traité de tumeurs, Paris, 1866, p. 174.

certain chemical reactions. The most familiar illustration is known in the case where sulphuric acid and water are placed together in a bottle or glass generator for the decomposition of hydrogen. In this process the metal zinc is immersed in the mixture to cause the movement of the sulphur and oxygen elements towards the zinc, thus setting free the hydrogen element in the form of gas, and the oxygen element combining with the sulphur and zinc elements forms a salt of sulphate of zinc. The disengagement of this originally formed combination of elements of hydrogen and oxygen as water, causes the discharge of a force known to physicists as electricity. The process of electrical discharge, or movement in a fluid of products of decomposition of one body towards another, is called electrolysis and represents a definite physical effect.

On the other hand, catalysis may mean anything, and generally is referred to by the writer as expressing some immaterial or mysterious agency which he himself cannot describe. On this account, though used by many writers as expressing an agency which is familiar to the person using the word, it should not be used in a common sense, because this use tends to mislead the reader.]

Gröh[1] states that, not only will the currents produce decomposition of the water around the electrodes in the tissues of the human body, but they will also act upon the tissues in proportion to the rapidity of the decomposition of the water. A weak current can produce extensive decomposition of tissue if continued a sufficiently long time; for instance if a couple of zinc and copper plates are strapped over an ulcer. Batteries which are employed for electrolysis are composed of a large number of small-sized plates, and the current from these is very painful. It is important that the battery should have great chemical power and should cause but little pain. Gröh thinks that a battery arranged for heat would be the most suitable for electrolysis—that unless the current be passed through a closed circuit, and thus be brought in contact with the tissues, its thermic effects will not be developed. This heat effect will not be produced unless the needles touch each other. He calls the action by the name of catalysis if the electrodes are applied to the cutaneous surface by means of moistened electrodes, as sponges dipped in salt water; and electrolysis, where needles are thrust into the skin, and thus carry the current into the deeper tissues. He uses common sewing needles,

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[1] Gröh, Die Electrolyse in der Chirurgie, Wein, 1871.

which are connected by copper wire and insulated by a covering of gutta percha. Clinical experience shows that physical action, possibly even absorption, can thus be effected by the surface contact by means of moistened electrodes, or by what Gröh calls catalysis; it would be accomplished only with currents of comparatively high tension or by currents of great quantity, on account of the great resistance offered by the skin. Gröh states that the battery should always be tested before its use in regard to its power of decomposing water. He used Frommhold's battery, of thirty-two cells, and when he wished a stronger action than he could obtain from this, a Grove or a zinc and iron battery. He advises against the use of steel needles or those made of zinc. Needles made of these metals oxidize too easily.

The advantages, claimed by Gröh, for the treatment of electrolysis are:

1. Diminished pain and odor of cancer.
2. In tumors no hemorrhage.
3. Size of affected glands can be reduced in cancer.
4. Very little nervous shock.

Its disadvantages:

1. Cost of battery.
2. Cleaning and repairs of battery.
3. Time required for treatment.
4. Non-portability of large batteries.

A review of the literature of the subject of the action of electrolysis exhibits strange inconsistencies among writers of note; it will be instructive to present this review somewhat in detail.

Another author[1] states that Berthelet has shown experimentally, that electrolysis may be possible in two ways: first, the action of electrolysis will be the smallest where the heat-current has been shown to be the least; and, vice versa, where the heat-current has been shown to be the strongest, the amount of electrolysis will be proportionally greatest; and, again, that no decomposition will be produced where the heat produced by the battery is less than that absorbed by the electrolyte in its decomposition. His experience shows that the most advantageous conditions are those in which the internal resistance of the battery equals the resistance of the electrolyte. A current passing through several conductors will be divided proportionally to their several resistances.

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[1] E. Doumer, De l'emploie des courants électriques en chirurgie, Paris, 1883. Thesis, Chapter iii., Electrolysis.

The following table of resistances presented by the tissues of the human body is taken from Eckhart. The resistance of the muscle is called 1. and the humidity is called 100.

	Resistance.	Humidity.
Muscle, ...	1	2 to 80
Tendon, ...	18 to 25	62 to 89
Nerves, ...	19 to 24	39
Cartilage, . . .	18 to 25	50 to 75
Bone, ...	16 to 22	3 to 7

The resistance of the skin is inversely proportional to its degree of moisture by imbibition, being greatest with dry skin.

Thus, it will naturally follow that the current strength should necessarily be increased to overcome any increase in the resistance of the human tissue comprised in the interpolar circuit.

All compound bodies in solution which act as conductors of electricity do so as electrolytes. Doumer states that, in nearly all cases of electrolytical action there is produced, at the surface of the electrodes immersed in the solution, "peculiar phenomena not completely understood," which cause an enfeeblement of the strength of the current; this is known under the name "polarization of the electrodes." Many writers explain this as due to a partial recomposition of the products of decomposition, on account of which a current is set in motion in a direction opposed to that which comes from the battery, through the electrodes to the tissues, in which the process of electrolysis is in operation.

The existence of this secondary or opposing current can easily be demonstrated by the substitution of a galvanometer in the circuit, instead of the battery circuit; by this means, it is proved that this opposing current is in operation during the period of action of the primary current.

Doumer presents the following summaries of the laws which govern the action of electrolysis in living tissues:

(Laws of Faraday.)

1. The decomposing force, or chemical power, will be the same in all parts of the circuit.

2. The quantity of the electrolyte which is decomposed will be proportional to the quantity of electricity passing in given time.

3. When the same current traverses successively several dissolved

binary compounds of the form AM, the weights of the elements, which are separated, will be to each other as their chemical equivalents.

4. The internal chemical energy of each couple in the battery will be equal to the external energy. Thus, chemical action is independent of the number of couples when the battery is arranged in series, [for tension,] and equal to their sum when arranged for surface, [for quantity.]

5. (Becquerel). When a current traverses dissolved binary compounds, which are different from AM, the electro-negative body will follow the preceding third law of Faraday. For instance, we should find in the electrolysis of hydrochloric acid (HCl), a result of chloride of copper (CuCl) and bichloride of copper ($CuCl_2$), dissolved in a solution, and at the negative electrode twice as much copper will be deposited from the protochloride as from the bichloride. This law of Becquerel is only hypothetical, and is not clearly established.

This author proves by a system of elaborate calculation that the energy of chemical action is equal in all parts of the circuit.

According to another writer, Scoutetten,[1] the mode of action of the current in cases such as a hydrocele with 100 grammes of fluid, cannot well be explained by the amount of water decomposed; because each gramme which is decomposed ought to yield 200 litres of gas; nor can the current in the short space of time required for one sitting produce so much decomposition. The absorption of the fluid must be either due to a mechanical transportation, by the theory of electrical osmosis, which would occur in fluids through an animal membrane without decomposition; or else this effect is caused by the process of absorption through cell tissue from physiological stimulation; the chemical effect would be due to a direct decomposition by electrolysis. This last mode of action could only explain a small part of the resulting decomposition. According to this same author, the escharotic action is due:

First, to the local chemical effect, as is commonly supposed, but in his opinion this is untenable; because a similar chemical action, which follows the local application of potassa cum calce, requires six to ten minutes to act as an escharotic; it is difficult to believe that the action of electricity is so much more chemically active when small currents are employed.

Second, the unquestionable calorific action of the electrical current

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[1] France Med., 1865, xii., 469. De la methode dite electrolytique.

cannot be separated from the chemical, for if the heat current be reduced, the power as well as the chemical effects of the battery is likewise diminished.

Third, electricity by its too powerful functional stimulation, probably from the very high tension of the current, may produce ecchymosis of the muscle and even gangrene; in the same way that animals overdriven will have the same condition of ecchymosis of their muscles. The eschars form only at the point of surface contact of the electrodes with the skin, because these eschars themselves protect by insulation the underlying tissue.

Electricity has not only a temporary and local action, but also an action upon the deeper tissues. According to this author a large number of small elements having a feeble chemical action are preferable to the use of three or four elements which have large surface. The coagulation of blood produced by the contact of the electrodes, as well as the cauterization, are the result of the chemical action; "but there is more than this."[1]

Von Beetz[2] states that conduction may take place for the passage of electricity with or without decomposition; it may occur in fluids without decomposition, *e.g.* mercury, but usually fluids undergo a decomposition. Again bromine, which is not decomposable, will not conduct at all: the same is true with pure water. By way of explanation it should not be overlooked that where conductors, whether liquid or solid, offer very slight resistances, it is generally known that the constitution of these conductors is not subject to alteration, so far as their chemical composition is concerned.

Tripier[3] contends that interpolar action will depend upon which of the poles are used, *i.e.* there is one polarization at the positive electrode, and also there is another at the negative. There are some cases of diseased tissue in which one should be used in preference to the other. His experience up to the present time has not been sufficient to guide his selection. In "tubular" cauterizations he prefers the negative electrode. It is not however, in his opinion, correct to conclude that a special "resolutive" action resides in the negative electrode, since the positive also has some such action. Tripier, in support of his opinion, reports a case where an orchitis was cured by the positive electrode applied to the surface of the scrotum, and the negative electrode applied to the perineum, or was held

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[1] Idem. xxiv., 769. Onimus.

[2] Von Beetz, Grundzüge der Elektricitätslehre. Stuttgart, 1878.

[3] Tripier, Arch. Gen. de Med., vii, 48, 1881.

in the patient's hand. He also reports a case of ulceration on the anterior surface of the tibial region, which had been unsuccessfully treated in hospital during several months, to which he applied the positive electrode; improvement commenced after the first application and complete cicatrization after the ninth sitting, as well as disappearance of the œdematous infiltration of the tissue. The introduction of a catheter may be managed without pain, if passed during the state of negative polarization of the urethra, which is independent of any appreciable cauterization; dilatation also of an urethral stricture by the local action of the negative electrode used as a catheter may be painlessly performed, and this will persist longer than when mere mechanical dilatation has been employed.

Sometimes, where there is an ulceration of the mucous surface at the stricture, it is more advisable to use the positive electrode, after which a healing of the ulcer as well as a permanent cure of the stricture will follow. These therapeutical applications tend to show that polarization will destroy the sensation of tissues in the interpolar circuit. This therapeutical application will be described more at length in another chapter; it is here mentioned simply to show an illustration of the local action of the chemical current upon the living tissue.

Neftel[1] states that Bruns obtained only negative effects by the use of electrolysis, while Gröh showed that the action was simply that of a caustic. These writers, however, seem to have used batteries arranged for high tension on the supposed principle that, as the current was to pass through the high resistance of the human body, this would be the most serviceable current for application in the treatment of tumors.

Ciniselli,[2] seems to have devoted his attention to the practical application of the electrical current, to its local action in the blood and other tissues of the living organism; he does not seem to have concerned himself as much with a study of the various forms of electrical current, and apparently prefers only the current which can be derived from the arrangement in Volta's pile, that is, to couple the discs of the Voltaic pile in simple series for tension. According to this writer a battery to produce sufficient chemical power should be composed of several small elements (arranged as above described). He also preferred to use for an electrode a metal which was

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[1] Neftel, Die elektrolytischen Behandlung Boesartiger geschwuelste. Repr. from Virchow's Arch., lxxv.

[2] Ciniselli, De l'action chimique de l'électricité. Gaz. des Hop., Paris, 1862, xxxv., p. 486, Resumé par Velpeau. Also idem 688, xxi., p. 206.

capable of being attacked by the products of decomposition; these should be directly inserted, one at each of two points, and the surface of tissue to which the opposite pole is applied should be sufficiently moistened to favor the conduction of the current. If electro-puncture be employed with iron needles there will be seen an inflamed red border of the elevated epidermis around the needle of the negative electrode, and serum (water?) will escape from the needle puncture; the needles can be easily removed, and their extraction is accompanied by the expulsion of the decomposed gases with crepitation. In his later operations Ciniselli preferred the employment of zinc electrodes, because this metal is acted upon by the products of decomposition. When it is remembered, however, that the zinc pole of a chemical battery even in a solution of inorganic salts will be surrounded with gas, and become insulated, it is difficult to understand why the same insulation will not take place around the zinc electrode when thrust into the living tissues; these tissues must be the seat of organic chemical decomposition of a very complicated character. The point of insertion, as is remarked with truth by Ciniselli, presents an eschar which resembles that produced by a caustic alkali, especially ammonia; but it should be stated furthermore that this author makes mention that the eschar produced from a caustic alkali involves deeper tissues than that which follows the local application of the electrode. If the track of the electrodal eschar be laid open it is found to extend to the depth of insertion of the needle, and is in the shape of a cone the base of which is at the skin. The author refers only to the effect of the negative electrode.

He describes the effect of contact of the positive electrode with the skin as somewhat different; after weak currents there is a small black point, not an eschar, but which is due to the oxygenation of the blood; this detaches itself without ulceration of the surrounding tissues after stronger currents; in addition, there is formed a dry yellow areola, which is deep and depressed without the development of gas or liquid; the iron needle can be withdrawn with slight difficulty, and will afterwards be found rusty with a dull point, and the open puncture will appear like a little round hole; the tract will be limited to the immediate vicinity of the needle, and a superficial ulceration will remain.

The writer of this treatise differs from this opinion of Ciniselli: the insertion of an annealed electro-positive needle made of iron is followed by the appearance of a small red point, which is a little larger than the needle which has been used, and is accompanied by a much smaller amount of water than would appear at the needle of the negative electrode, and also, with less gas; but, though there is rarely any œdematous infiltration near the puncture, the areola is at first red, and afterwards becomes bluish red. This last color will persist for several days or even weeks. It is quite true that no dry scab will result, for the exudation is too scanty to form an eschar; when Ciniselli used gold or platinum needles he reports that the destroying action went deeper into the tissues. In these cases the local destructive action takes place rapidly with the development of considerable gas and accumulation of water, and the appearance of a frothy foam; the eschar was, also, conical, larger, softer and deeper.

Ciniselli speaks of the importance, especially in the treatment of aneurisms, of a clear understanding that the oxidation of an iron needle makes a protecting layer around the needle; there will be more protection afforded by the positive, on account of the larger amount of oxygen which collects at that electrode, than at the negative electrode to which the hydrogen primarily is attached. The inflammatory action is usually slight, unless erysipelas be present, especially when important organs are involved; probably because in our opinion these latter tissues offer a better conducting medium from the fact that they are more fully supplied with blood. Suppuration, according to Ciniselli, may occur around eschars: at the negative electrode on the fifteenth to the sixteenth day, and on the sixteenth to the eighteenth (rarely the thirteenth to the sixteenth) for the positive, at which time a separation of the eschar will take place. The period required for the separation of these eschars will vary, somewhat with the individual case, but the formation of eschar will always separate in the same individual at the seat of the positive electrode, sooner than at that of the negative electrode. The scab at the positive electrode is hard and dry from the first; that at the negative at first is soft and moist, and becomes still more so from subsequent suppuration, but after the eleventh day it will become dry and black.

There is this difference between an eschar produced by electricity and that by a chemical caustic; the former attains its maximum at once and does not subsequently enlarge, while the latter acts in the opposite manner. Cicatrization takes place under a scab on the twentieth to the twenty-fourth day. Varnishing has been tried to prevent the local action on the external skin; but, according to the above writer cauterizing of the skin is produced by the use of unoxidizable needles (gold, platinum, etc.,) and by the use of a needle as the negative electrode, before it has been surrounded by a clot which has been formed by the action of the positive electrode upon the blood. The best insulation of the surrounding tissues is that which is furnished by the black oxide of iron. A battery should be employed, which possesses the least possible tension combined with considerable chemical power, as well as tension. Ciniselli prefers the arrangement of twenty to fifty discs, (coupled in series) like Volta's pile. Each of these discs should have a diameter of five to ten centimeters, and should be moistened with vinegar; this battery should maintain an action for an hour, and the effect is not severe, and is easily watched. He refers to its application to cases of aneurism. Great current tension will cause pain, and a rapid action from the battery will not be limited to the selected portions of the tissues. According to this author, two Bunsen cells or six Daniell's cells will afford a sufficiently strong current and will not cause too strong heating action on the skin. It will be advisable to test the strength before the application is made on a patient.

This can be calculated by decomposition of acidulated water. One part sulphuric acid and thirty of water, when mixed together and submitted to electrolysis, should yield from 35.125 cubic millimeters of the mixed gases of decomposition per minute. Gold or platinum needles should be used for the purpose of powerful cauterization; in order to obtain the best chemical effects the current should be constant; carbon electrodes cannot conveniently be used because they develop heat from their own resistance. The electrode should be adapted to as close a contact with the skin as possible; if the epidermis should be hard and dry, a local skin bath may be previously taken in order to soften it; the skin must not be dripping wet, as the current will be dissipated. The same effect may result with too feeble currents; for if the acids and alkalies are produced in too small amounts to cauterise, they may irritate and cause a flow of serum (sic ?) which will disperse the current. A continuous effect may be obtained by a couple of metallic plates on the skin, preferably on a raw surface; the greatest effect is under the zinc pole. The effect of the electric thermo-cauterisation may be prevented by the occurrence of a hemorrhage. The apparatus required to heat a platinum wire to a white heat is costly, difficult to manage, and its action can not easily be limited; the chemical action on the other hand is easily managed even in long tracts surrounded by important organs. The action in the latter case is slower and the eschars more profound. Compared to chemical caustics, the effect is the same in less time, without the same degree of pain; zinc and copper plates locally applied to skin are not usually to be preferred, because the action will be too painful and slow; frequently there is no visible action except under the zinc plates. These may be used as revulsants in profound articular alterations and in diseases of the nervous system; good effect sometimes follows their use in chronic ulcers.

Tripier[1] discusses the question of electrolysis by propounding the query:—What passes in the interpolar zone? Can the theory of Grotthüs be applied here: that the terminal molecules of an electrolyte are decomposed, the acid going to the positive and the alkali to the negative, while a recomposition of the remaining elements continually goes on with adjacent molecules? This is only an hypothesis; "it responds to nothing apparent." If the positive pole be placed on the tongue an acid taste is developed; similarly an alkaline taste results from the negative pole. If now the positive pole be placed on the cheek and the negative in the hand the same effect is obtained, and similarly with the negative on the cheek; the explanation of this fact seems to be in an extension of Grotthüs' theory, that at (and also around) the poles there is an "atmosphere" of acid [or alkali] developed. That is to say, that there is a territory around each pole which partakes in chemical reaction of the characteristic of the governing pole. This view is confirmed by the fact that if the two electrodes are placed one on each cheek, a taste neither acid nor alkaline, but metallic, is developed, which shows a neutral zone as might be expected; the latter is intensified by the breaking of the current. Thus the current extends beyond the poles, and it has the power to supply the tissues with elements in their nascent condition. This excitement is not limited in time to the duration of the current, because the polarised zone gives a secondary reverse current after the cessation of the battery current. Tripier thinks that the electrolytical theory is insufficient to account for the work done in causing resorption of liquid tumors; this is due to the reaction of the nervous apparatus and to the modification of the circulatory conditions. The nervous reaction develops slowly after cessation of current. Thus from the passage of the current there result: 1, the electrolytic decomposition, 2, the polarisation of the electrode, as was a priori shown by Grotthüs and proved by Tripier's gustatory experiments. The consecutive results are: 1, the subsequent combination of the liberated acids and alkalies with the tissues, and 2, to polarisation succeeds de-

[1] Tripier, Galvano-caustique et electrolyse. Bull. Gen. de Therap., cl., p. 248, 1881.

polarisation, which does not manifest itself under the conditions in practical medicine, and would occur unperceived. But if the circuit should be broken [the circuit of an interposed galvanometer remaining in contact with the parts] the current resulting from the depolarisation becomes at once evident from its inverse direction; the same result will occur when, after the circuit is broken it be again closed. However, the current which is obtained directly from the battery, that of polarisation, is the only one of which we have any means of recognition in electro-therapeutics; the greatest therapeutical effect, according to Tripier, is that which occurs subsequent to the current. He has used the "tubular cauterization" with good effect in the opening of buboes, abscesses, etc. He has experienced very good results from this treatment in abscesses of the labia majora; in two of these cases the cure was absolute, although in one of them the return of the abscess would repeatedly recur after periodical spontaneous openings.

From this review, it would appear that no very definite explanation of the modus operandi of electrolysis in the action upon living tissues has received the sanction of medical electricians. Very little attention seems to have been paid to the effect of electricity in the life and nutrition of the living cell, at least in the animal organism; more attention has, however, been paid to the effect of the action of electricity on the cultivation of plant life. It would perhaps be advisable to close this present chapter with a brief summary of the actual facts which may be gathered from the various observations of authorities, the details of which have been rehearsed in the preceding pages.

First, there appear to be local actions of the electrodes upon their points of contact with the living tissues.

(*a*) These local actions may be subdivided into the results which are caused by the character of the electrodes employed;—if metallic electrodes are applied to the surface of the dry skin, the current will pass with difficulty through the circuit of the body, unless these metallic electrodes be thoroughly moistened, so that the skin also is well wetted; consequently the strength of the current must be increased, in order to drive a sufficient tension of electrical impulse through the resistance of this skin; in this case we shall obtain a different action from that of the electro-chemical decomposition which is usually ascribed to true electrolysis.

(*b*) There appears to be another action than that of pure electrolysis which has also its effects upon tissue changes: This is the physical effect of electrical osmosis, or the cataphoric action of electricity; this peculiar property is the same for all fluid bodies, and consists of the power of actually transferring the particles of fluid towards the negative electrode. There seems to be a sufficient amount of evidence adduced to show that the particular form of the tissues in the human body is so arranged, by means of porous mediums and the disposition of their contained water or saline solutions, to favor especially this cataphoric action of electricity. By means of this physical principle we may assume that there is an accumulation of the saline and watery solutions at the negative electrode; from this accumulation the effects of nutrition and metabolism of these tissues nearest to the electrodes must be subjected to some action, which may assist or retard the functional activity of cell life. At any rate, we have the right to assume that the saline materials of the tissues must go along with the water thus transferred by the process of electrical osmosis, and it is these substances which affect the nutrition of the cells.

(*c*) If the electrodes are formed of metallic needles, which are inserted into the deeper tissues, it is supposed by some authorities that the current passes more readily through the human body from one electrode to the other. Unfortunately for this theory of a different effect to be ascribed to use of the electro-puncture, the current strength is no more readily conveyed by this method than by the use of moistened electrodes which are applied to the surface of the skin.[1] Ciniselli states that the skin should only be moistened and not dripping wet, "for fear of dissipating the current." It can readily be determined by any one who will make the trial, that a weaker current is actually carried through the human body by means of the electro-puncture, even when several needles are thus inserted, than by the surface contact of sufficiently large moistened electrodes; a galvanometer and a rheostat will easily bear witness to this fact, which has frequently been observed in the author's experience.

(*d*) There is shown by the experience of most every observer that the local action at the points of contact of the electrodes with the skin will be followed by a different effect, dependent upon the strength of the current employed. When the current is stronger, the eschars will be more marked and in a shorter period of time than when the current strength is weaker. A difference in the appearance of the eschars will depend upon the pole

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[1] This is proved by the comparative amount of deviation of the galvanometer needle, which is placed within the external circuit in either case.

which is observed; that at the positive will be dry and small and hard, as compared with that developed at the negative electrode, and *vice versâ*.

(*e*) When the electrode is applied to the dry skin on a wet compress, the primary action will consist of a rubefaction. Unless the moistened contact be allowed to become dry, no eschar, with currents such as ordinarily are used, will be formed upon the skin in less than twenty minutes; and only then, when the skin exposed to its action is what is generally called tender.

(*f*) When the electrodes are formed of metallic needles the degree of local action will depend upon the metal of which these are composed. If they be composed of iron or steel the oxidation of these metals at the positive pole will cause their partial insulation; this will have the effect of lessening their power of conduction, and consequently of weakening their local action, as, also, the strength of the resulting current. If these metals be first annealed they will not so readily become oxidized. If platinum be used as an electro-needle the current will be conducted more readily, and the local action at the puncture through the skin will be more intense; and, if the current be continued long enough, there may result a local process of inflammation or of suppuration. If these needles be made of gold or silver the same effects will follow. If these needles be made of zinc, the local action will be more severe than in the preceding cases; yet, the skin or its hypertrophied tissue will form at the puncture a drier scab, which is equal in extent to that produced by the previously mentioned metals offering good conduction.

Second, the effect upon the changes in the deeper lying tissues is also dependent upon the character of the electrodes employed for their contact with these tissues.

(*a*) The moistened electrodes applied to the surface of the skin appear to produce some feeble action upon the deeper tissues which underlie them. This action is rather feeble and slow, but still the preponderance of the evidence will show that the action will result frequently in tissue absorption, or of resolution of hypertrophied tissue growths, and ought to be ascribed to the cataphoric action of electricity, which has been previously described. In fact, the evidence is strongly in support of the theory of promoting endermic absorption of medicinal substances in this manner.

(*b*) The method of electro-puncture does certainly effect the destruction of that portion of the skin directly brought in contact with the electrodes; and, where these tissues are particularly vascular, the destruction is greater and is more rapidly accomplished; on the other hand, where the tissue has less amount of blood supply, the process of destruction is more feeble and more slowly accomplished.

(*c*) Electro-puncture produces a much more rapid resolution of hypertrophied structure than can be accomplished by the surface contact of moistened electrodes applied to the skin; this resolution would appear to be more easily effected, when the irritating action around the punctures is not too intense; thus the long continued electrolytical effect of a weak current will promote this resolution better than the short action of a strong current. Another superior advantage to be gained from the prolonged action of a feeble current consists in restricting the effects of the resolutive action to the tissue which is the especial object of attack, and in this way the risk of causing the spread of inflammatory action beyond the point selected for electrolysis will be lessened.

(*d*) Currents of high tension will undoubtedly cause a greater effect upon the tissues embraced within the inter polar region, but their action cannot always be restrained to this region, and the action upon the adjoining tissues may produce troubles of inflammation which, in the case of serous membranes, may provoke dangers that should be avoided by the operator; because the electrolytical action properly so-called is not due to secondary effects of inflammation; or at least, it should show its effects upon the nutrition of the cell, and thus expend its energy in the effect of quietly, and not violently, inducing destructive metabolism.

The effects of electrolysis, which are the result of the resistance which the current meets in the tissues, can be more correctly understood in the light of the knowledge of the physical laws of the resistance of electricity and of diffusion of currents. These are described in a following chapter.

CHAPTER III.

THE BATTERIES FOR ELECTROLYSIS.

THE mistake is often made by those who have not studied into the question, that an electrical battery is a simple matter of selection, and that it should only answer the requirements of portability and convenience in practical use. In the commercial uses of electricity, no battery has yet been found that perfectly meets the requirements, yet in medicine physicians seem content with apparatus which the commercial electrician has discarded. The inconveniences of an electrical battery may be comprised under the following heads.

First, the space required:—It is often a great inconvenience to place a battery in a house or office, on account of the necessary amount of room which is required for the large number of cells composing it. The battery is often relegated to a closet or cellar; rather than to bring conducting wires through the walls or floor of his office a physician is induced to buy a cabinet battery. These batteries are often too costly for the regular practitioner. It would be much wiser to buy the kind of battery which should be contrived so as to furnish that particular form of current which the practitioner will find most particularly fitted for his special requirements. Portability and effectiveness of the battery are generally inconvenient inconsistencies; moreover, it is difficult for the physician to repair a portable battery, which is liable to become unsuited for its work from the warping of the wood of which the box is made, or from the corrosions and oxidations of its various metallic connections.

Second, the destructibility of the battery electrodes:—If by accident the terminals of the battery are left in connection, the zinc elements will naturally be wasted by the continuance of the chemical action in the battery solution. This inconvenience can be obviated by placing the battery in such a position that its various parts can be easily overlooked and examined without taking the battery down.

Third, the evaporation or spilling of the liquid from the battery cell:—This inconvenience is more likely to occur in the boxes of portable batteries in which the cells are placed; and can be obviated by placing the galvanic cells which form the battery in some cool damp place. If the battery is inspected once a month, not enough water will evaporate within that period to do any material damage.

Fourth, single fluid batteries:—These soon exhaust themselves when not in use. To obviate this difficulty many of the older batteries, such as, the bichromate battery, Stohrer's, Trouvé's, should be so arranged that the battery elements (electrodes) could be removed from the solution and thus stop the electro-chemical action when not required for use; most of the modern batteries, however, are now so arranged that electro-chemical action in the galvanic cells will cease when the terminal wires are not in connection.

Fifth, variations in the electro-chemical action and inconstant strength of the electrical current while the cells are in use:—This is one of the most important inconveniences for a battery which is to be used for electrolysis; because in some of its practical applications to medicine, a battery may be kept in constant use for half an hour to two hours. This inconvenience and objection can only be overcome by selecting that form of galvanic cell, in which the electro-chemical action is tolerably constant when at work. This objection will be more fully discussed later on. (See page 57.)

The most suitable forms of battery used for electro-metallurgy cannot, for obvious reasons, be adapted for electrolysis of living tissues. The substances subjected to electrolysis in the arts are usually immersed in the solutions contained in the galvanic cells. Daniell's sulphate of copper cell, which, in its improved form, is used so generally in telegraphy, has been until recently the most constant and uniform galvanic cell for continuous service. It is, however, a dirty cell, and has to be kept constantly under inspection, and the porous cell is apt to be incrusted with copper.

The galvanic cell, sometimes known by the name of Callaud's, or gravitation cell, has a very constant action, and is so arranged that the difference in the specific gravity of the resulting salts, of sulphate of copper and sulphate of zinc, will keep these two solutions separated so that the upper surface of one solution is in contact with the lower level of the other; it thus provides for a continuous electro-chemical action so long as the solutions are saturated, and the vessels containing them are at rest. Its electro-motive force is about equal to that of the Daniell cell. An inconvenience is shown in the use of this cell by the fact that the vessels should constantly remain in a state of rest to prevent the mixing of the two solutions which are kept apart only by their difference in specific gravity.

The Bunsen and Grove's cells are not convenient for medical use, though their electro-motive force and constancy are all that can be desired; these objections, and others besides those mentioned in respect to the Daniell and the gravitation cells, will naturally arise from the disadvantage in the expense of maintenance and the necessity for their being dismounted after each time they are used. The electromotive force of these batteries is here given, because they are referred to in other portions of this treatise. Electromotive force of these cells as compared to that of Grove's:—

Grove's cell taken as a unit, ...	100
Bunsen's, ...	76
Marié-Davy, ...	76
Daniell's, ...	56
Chloride of silver, ...	62
Smee's (when not in action), ...	57
" (when in action), ...	25

Taken upon the unit of measurement, of a volt, which will be explained later on:

Grove's cell gives an electro-motive force of .	2.00 volts.
Bunsen's	2.00 "
Marié-Davy	1.50 "
Daniell's	1.08 "
Smee's	1.00 "
Leclanché	1.50 "
Bichromate of Potassa	2.00 "
Chloride of silver	1.00 "
Gravitation cell	1.08 "

The chloride of silver battery is usually formed of many small cells; consequently, it is the most convenient form of portable battery, is quite durable, and has a constant action; in this battery the silver ribbon is encased in chloride of silver covered with unsized paper, but unless it is very carefully made it soon becomes useless. The materials of which it is made being naturally expensive, its initial cost is very high; the cost of repair is also very great unless the materials are saved. Its internal resistance is from four to seven ohms per cell, which is nearly six to twelve times more than that of the Leclanché cell. Its electromotive force is only two thirds of this latter cell.

As before stated, the most important consideration which should govern the selection of a battery for purposes of electrolysis, is that of constancy. The strength of the current, that is, its electromotive force divided by the resistance of the circuit, may be regulated by the number of cells used in proportion to the resistance in the external circuit. The matter of constant or inconstant strength of current is one which can be governed only by the form of the galvanic cell of which the battery is composed.

In the portion of this treatise devoted to the practical application of electrolysis in diseased tissues, it will be noticed that the electromotive force of a battery need not exceed thirty volts. It should be observed, however, that where there is great resistance in the external circuit, there should be sufficient current strength given by a galvanic battery, not only to overcome this resistance, but also to be conveyed to and displayed in that portion of the tissues which is selected for treatment. In the chapter devoted to a consideration of the laws of resistance and diffusion of current the reader will notice, that there may be cases where the transmission of the electrical current meets with so much opposition, that it becomes necessary to have an excess of the original current strength; this should be sufficient to induce chemical action through the resistance in circuit. It will there be learned that the poorer the conductor of electricity, the greater will have to be the initial strength of current to convey a sufficient quantity to cause the physical changes which result in the alteration of organic structures. It should, however, be here stated that any peculiar difference in the effect of a current which may originate from many cells, rather than from a single one, is not due to any difference in the current itself, but should be ascribed to the difference of relation which exists between the current within the galvanic cell and that in the circuit which is external to the cell. In reality, two currents generated from different sources, which give off equal quantities of electricity, must be equal in power. The quantity of electricity is measured by the amount of work which it accomplishes, and the strength of the current is represented by this amount of work done in a unit of time.

We have already seen that an electricized body exerts a repelling force upon a body charged with a similar kind of electricity. In order to overcome the opposing energy an expenditure of a definite amount of force must be used, which will be greater according to the higher amount of electricity with which the opposing energy is brought in opposition. Now, in bringing up this opposing force against the repelling force, a large amount of expenditure is required which is not appreciable because it is neutralized by the energy which it opposes. By way of illustration, if we raise a pound a distance of one foot we store up an energy of one foot power, which if it be allowed to fall, will itself perform one foot power of work. In the same way, if we set free a negative unit of electricity which we have raised to a potential of one unit, we shall find that we have stored up an amount of energy which is equal to the amount of work required to accomplish this; for in obeying the force of repulsion this unit will go off to an infinite distance, thereby performing one equivalent of work. "The fact that work has been done either in raising a weight or in electrifying a body to a certain potential shows that there has been a forcible disturbance of equilibrium, which nature will restore at the first opportunity. The weight, then, will fall as soon as released, and the unit charged will also fall as soon as given a medium, or conductor, through which it can fall. The reason will now be plain why electricity will flow through some substances; for we see that it is only endeavoring to expend energy by falling from a higher potential to one of lower potential; and that the conductor is merely a medium through which it can fall, in the same way that air is a medium through which a weight can fall."[1] Therefore, where the body acts as a medium of conduction the amount of electricity which flows into it from the point of origin, will, wherever it meets with resistance, be continuously subjected to an expenditure of force, which will be used up, or stored, as latent energy, and thus be deprived of its power of acting as an electro-chemical equivalent in destroying the organic compounds with which the electrode may be in contact. When, however, this latent energy is free to act, it will perform work in some way or rather upon living tissues whose composition forms a part of organic structures. Therefore if an excess of current strength pass out from the body and back into the galvanic cell from which it originated, its energy will be expended in decomposing the chemical compositions which form this

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[1] Fisk: Electricity in Theory and Practice. New York, Van Nostrand, 1884.

organic structure, or else the energy furnished by electricity will be expended in producing some other form of energy.

Galvanic Battery.—A galvanic battery is formed by the union of two or more galvanic cells. The theory of the action of these cells and their union in galvanic batteries has been explained in the second chapter. The methods of using these batteries will be presented in this present chapter. From what has been already mentioned it will naturally follow that the selection of a proper form of galvanic çell will depend upon the circumstances upon which it will be used for practical purposes. It is extremely doubtful whether electrolysis can be used in tissues in which the process of destruction by disease is already seated; it is hardly probable that the process of suppuration, or even inflammation, can be modified by electrolysis; but it is equally certain that the products of this suppuration or inflammation may be destroyed by the contact of an electrode placed directly upon them and that the healthy tissues underneath may be stimulated to form a healthy growth; this is especially true in the use of the positive electrode, because this terminal has the property of generating an acid reaction and repelling moisture. Great caution should be exercised by the physician in the use of electrolysis in the cases referred to, lest the very processes of disease or decay may themselves be hastened or increased.

It is also a question of judgment as to what quantity or strength of current should be selected for use in a given case presented for treatment; for there is a risk of stimulating the growth of abnormal tissue, the setting up of inflammation, or of suppuration, in these tissues or others near them. A careful analysis of the cases which have been published, many of which have been collected in this treatise for the reader's information, shows the necessity of this suggestive caution. We have indeed a weapon which we may use as a destroying agent; yet, fortunately, the very conditions under which electricity manifests itself in organic structures can be bandaged, as it were, by the very principles upon which these manifestations are founded; thus we may exercise a needed caution to prevent harmful injury. Experience will not only tell us when to make use of, and when to avoid the use of, electricity as a curative agent, but will also show us how to use in a skilful manner an agent whose property is probably, as it is now known to us, a destroying engine. We should seek to employ it as a mechanic uses steam, remembering that the very power which it possesses makes it useful only when restrained and controlled by discretion. Hence, it is important to select that form of galvanic cell in battery which will be appropriate to the effects which are desired.

Form of Battery for Electrolysis.—It is commonly supposed by physicians, that a battery of galvanic cells are always united together, zinc with copper and copper with zinc; and that if we wish to increase the current strength, we have only to multiply the number of cells or to increase the surface of the battery elements in these galvanic cells, as well as the surface of the exciting chemical fluid in them. The following quotation is presented from DeWatteville:[1] "In order to obtain the strongest current possible with a given number of elements through various external resistances, we should be able to alter their arrangement with every change of external resistance, so as to make in each case the internal resistance equal to the external resistance. Some writers have committed the error of taking this statement to mean that *under any circumstances*, the best battery is one in which the internal resistance is equal to the external resistance to be overcome. This is pure nonsense; the statement concerning the advantage of making the internal resistance equal to the external applies only to cases where a given number of given cells has to be used for a certain purpose. Whenever we are free to choose, we shall evidently prefer the cells in which, *cœteris paribus*, resistance is smallest."

Those batteries produce the best effects of electrolysis whose electro-chemical producing qualities are the best attainable. According to Faraday's law (as mentioned in a previous chapter) each ION has its own electro-chemical equivalent, and a given quantity of electricity (whether administered in large amounts in a short space of time or in smaller amounts during a longer space of time) should separate a given amount of that ION. The equivalents of an inorganic compound and their combination in chemical salts, have been definitely determined and arranged in tables (see page 18) which give these electro-chemical combining equivalents. This has not only been established for the simple IONS, but has also been calculated and determined for the complex ION; thus it has been proved that the electro-chemical equivalents of a complex ION is the sum of the electro-chemical equivalents of its component simple IONS. Therefore, where we have to deal with the compositions of the inorganic kingdom, the rules laid down in physics for the decomposition of chemical compounds can be safely followed and the battery can be mechanically

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[1] Medical Electricity. London, 1884, p. 36 and foot note to p. 37.

arranged to bring about these decompositions in a skilful and certain manner; for this purpose the battery should be selected and arranged in such a manner that it shall develop and deliver the electrical discharge or disturbance in a constant manner and in sufficient volume, by means of suitable conductors or conduits which will keep up a regular and uniform decomposition. If we knew, as well, the physical laws which control the composition of the elements of the organic kingdom, and if we did not have such a variable conductor as the human body forms, we could formulate and arrange the amount of current strength which will cause the decomposition of the elements from the definite structures which they form in nature and life. Before we consider the question of the application of the force of an electrical current in the decomposition of organic compounds and their arrangement in the form of organic structure of living tissue, it would be well to understand what is more positively known of the arrangement of galvanic cells of a battery, and which are capable of accomplishing most readily and conveniently the decomposition of inorganic chemical compounds. It must be again remarked that the larger the surface of the battery electrodes exposed to the chemical action of the solution in the galvanic cells, *cæteris paribus*, the larger will be the quantity of electrical force generated; this is again illustrated by the reservoir governing the flow of water, for it is well known that the larger capacity of a cistern the longer will be the supply of water; the higher also the height of water in the cistern and the wider its outlet the greater will be the quantity delivered in a unit of time. So, too, will be the effect with the electrical current, or force, generated from the galvanic cell, if the chemical action between metallic elements and the chemical compound be more active, or, in other words, be less subject to variation in the internal resistance of the galvanic cell.

It should be remembered that the disruption of the combining equivalents will deliver up the latent energy which was stored in the original combination, and that this liberated force must expend itself along the path which the electrical current traverses, provided that path be unobstructed. The force of the current would be expended in overcoming any obstruction which it meets, and will appear in the display of some form of energy. This latter effect is illustrated by the heating of a metallic wire, platinum for instance, which is made small enough to offer a resistance to the flow of force exerted from too great a volume of electricity which is discharged from the galvanic cell. In this case platinum acts as a conductor of electricity, but the electrical force meets with the obstruction offered by a thin wire which is also short enough to conduct the current through the circuit; but in doing this, the platinum molecules are so disturbed and set in active motion that heat is generated, and if the wires be too small the heat will be so great as to fuse the platinum in its thinnest part; if the wire is shorter and the current force no stronger, the force passes along the platinum molecules with so much greater ease that the disturbance is not sufficient to actuate the rapid vibration of the platinum molecules, which move more slowly and the heat will be so lessened as to become inappreciable. This same effect can also be known from the common illustration of a string of wooden balls suspended in air and so arranged that each is in contact with the other in a direct line; a light blow upon either end ball is communicated to the next and so on until it is expended, and the ball at the opposite end is unaffected and remains at rest; or the force may be so violent that it sets in motion every ball and may even pass back again over the same route. To follow the comparison closely the reader may imagine the platinum wire to be formed of a large number of platinum molecules always in contact, and in this way he may apply the principle to each case.

Electricity is simply a force transmitted and the effects of transmission may be represented and seen in many ways. Thermo-cautery and electrolysis are each translations of the same force. A heated wire and a chemical cautery may each be destroyers of living tissues, but the former cuts like a knife and the latter acts like a destroying chemical. To produce a thermo-cautery a battery of galvanic cells must be so arranged that a large surface of battery electrodes should be exposed to a large amount of an exciting solution, and the circuit, which is external to the battery, must be closed by a metallic conductor which will conduct the force with just such resistance that the molecules will be set in rapid vibration. It makes no difference whether the battery elements be only two in one cell or many couples in several cells, provided in the latter case that all similar metals be connected together by metal connections; in other words, all the zincs shall be united together, and all the coppers or carbons be united together. In this case the chemical decomposition occurring in the circuit within the cell expends its latent energy upon one element, which latter translates its combination with another chemical into the active development of electrical force, and is transmitted through the external circuit back again to the opposite elements. (See Chap. II., page 15). A qualification of this statement should be made which will be understood by reference to page 58; viz., that if the couples of battery elements be divided among a large number of cells rather than in one, for the purpose of obtaining a larger surface of exposure to the chemical fluid, the resistance occasioned by the distribution of the electrodes by metallic connections is somewhat greater, than if they were in only one; because no material substance is a perfect conductor of electricity. This is so evident that it needs no further explanation.

In a general way it may be said that galvanic cells may be classified under two varieties or classes, one of which contains the battery elements and solutions in one vessel or cell; in the other class the two solutions are separated in each cell by a porous medium, so that each element is immersed in a separate solution.

No single-fluid battery can give an electrical current of uniform constancy of strength, on account of the polarization caused in the solution; this polarization, as has been before remarked, causes an insulation of the battery electrodes, from the fact that, in the electrical discharge which results from changing the electro-chemical substances from a higher to a lower potential, another current is excited in the opposite direction, in order again to restore the equilibrium between the two kinds of electricity. It must be understood that electrical motion in a conductor is simply due to its being charged only with one kind of electricity which is seeking a combination with its opposite to restore electrical equilibrium; the metallic element which dips into the fluid would be charged with one kind of electricity while the chemical fluid is charged with the opposite kind. Unless, therefore, there be some means in the cell of continuously charging these two opposite conductors, the metal and solution, the electrical current will not be transmitted in an uniform or constant manner. Hydrogen and oxygen, which are the products of decomposition in the galvanic cell, will not recombine to form water unless favored by a suitable conductor; but, owing to the laws of dissipation of energy, not all the molecules of these two gases can recombine, because some of the latent energy used in the recombination will be dissipated. Pure water itself opposes a much higher resistance to the conduction of electricity than any of the chemical solutions employed in a galvanic cell; the addition of sulphuric acid decreases the resistance of water, but this acid oxidizes the zinc used as an electrode; on the other hand, the resulting sulphate of zinc does not alter the character of the electro-chemical constituents which are usually employed in the exciting fluid. Another serious objection to single-fluid galvanic cells will result from the fact of the continual alteration, while the battery is in use, of the substance used in the solution as a depolarizer; in a cell which contains sulphuric acid solution this acid will become gradually exhausted from use, and must be renewed from time to time.

In the second class, the galvanic cell is so arranged that the materials used in the exciting solution, as well as the depolarizing agent, are being constantly renewed. In the Daniell cell, for instance, the zinc electrode is immersed in a solution of sulphate of zinc, the copper electrode in a saturated solution of sulphate of copper; the chemical reactions which follow are, first: zinc combines with oxygen to form an oxide of zinc and the latter combining with sulphuric acid forms sulphate of zinc; second, from the sulphate of copper in solution an oxide of copper is formed, from which the oxygen is afterwards separated leaving metallic copper; third, the oxygen collected at the zinc pole, and the hydrogen collected at the copper pole, combine to form water; but owing to the fact, that the decomposition and recomposition are constantly in process, this third reaction neither adds to nor detracts from the electro-motive force of the cell. The dynamic value produced in the Daniell cell by the combination of one gramme of zinc with oxygen is equal to 1,301 heat units. 1.246 grammes of oxide of zinc combining with sulphuric acid is equal to 369 heat units. The equivalent quantity .9729 of a gramme of copper combining with oxygen is equal to 588.6 heat units. The combination of 1.221 grammes of oxide of copper with sulphuric acid is equal to 293 heat units. The thermic equivalent of the whole chemical action to each gramme of zinc is therefore $1301+369-(588.6+293)=788.4$. The electromotive force of a Daniell cell is, furthermore, as calculated by Sir Wm. Thomson, equal to about 112,000,000 heat units.

Siemens' and Halske's Battery.—This is a battery of the same kind as the Daniell with the addition of a porous jar made of parchment paper. This porous partition offers but little resistance. The copper in the shape of a bell is placed at the bottom of a glass jar. Within the parchment paper cell is placed a chimney within which is a mass of paper pulp, which has been previously moistened with sulphuric acid and dried; the zinc, made in the form of a very thick cylinder which is melted in a mould, is then placed on top of the dried pulp. The supposed advantage of this form of cell pertains to the fact, that the great thickness of the porous jar suppresses almost completely the diffusion of the sulphate of copper; and consequently the waste chemical action and unnecessary consumption of zinc and sulphate of copper are avoided. The internal resistance of this galvanic cell, however, is very great.

Bichromate of Potassa.—This battery originated with Poggendorff, and generally is in the following form: the porous jar containing carbon is placed in a glass vessel, in the latter of which is amalgamated zinc. The zinc is immersed in dilute sulphuric acid (1:10). In the porous jar in which the carbon is placed is a solution containing three parts of bichromate of potassa, four parts of sulphuric acid, and eighteen parts of water. Bichromate of Potassa is formed of

KO	47.11,	as an equivalence;
$2CrO_3$ . . .	100.56,	" " "
and results in	147.67,	total combining equivalence.

Sulphuric acid is formed of:

HO_3	40.	as an equivalence;
HO	9.	" " "
and results in	49.	total combining equivalents.

Four equivalents of sulphuric acid ($HO\text{-}SO_3$) will have a weight equal to $49 \times 4 = 196$. Thus the theoretical proportion is that of 147 to 196, or as 3 to 4.

The chemical reaction would be represented by the following equation: $3Zn + KO2CrO_3 + 7SO_3HO = 3ZnOSO_3 + Cr_2O_33SO_3 + KOSO_3 + 7HO$. Therefore one equivalent of bichromate of potassa (147.67) and seven equivalents of sulphuric acid ($49 \times 7 = 343$) are theoretically necessary. The electromotive force of this battery at the beginning is about equal to 1.77 to 1.80, but the resistance within the cell increases very rapidly, so that its action grows weaker and weaker after the first five minutes' use. Fuller's battery is a two-solution improved form of this bichromate battery, and its electromotive force is about two volts, and its resistance one ohm. The amalgamation of the zinc is an important modification of this battery. A great objection to using this battery is the formation of crystals of chrome alum, even when the battery is not at work.

A new form of battery has only recently been introduced, in which a bichromate of soda solution is used instead of the bichromate of potassa.

This battery is called "The Volta Pavia battery." It contains a large amount of solution, about six quarts, which is bichromate of soda [$Na_2O_2Cr_2O_5$] in dilute sulphuric acid [$4H-O-H(SO_3)$]; the chrome solution is placed outside the porous cell in which the carbon or positive pole is immersed, and the porous cell holds the solution of dilute sulphuric acid in which is immersed the zinc; both of the battery elements present a large surface to a large quantity of fluid. The chemical reaction is:

In outer jar,

$$Na_2O_2Cr_2O_5+4H-O-H(SO_3)=Na_2Cr_2O_8(SO_2)4+4H-O-H+3O;$$

In the inner porous cup,

$$3H-O-H(SO_3)+3Zn=3ZnO(SO_3)+3H-H.$$

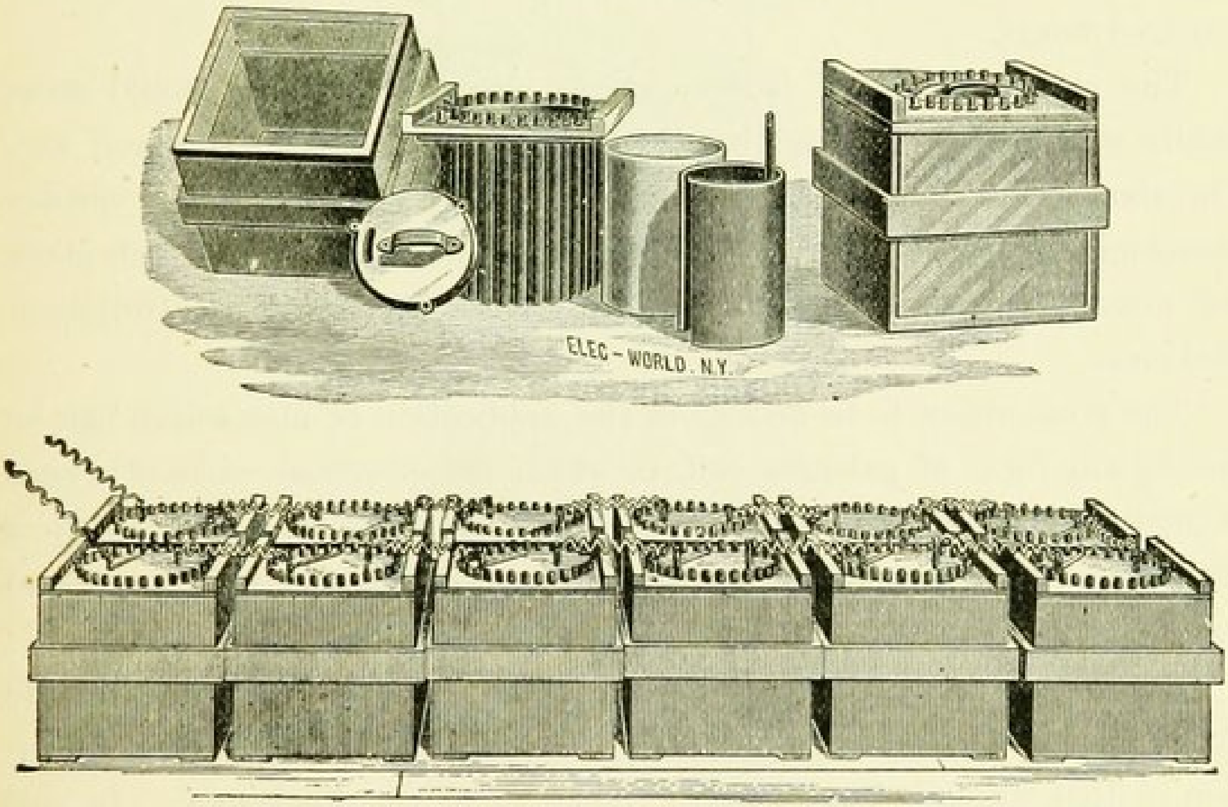


FIG. 6.

The electromotive force of this battery (open circuit), =2.2 volts. The internal resistance of this battery equals .05 ohm.

The electromotive force of this battery (closed circuit), after 6 hours work=1.9 volts.

If the electromotive force of this cell is 2.23 volts, as claimed by its inventor; and if the internal resistance is only .05 ohm, this new cell would give the current which passed through an external circuit of negligible resistance 44.6 ampères; this would be capable of precipitating 178.4 grammes of silver per hour, or 5.31 grammes of copper, or of decomposing .41646 gramme of water per second. It should be noticed that this form of cell produces the strong ampère current from the fact of the very small amount of its internal resistance which is claimed by its inventor. In the case of the external resistance being greater the effect would be caused of reducing this ampère strength by an amount corresponding with this external resistance. There are other advantages claimed for this particular form of cell; these consist of the constant and prolonged action with smaller corresponding loss of current strength as compared with other batteries. If the few trials which the author of this treatise has made of this cell be of any value, it would certainly appear that the constant action of this form of cell is the best of any of those which he has tried. It is claimed as the working power of the bichromate of soda battery, that an incandescent electric lamp of a low resistance can be maintained for three hundred hours.

The various forms of battery are so numerous, that it would seem hardly worth while to describe all of those which are in common use. The above description of the two general classes into which the various forms may be divided, will give a sufficient information, from which other and newer forms of battery may be selected for the use of electrolysis in medicine.

The great object to be desired in the application of electrolysis can be met by any form of galvanic cell, in which the electrical current is kept in motion in a constant manner and of sufficient volume, to keep up a regular and uniform chemical action of the organic structures we seek to modify.

Another convenient form of battery in the author's experience is made up of what is called the cylinder cells. This cell is an improved modification of that which is known under the name of the Leclanché. In this form of cell, illustrated in figure A, the zinc is immersed within the carbon cylinder, as shown in the sectional view of plate B, of the same illustration. The electromotive force of this cell in open circuit in ordinary use measures 1.4 volts with an internal resistance of 1.5 ohms. A description of this cell is given under the head of the Leclanché cell.

The two elements or battery electrodes should have the property of being rapidly depolarized. In short, an effective battery should not allow of the collection and adhesion to the cell elements of the *ANIONS* and *KATIONS* which would in such cases impede the flow of the electrochemical bodies to the elements, and thus obstruct their action, and make the current discharge unequally and ineffectively. A cell which contains as an exciting fluid a solution of bichromate of potassa is inconvenient for constancy of work, though its initial electromotive force is very high as compared with other galvanic cells. This single-fluid cell is liable to become rapidly polarized, thus increasing its internal resistance, when in use for a few moments. Agitation of the solution may remedy temporarily this polarization, but the deposit of secondary chromate salts, which is insoluble in a crystalline form around the battery electrodes and on the glass cell, will soon increase the internal resistance of the elements within the cell, and in this way impede the chemical action; thus

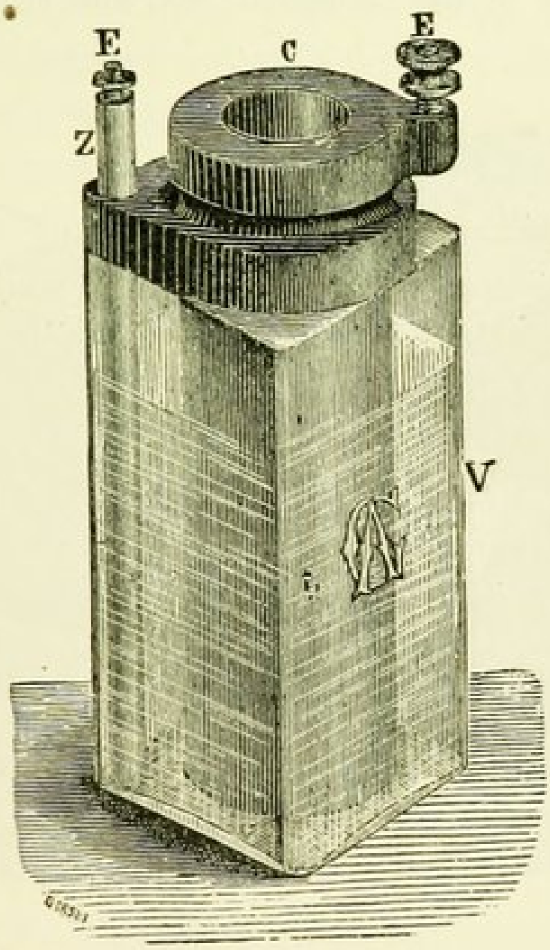


FIG. 7.

the frequent renewal of the exciting solution is required. Single-fluid cells, of which this has been the most popular in use, have now quite generally passed out of medical use.

The regular Leclanché cell which is so generally known from its common use is not a convenient working battery for closed circuits, that is for a continuous use of the electrical current. Its initial electromotive force is higher than that of the Daniell cell previously mentioned, but after a very few minutes of continuous work, its force will diminish and gradually fade out; when at rest it soon will resume nearly its original strength, and ordinarily will last in circuits of high resistance as long as it is replenished with new zinc, provided that its circuit is closed for a few moments at a time. In this form of cell the depolarizing agent, manganese oxide, acts so slowly that the electro-chemical action with a closed circuit keeps ahead of the depolarizing action contemplated by the inventor, thus requiring a few moments for rest and depolarization. Of course, when this battery works through a circuit containing high resistance the circuit back to the battery is impeded, and consequently its electro-chemical action will be better maintained.

M. M. Gaiffe and Clamond have also endeavored to obviate the disadvantages presented by the Leclanché cell, and have placed within the

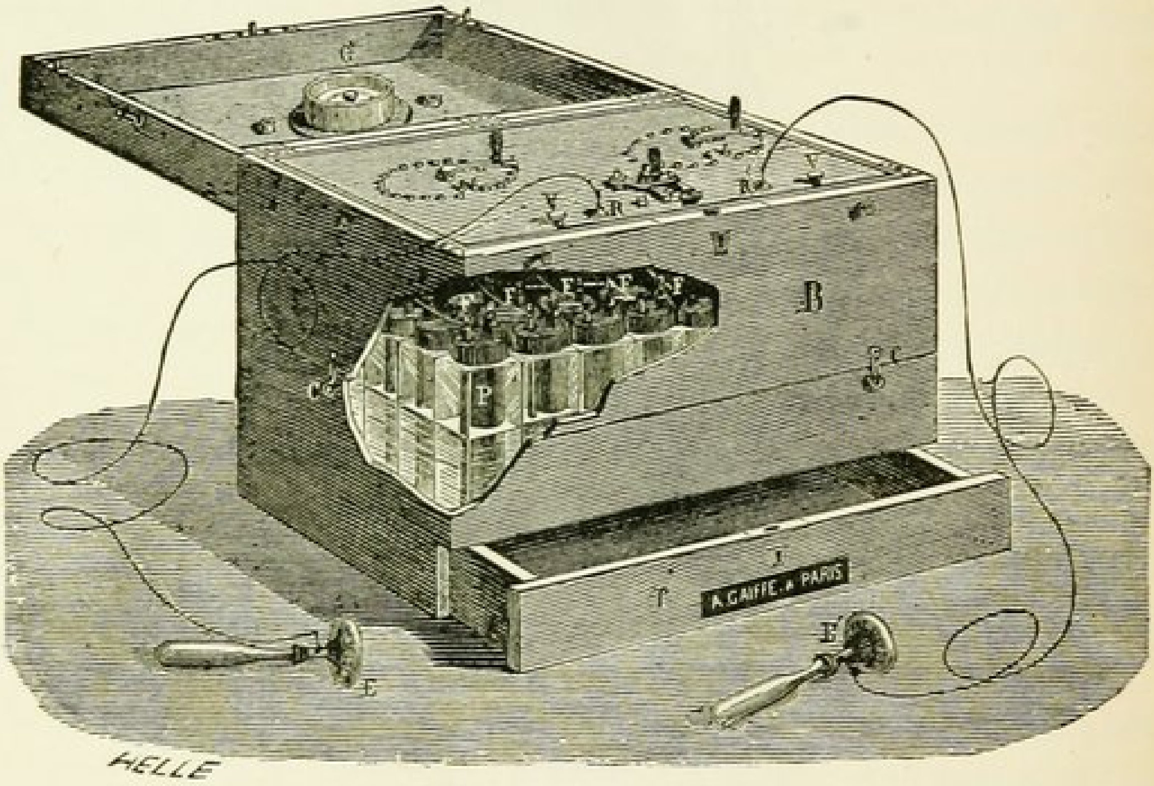


Fig. 8.

hollowed carbon the manganese oxide, and by means of small holes pierced, the liquid is allowed to pass in and out of the carbon chamber to this depolarizing agent. Then instead of using chloride of ammonium (sal ammoniac) as the exciting solution, they use a neutral salt of chloride of zinc, free from lead contamination. By this means they avoid the presence of nitrogen, one of the components of the ammonium salt; and the formation of ammonia gas, as in the original Leclanché cell, is substituted by the more simple chemical salt of chloride of zinc and its decompositions. The zinc chloride should form twenty per cent. of the solution and therefore supersaturates the water. This modified form of Leclanché cell has an electromotive force nearly equal to the original, but has a higher resistance within the cell. This form of battery arranged in a portable shape is shown in the figure. [Fig. 8.]

One of these cells, which had been in pretty constant use by the author, was recently measured, and found to have an electromotive force of 1.35 volts and an internal resistance of 7.08 ohms, on open circuit in ordinary use.

In the ordinary Leclanché cell the chemical reaction is as follows:

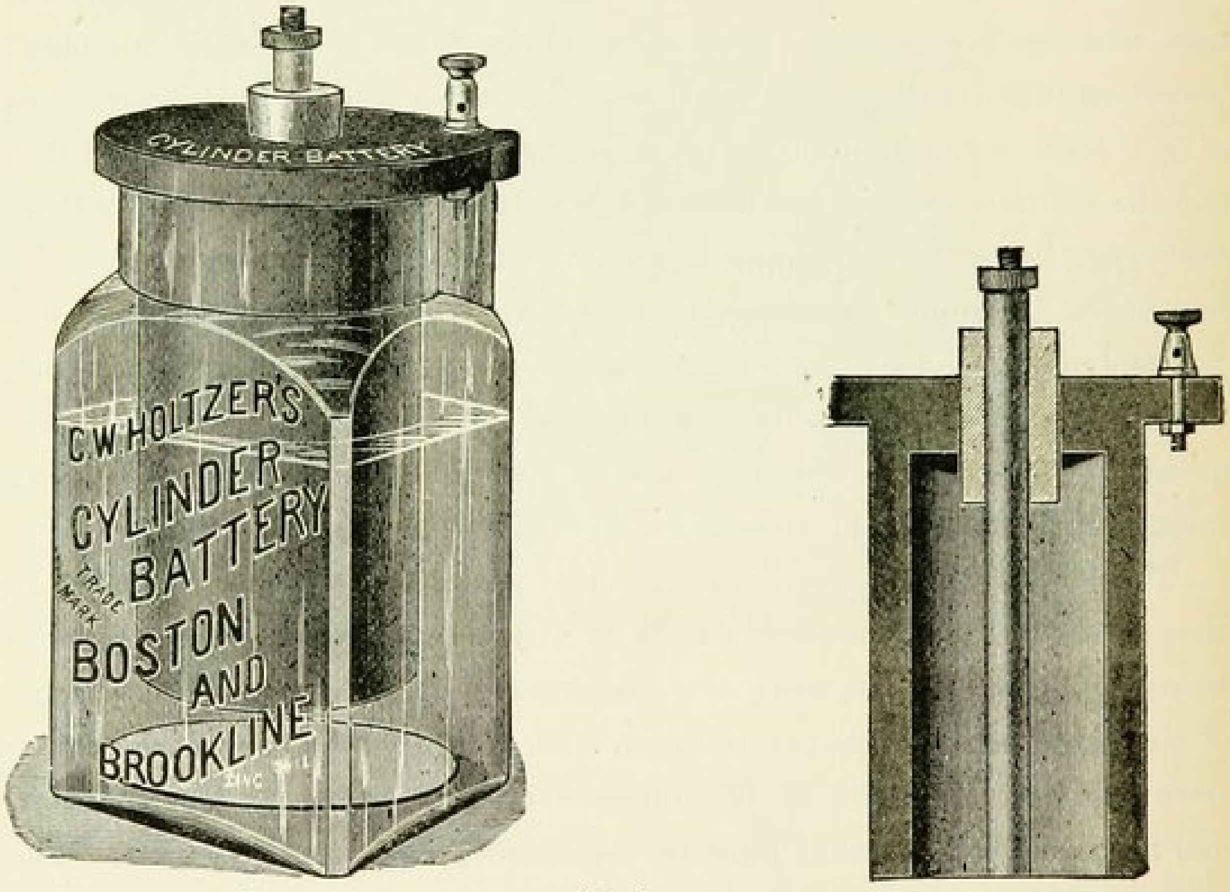
$$2Zn+2NH4Cl+2MnO_3=2Zn\ Cl_2+HO+2\ NH+Mn_2O_3.$$

This battery when used for medical purposes in small vessels has the disadvantage of depositing upon the zincs, even when not in use, crystalline oxy-chloride of zinc together with a double salt of chloride of zinc and ammonium; the ordinary form of the Leclanché cell is well adapted to medical uses, and has accomplished good work where its use is required for short periods of time for diagnosis; but for the purposes of electrolysis other forms of cell, such as that of chloride of silver, are more generally used. Gaiffe's and the cylinder cell are in the author's opinion much superior to both of the former because their action is more constant. The cylinder cell is the best of the Leclanché principle, because in this cell the amount of the solution and of the surface of the metals which are exposed to its action is very much larger, and in this way the internal resistance is decreased; consequently, the electro-chemical action is less liable to obstruction during short periods than in the smaller cells of the same kind.

These cells will require the renewal of the zinc elements from time to time according to the amount of use to which they are subjected. It will be remembered that the work of a galvanic cell is measured by the amount of zinc which enters into combination with the hydrochloric acid resulting from the decomposition of the chloride of ammonium of the solution, and therefore this element must be replenished as fast as it is used. The action on this metal is principally at the level of the upper surface of the solution, and consequently this should be the place of inspection of the condition of the cells. Frequently the zinc may appear to be intact, when really at this point it has become corroded, and it will suddenly break off and interrupt the conductivity of the battery. If the cells of the battery are connected in series the whole battery current may thus be cut off, and made unserviceable.

The deposition of oxy-crystals interferes with the chemical action of the zinc and salts in solution. Gaiffe's and Clamont's cells are practically free from this objection. One of their batteries purchased two years and a half ago by the author in Paris, and used pretty constantly ever since, is in as good condition as it was originally. The zincs and solutions have been renewed twice and the battery is as strong as ever to measurements by the Voltameter tests. This cell is represented of half its natural size in figure 7.

The prism cell is made of pyrolusite formed by the moulding of manganese oxide and powdered gas carbon in the form of prisms under a temperature of 212° F. (100 C.), and a hydraulic pressure of three hundred atmospheres. This is also a modification of the Leclanché cell, and is used without a porous cell, but unless it is kept wet with the solution the pyrolusite becomes hard and impervious.



B. FIG. 9.

Holtzer's modification of the Leclanché cell, called the Cylinder cell (Fig. 9), is formed of an agglomeration of carbon and manganese under heat and hydraulic pressure of three hundred atmospheres. This element is formed of an agglomeration under heat and hydraulic pressure of gas carbon and manganese which is moulded in cylindrical form with a top plate of carbon. The zinc element is separated, or insulated, from this carbon by a cork through which it passes within the cylinder, and is immersed in the chemical solution of chloride of ammonium; unless, however, the sides of the glass cells are made of a bulging shape, adjacent carbon covers are apt to make connection by contact of the opposite terminals of the cells. These glass vessels, therefore, are now made in this form. This cylinder cell has the advantage of presenting a very large surface.

A few pieces of zinc at the bottom of the vessel will prevent the incrustation of crystals previously mentioned as one of the disadvantages of the Leclanché cell. The electromotive force of these cells is so much greater than the Daniell's cell that 25 of Leclanché are equal to 40 of Daniell's, and to even more of the chloride of silver battery.

A closed circuit in any of these Leclanché cells will soon cause the current to be enfeebled. The amount of work done by any galvanic cell is marked by the amount of zinc lost from the zinc element, as mentioned above, and in a Leclanché cell when this is used up a new zinc can be substituted and the work of the battery again be renewed, water being added to make up what may be lost from atmospheric evaporation.

If we assume that the resistance of the human body is 2,000 ohms it will require about three of these cells to produce two milliamperes (see p. 265), which is usually the smallest amount of electricity required in its practical application in medicine. To illustrate the comparative power contained in this form of galvanic cell, a six candle-power electric incandescent lamp (five ohms), can be maintained at an uniform bright glow for about thirty minutes, after which the light will gradually diminish, and in an hour will become of a dull red color, but after another hour's rest the battery reassumes nearly its initial power. Twelve of these cells in action for half an hour in constant use on patient, and for a second.half hour working through a voltameter, decomposed during the next fifteen minutes 100 c.m.m. of mixed gases from a one per cent. acidulated solution of water; these same cells were allowed to rest for twenty-four hours, and then they decomposed 35 c.m.m. during the next four minutes, working through a resistance of 2,000 ohms. The same cells at another trial, being previously connected during an hour in a circuit having a resistance of 2,000 ohms, then decomposed 35 c.m.m during four minutes. This same operation was repeated with the same result, and then with no resistance in the circuit, these same cells decomposed 125 c.m.m. in fifteen minutes. These same cells at another trial were connected through 2,000 ohms resistance during eighty minutes, and with the same resistance of circuit decomposed 35 c.m.m. in four minutes, and immediately after, without any resistance in circuit, decomposed 100 c.m.m. during four minutes.

Batteries which are arranged only for open circuit, like the Leclanché, will quickly run down when used on a closed circuit, unless they are working through pretty high resistances. These suggestions are important, since it must be admitted that, up to the present time, no battery has yet been found which will stand the test of working through a very low resistance without rapidly running down. The nearest approach to this is the action of the bichromate of soda cell, which has already been mentioned on a preceding page. In this battery the zinc electrode weighs nearly a pound. The action of the open circuit battery may be compared to that of the main spring of a watch, the tension of which, after being wound up, will keep the watch running uniformly for a certain period of time; but if the balance wheel and escapement be removed, the watch train will rapidly run down. In like manner, if a chemical battery is connected with a poor conductor of electricity, or in a voltameter where it is decomposing water, its action will continue for a longer or shorter period of time, which will be commensurate with the amount of resistance offered in the external resistance of the voltameter or other conducting agent; whereas where easy transmission in a circuit of very low resistance is afforded for the passage of electricity from one pole to the other, the continuation of the chemical action in the galvanic cell will be short, because either the zinc is used up, or becomes covered with non-conducting substance, or the solution will become polarized.

Gaiffe's battery of modified Leclanché cells has the advantage of portability, over that of the Leclanché and the bichromate of soda battery; the latter especially is unsuited for transportation, because the vessels which hold the solution are made of lead and are consequently very heavy.

Gaiffe's box battery which has previously been described and illustrated occupies a space of eleven inches in height and length and seven in width, and for the purpose of epilatory electrolysis answers very well; yet its current is not so suitable for the major operations in goitre or for the removal of nævi, warts, lupus, or for treatment of chronic abscesses, or fistulous tracts and lymphatic enlargements; in these latter cases a battery will be required which has greater strength of current. It is undoubtedly true in theory that the human body is a conductor of high resistances; it therefore will require a current of high tension to overcome this great resistance; yet, it is a fact derived from practical experience that the currents of high tension produce a local action at the points of contact of the electrodes, which may be accompanied with inflammatory effects; these currents may therefore set up an irritation, which may do one of two things: this action may provoke an increase in the formation of the growth which we are seeking to arrest or diminish, or they may cause an inflammation which it would be advisable to avoid. In either of these cases a battery of more quantity and less intensity would be more advantageously employed;[1] only in the latter instance the current would meet with so much greater resistance that its action would have to be prolonged, in order to obtain the same physiological or chemical effects. The teachings of physical science do not seem to be of ready application in these cases, for the action of electrolysis is not the same as it would be in purely chemical compounds, and will appear to have a different effect upon structures which are endowed with the so-called vital functions of organic cell life.

It is well known that there are two systems of electrical force by means of which heat and illumination may be obtained from its action upon the inorganic substance; reference is here made to the two methods of procuring light from the passage of an electrical current through the resistance of carbon, by means of a current of low tension and one of high tension in the arc light. In these physical illustrations carbons may be heated to a state of incandescence by means of a current which passing through the human body may destroy life, or which passing through the human body at low tension (the Daft system), may not be felt by the person acting as a conducting medium; in both instances the same physical effect is produced upon the carbon, which is in a high state of illumination. It makes no difference in its application whether the source of electricity be derived from a chemical battery, or from a dynamo-machine, provided the character of the transmitted force be the same.

Batteries are sometimes coupled for surface, or arranged for quantity, as explained in the following chapter; for this purpose zincs should be connected, either in groups or all together, for one pole, and the same number, either in groups or all together, of carbons connected for the other pole; in such cases the battery is arranged like one or more single cells,

[1] This use of the word quantity is not exactly correct; it is intended to convey the idea that the delivery of an electrical current through a resisting conductor should pass slowly, and that the initial strength of the battery should not be allowed to accumulate at the connection between a good conductor and a feeble conductor; in other words, the action within the battery should be slowly going on, so that the tension should not be dammed up at the connection of the metallic rheophores with the human tissues.

according to the number of groups. In these its internal resistance is practically reduced to that of one cell, and the electromotive force of each group is equal to that of one of these cells. The tension of the electrical current is only equal to that offered by one cell; because, according to Ohm's law (I equals $\frac{E}{R+r}$), the tension is equal to the electromotive force divided by the resistance. This arrangement of battery, if in one group, forms a simple circuit, or is coupled for surface; it may be considered as one large cell with two large elements having the electromotive force of the particular form of cell used, say a Daniell's cell, which in that case will be equal to about one volt, working through one ohm.

When, on the other hand, batteries are connected in series, that is, each zinc connected with each successive carbon of the cell next in line, the resulting current will be that of a compound circuit; according to Ohm's law, this will be equal to the result obtained by multiplying the number of cells used, and dividing the product obtained by multiplying the internal resistance by this number of cells, and increased by the amount of external resistance.

If, again, we desire our cells arranged in groups of two or more (whıcn groups we may afterwards combine in simple circuit), and then combine these groups in series, we have a mixed form of battery. In this arrangement we will find more internal resistance than in the simple circuit, and less resistance than in the compound circuit.

For ordinary purposes, to obtain theoretically the best results from a given battery, the number of cells used should be multiplied by the quotient which will result from the external resistance divided by the internal resistance; then the number of cells, which result from extracting the square root of this number, will determine the number of groups into which the original cells should be divided. If the problem has been correctly solved it will be found that the internal resistance of such an arrangement of cells will be about equal to the external resistance through which the current ought to pass.

The application of the foregoing rules in physics is a simple matter as compared to their application in the domain of physiology; in the former we usually deal with simple chemical compounds whose physical properties are to a limited degree within our control; in the latter there exists a complicated structure of functionally active cells, the display of whose functions under varying circumstances will produce different results, and the character of which is almost unknown to us. These cells are placed in the midst of organic and inorganic chemical compounds; again, application to natural physics of the effect of a current of definite strength can usually be known and reproduced a second time almost exactly as at first, while in living tissues a repetition of the circumstances and methods of manipulation may be attended with almost totally different effects upon the conducting medium. We may add to this embarrassment that the effect of passing a current through the human body is still further complicated by the fact, that this conducting medium is a complicated machine, which of itself will form an electrical battery of its component particles; this will set up an opposing force which may counteract the original current, or may oppose the latter so that it will become nugatory.

By the application of the foregoing rules of physics we may calculate in advance the strength of current required to overcome a definite and constant resistance of a chemical compound, whether it be organic or inorganic, but the rule may not be applicable to portions of the human body in the interpolar circuit. If we wish to heat a platinum wire for use in the galvano-cautery, we may reduce the problem by means of the above-mentioned formula; the use of this may show us how to arrange the given number of cells so as to obtain a constant and uniform result; therefore we need not be surprised to find that the effect of galvano-cautery has its recognized place in surgery, and that electrolysis has yet to establish its position. Thermo-cautery, whether effected by a peculiarly mechanical mode of heating as by gas, or by a volatile fluid acting upon metal, or by the use of an electrical generator acting upon a resisting conductor of electricity, is a totally different therapeutical agent from electrolysis. In the former the action is that of a knife which will separate the tissues by a more or less sharply dividing line of demarcation, while in the latter the action is diffusive beyond its point of application. Consequently, the form of battery and its arrangement in series or surface method of coupling, will be different in each case; so, also, will be the choice of the kind of cell required for use in either instance. If we wish a current of electricity which will heat a wire and maintain this heat at the requisite temperature, we ought to select a battery containing a large amount of surface elements in a large quantity of electro-chemical solution. On the other hand, if we should wish a current of an effective physiological action which will work through a resistance of living cell structure, we must select that form of galvanic battery which will act in the interpolar region in a uniform manner; the strength and tension of the current need be only sufficient to overcome the resistance of the feeble conductor. Consequently, the matter of the internal resistance of such a battery would theoretically be of small importance, unless this resistance should be one which is the result of polarization within this battery current; for in the latter case its effect would be to interfere with the constancy of the electro-chemical action within the galvanic cells which form the battery. This part of our subject is more fully discussed in another chapter, and is only referred to here because a proper understanding of the principles belongs more especially to the matter of selection of batteries most suitable for electrolysis.

Formerly the method of thermo-cautery was applied to the treatment of lupus. It will be readily seen that this method is not as applicable to the radical cure of this disease as that by electrolysis, because the action of the former is immediately exercised upon the tissues which are directly in contact with the heated wire, and do not extend beyond this point, whereas the latter has an action which will extend comparatively to a considerable distance beyond the point of application. It has been found from the practical experience of the author that the most appropriate and suitable current for the purpose of electrolysis of the living tissues of the human body will be obtained from an arrangement of the galvanic battery in surface combined with series; this arrangement is more fully described in the next chapter. The arrangement in series is not theoretically the best adapted for driving a current of electricity through such high resistances as that which is furnished by the tissues, but the current appears to produce very much less inflammatory effects upon the skin and its subjacent parts at the points of contact of the electrodes, whether these are used by electro-puncture or by surface application. This arrangement appears to produce a sufficient physiological effect upon the tissues, and is followed by equally as good results in inducing metabolisms as that which ensue after the application of currents which have high tension. It is difficult to explain the physical cause of this difference in the action of the current, and it will probably be easier to understand the relative effects, when we have studied the conditions of the electrolysis of chemical currents as observed in laboratory experiments; we will, therefore, postpone the further consideration of this matter until later. It will perhaps be advisable to state here, however, that an examination of the reports of the clinical experience of other observers will confirm this opinion of the present author.

In order to have a constant electro-chemical action in the galvanic cell, means should be provided in the elements of which it is formed, so that the resulting products of decomposition of the substances in the solution shall find a ready and immediate recombination with other elementary bodies. In this way the presence in the tissues of a number of uncombined elements will set up an opposing current of electricity, which would otherwise occur from the sudden change of potential energies of these various elementary bodies. In other words a means of rapidly inducing a depolarization within the galvanic cells of the IONS which are liberated from their chemical combinations should be provided. This effect may be accomplished in various ways, and it is upon these principles that the many improvements in modern batteries are founded. For instance, the Leclanché is arranged so that a substance which is greedy for any liberated hydrogen is incorporated with the carbon element; this substance is binoxide of manganese, which always stands ready to furnish a molecule of oxygen to combine with the hydrogen liberated from the compound of chloride of ammonium (NH_4Cl), and thus to form water; otherwise the carbon pole would be surrounded with the ION, hydrogen, in the solution. If the latter condition was constant it would result in the metallic hydrogen being placed in a free condition, and thus seeking a substance with which it might combine; this effect would change the condition of the potential energies within the solution, and would incite another electro-chemical action which would act in the opposite direction and prevent the display of the original current.

Gaiffe's modification of the Leclanché and the modification of Holtzer's, as has been referred to in the preceding pages, seek to still further provide for the depolarization of these galvanic cells. Neither of these batteries, however, entirely meet the requirements, because the depolarizing action is too slow, unless there is a certain amount of resistance furnished by the external circuit, which will also retard the electro-chemical action within the galvanic cell, and in this way keep pace with the depolarization contemplated.

Frommhold's battery, the use of which is mentioned in connection with the clinical cases reported by Gröh in the seventh chapter, is composed of any number of galvanic cells, formed somewhat on the pattern of Smee's; the battery elements in this form of galvanic cell are composed of platinum, which are coated with lead, and of heavy masses of zinc. These elements are then immersed in a solution of sulphuric acid and mixed in the proportions of one part of the acid to sixty parts of water (1 to 60). The zinc plates measure one and three-quarters inches by seven inches, and are, consequently, very heavy in weight. An objection to this form of battery consists of its irregular action; for, if sulphuric acid is used with the zinc, the formation of sulphate of lead will result, which is insoluble, and consequently the electro-chemical action within the solution will be prevented. Another objection to Frommhold's battery is the great weight of the metallic elements.

Any further information in regard to batteries for application to electrolysis can be more readily learned by a reference to standard works on electricity, but for the convenience of the reader the following analysis of practical results of the working power of chemical batteries and of their components is borrowed from Hospitallier's Practical Formulary, translated by Wigan, and will serve to conclude this part of one subject:

CHEMICAL AND ELECTRO-CHEMICAL EQUIVALENTS.

ELEMENTS.	Atomic.	Chemical Equivalent. [e]	Electro-Chemical Equivalent in millemetres per Coulomb. [z]	Number of Coulombs necessary to liberate one gramme.	Weight in Grames liberate by one Ampere hour.
Electro-positive Elements.					
Hydrogen	1	1	.0105	96,000	.0378
Potassium	39.1	39.1	.4105	2,455	1.468
Sodium	23	23	.2415	4,174	.8694
Gold	196.6	65.5	.6875	1,466	2.475
Silver	108	108	1.134	889	4.0824
Copper (*cupric*)	63	31.5	.3307	3,079	1.19
" (*cuprous*)	63	63	.6615	1,540	2.38
Mercury (*mercuric*)	200	100	1.05	960	3.78
(*mercurous*)	200	200	2.1	480	7.56
Tin (*stannic*)	118	29.5	.3097	3,254	1.1149
" (*stannous*)	118	59	.6195	1,627	2.2298
Iron (*ferric*)	56	14	.147	6.857	.5292
" (*ferrous*)	56	28	.294	3,429	1.0584
Nickel	59	29.5	.3097	2,254	1.1249
Zinc	65	32.5	.3412	2,953	1.2283
Lead	207	103.5	1.0867	928	3.9041
Electro-negative Elements.					
Oxygen	16	8	.084		
Chlorine	35.5	35.5	.3727		
Iodine	127	127	1.3335		
Bromine	80	80	.84		
Nitrogen	14	4.3	.049		

The electromotive force of polarization of an electrolyte is a measure of the electro-chemical work done by the current in its decomposition. The principle of the conservation of energy will enable us to calculate this electromotive force by determining the equality of the work done by the current in overcoming this polarization, as compared with the mechanical equivalent of the quantity of heat which the liberated element would disengage in its recombination, so as to restore the electrical equilibrium of the electrolyte.

For the sake of illustration, let E be the electro-motive force required for the polarization of an electrolyte (in volts), Q the number of coulombs which has passed through it, the electro-chemical work of decomposition will be:

$$\frac{QE}{9.81} \text{ kil'gm.}$$

If z be the electro-chemical equivalent of the liberated element, the total weight liberated by Q coulombs will be equal to Qz.

Let H be the quantity of heat disengaged by one gramme of this element in its combination to form the original electrolyte, then the heat disengaged by the weight Qz of this element will be QzH. As the mechanical equivalent of heat is .424 kil'gm per calorie the heat disengaged by Qz grammes will be:

$$.424QzH.$$

The equation of these two terms will therefore be:

$$\frac{QE}{9.81} \text{ kil'gm.} = .424QzH, \text{ or finally,}$$

$$E = 4.16zH.$$

If we apply the above formula to the electrolysis of water, the heat disengaged by the oxidation of one gramme of hydrogen is 34450 calories, and the electro-chemical equivalent of hydrogen is .0000105, and we get:

$$E = 4.16. \times .0000105 \times 34450 = 1.5 \text{ volts.}$$

The electromotive force required for polarization of water is thus 1.5 volts. This will explain why one Daniell's cell is unable to decompose water, since the electromotive force of one of these cells is about one volt, and therefore two in series will be required.

If one of the elements or conductor used for the purpose of electrolysis, for instance the anode, be immersed in a solution of pure salt of the same metallic conductor, in which the metal is soluble, there will be no polarization; in this case the work done by the current is simply that of a transportation of material from one metallic plate to the other, and this will require only a very small expenditure of energy, which is practically reduced to the heating effect produced by the passage or transmission of electrical force. The amount of this required energy may be calculated by means of Ohm's law; if W represent the work,

$$W = \frac{RC}{9.81} \text{ kil'gm. per second.}$$

R in this case will be the resistance of the solution in ohms, and C the strength of the current in amperes. Practically, however, no solution is perfectly pure, and a certain amount of polarization must therefore take place in the solution, and should be considered in the account.

By the equation above mentioned in regard to finding the electromotive force of the polarization of an electrolyte, the electromotive force of a battery may also be theoretically calculated; in this calculation it will be found that this electromotive force in the Daniell's cell will be equal to the difference between the heat disengaged at the zinc and that absorbed by the deposit of copper, or between the electro-chemical decomposition of these two metals as found from their chemical equivalents, *i.e.*, $2.36 - 1.21 = .115$, the practical value being 1.079 volts.

With these general remarks on batteries we will pass on to the consideration of the laws of resistance and the diffusion of the electrical current.

CHAPTER IV.

ON THE RESISTANCE AND DIFFUSION OF THE ELECTRICAL CURRENT.—THE EFFECTS OF ELECTRICITY AS SHOWN BY THESE LAWS UPON THE HUMAN BODY.

BEFORE proceeding to a discussion of the effects which are produced by the passage of a current through a conductor, it might be advisable to define what is usually meant by the word "CURRENT."

DEFINITION OF CURRENT.—A current of electrical force is the quantity, or measured amount, of electricity which traverses during an unit of time any section of the conductor through which this force is transmitted: if this unit of time is one second, and if the quantity which traverses the section of the conductor is the unit, the measure of the unit is represented by the resulting current.

A unit of current is assumed to traverse a conducting medium when the unit quantity of this current has passed through any section during the time of one second.

It has already been stated that a current of electricity will result in a conducting medium when two points in that conductor are at different potentials. According to Ohm's law, the current which passes between any two points in a conductor is directly proportional to the difference in potential energy which exists between the two points, provided that the conducting medium which unites these points remain the same and in the same original condition. If the chemical state or the temperature of the conductor is constant, the current will be also constant; it should be particularly remembered that the constancy of the physical condition should remain the same throughout the whole circuit, internal and external. Mention has been made in the previous chapter of the internal resistance which occurs in the galvanic cells and their arrangement in battery, as well as the modifications which are produced by it in the current of electricity inside of the cell. It has there been shown, also, how the current in an external circuit containing no comparative resistance will have the character of its original strength.

The nature and complications of the resistances in the external circuit, which is outside of the cell, are of equal importance in their effect upon the current with those which occur in the internal circuit, that within the battery. It has, also, been there shown that, in order to complete the circuit and to continue the electrical current which results from the electro-chemical action within the galvanic cell, the two poles of a battery should be united by a conducting medium; the current which proceeds from the zinc to the copper within the cell will flow from the copper to the zinc without the cell. The former of these is called the internal circuit, and the latter the external circuit.

The zinc element is the positive pole of the battery, and the carbon is the negative pole of the battery; ordinarily in medicine, when the external circuit is closed, these terms are transposed; and to distinguish this change the wire coming from the electro-negative element, carbon, is called the positive electrode; in the same way, the wire coming from the electro-positive element, zinc, is called the negative electrode. The explanation of this confusing use of these terms is based upon the change of direction of the currents in the two circuits.

In general, it may be said that no electro-chemical action takes place within the cell unless the circuit be closed; yet, this is not exactly true in the case of some batteries, as the Daniell's, in which the electro-chemical action will continue even while the circuit is open. Usually, batteries arranged for medical use have little or no action when the poles are not connected, in which the circuit is open.

It would be a hopeless task to present in this treatise a synopsis of all that has been investigated, or written upon the subject of external resistance, and our attention will be occupied only with that portion which concerns the use of electrical apparatus in medicine.

We should bear in mind that the flow, or transmission of electricity, can be best understood by the commonly used comparison with the movements of a fluid, like water. We must not suppose that electricity, which is a force, is a ponderable body, but that it is a kinetic energy (so called), whose properties are recognized by the disturbances which the transmission of this force produces in its conducting mediums.

Electrical flow therefore resembles, or is analagous to, the flow of water from one cistern into another by means of conduits or pipes; if the elevation of one is on a higher level than that of the other, the flow will be toward the lower level; or, in other words, the movement of electricity proceeds from the higher potential of energy to a lower. The energy, which is produced by the decomposition of zinc with the acid combined as a salt in solution, is at a higher potential than that produced by the decomposition of the sulphate of copper solution and the oxidation of copper, and the subsequent deposit of metallic copper at the other pole. As in the comparison with water, in which the strength of the flow will depend upon the comparative difference in the level of the two reservoirs, so in electrical flow or circuit, the greater the difference between the potential energy of the bodies which are charged with opposite kinds of electricity, the greater will be the electromotive force and strength of the current. Again, as the amount of water flowing from one cistern to another will be influenced by the diameter of the conducting pipe, so, too, will the transmission of electricity be favored or hindered by the conductibility of the medium through which this force is made to traverse, the resistance of the conductor acting as an obstruction. Therefore, the resulting strength of the current will depend upon these two factors: viz., the difference in the potentials and the ratio of conduction in the conducting medium. If we suppose the difference in potential to be the same, the relative conductivity of two mediums produce a resulting current, which is stronger or weaker, and which will be inversely as the ratio of conductibility; or, in other words, the resistance which the electrical current meets in the conductor will decrease the initial strength of the electro-chemical force. Now, all bodies offer more or less resistance to the transmission of electricity, and the amount of resistance affects the stability, if we may use the words, or the equanimity of the molecules of which such a body is composed. This same interference in physical stability of quiescence of bodies is caused by other forms of energy; as, for instance, in the production of heat, which will be greater or less according to the rapidity of molecular vibrations produced in the body by a force transmitted to it by some external agency.

THE RESISTANCE OF A WIRE, OR OTHER CONDUCTOR, IS PROPORTIONAL TO ITS LENGTH.

This resistance will be inversely proportional to, or, in other words, will diminish with every increase of, the area of its own section. The resistance of a conductor of given length and diameter will depend upon the material of which it is made, that is, upon the SPECIFIC RESISTANCE of the material.[1]

[1] DeWatteville, op. cit., p. 11.

The late Professor Ohm had established, by researches and experiments, the theoretical conditions which regulate the action of the galvanic or voltaic current, and since his time these experiments have been confirmed by their practical application at the hands of other distinguished scientists, among whom may be mentioned Wheatstone, Fechner, Daniell, and De la Rive. The force by which electricity is set in action through the galvanic current is called the ELECTROMOTIVE FORCE, and the amount, or quantity, which is transmitted through a section of the circuit is called the INTENSITY, or TENSION, OF THE CURRENT. This intensity or tension is the same in all parts of a given circuit, no matter of what materials it may be composed. It is known, also, that the same current which traverses a short wire will produce a greater deviation or deflection of a galvanometrical needle from a neutral point than the same current which traverses a longer circuit of the same wire; hence, the expression of Ohm's law is:

"THE RESISTANCE IS INVERSELY PROPORTIONAL TO THE INTENSITY OF THE CURRENT," AND "THE INTENSITY OF THE CURRENT IS EQUAL TO THE ELECTROMOTIVE FORCE DIVIDED BY THE RESISTANCE."

This law is usually expressed by the simple formula:

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

I representing the intensity of the current, E the electro-motive force and R the resistance of the circuit within the galvanic cell.

Now, the less the conducting property which an electrical conductor possesses, the greater will be its resistance; hence:

"THE INTENSITY OF A CURRENT WILL BE INVERSELY PROPORTIONAL TO THE LENGTH OF THE CONDUCTOR, AND DIRECTLY PROPORTIONAL TO ITS SECTION-AREA AND CONDUCTIVITY."

When a galvanic battery is formed of several cells, the intensity of the resulting current will be equal to the sum of the electromotive force of all the couples (elements), divided by the sum of their resistances. A battery which is formed of the same kind of cell, will always have the same electromotive force and the same internal resistance. The external, or interpolar, resistance will depend upon the medium, which acts as the conductor between the two terminals of the battery, the resulting resisttance being the same in all parts of the circuit. The internal resistance of the battery has been described in the preceding chapter. Treatises on electricity express the internal resistance of a battery by the symbol R; the interpolar resistance, or external resistance is usually expressed by r. Ohm's law of interpreting the tension of the resulting current in view of the two resistances is expressed by the formula:

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

Now, when any number, n, of a similar kind of galvanic cell are joined together in series, the resulting current tension of the circuit will be n times the two resistances. Again, if the interpolar, or external, circuit be closed by a short wire which may have a good conductivity, like copper, r is so small in comparison with R that it may be neglected, the formula to find the resulting current of tension being then expressed:

$$I=\frac{nE}{nR} \text{ or } \frac{E}{R}$$

or, in other words, when the $\frac{E}{R}$ resistance within each cell is equal, the tension of the current will not be increased by an increase in the number of couples. When, on the other hand, the interpolar, or external, resistance r is great, as in the case of a small thin wire, or in a solution, the tension of the current is usually about equal to the number of couples used for the battery.

Again, if the surface of the battery "elements" be increased, there will be no increase in the original electromotive force; yet the internal resistance of each cell will be diminished, owing to the exposure of an increased surface area to a larger surface of the exciting solution, and consequently the intensity of the current will be practically increased because the internal resistance within the battery is decreased. The expression of this fact is represented in the formula by

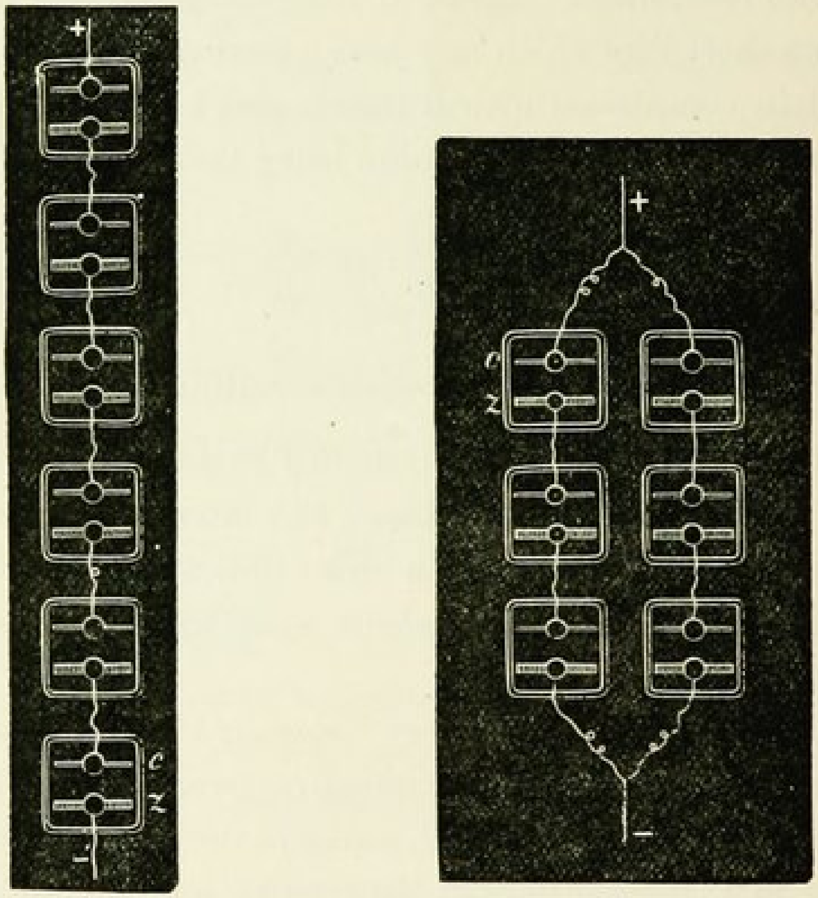
$$I=\frac{E}{\frac{R+r}{m}} \text{ or } =\frac{mE}{R+mr},$$

where m represents the increase in the surface measurement of the battery elements; we shall find that this increase of tension is influenced by the fact that the external resistance, R, decreases in proportion to the amount of r, or external resistance, and the tension will always be about as expressed in the formula

$$I=\frac{E}{r},$$

or will be equal to the electromotive force of the cell divided by the resistance in the external, or interpolar, circuit.

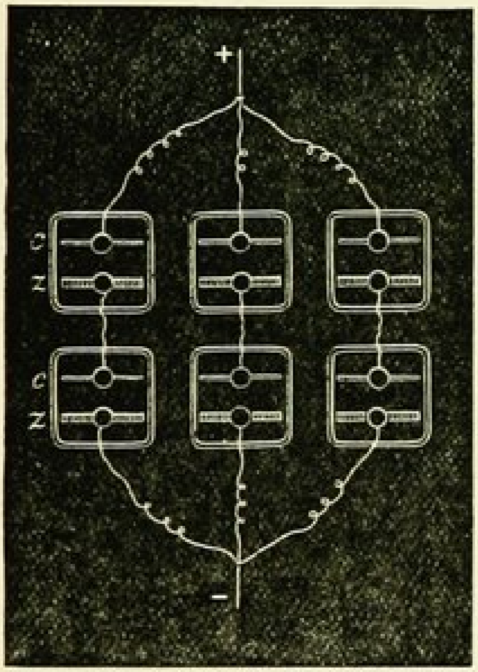
Thus, for the purpose of regulating the relation between the two resistances within and without the cell, we may arrange a battery as for instance of six cells in three different ways, as shown in Figures 10 and 11. First, we may arrange in a single series (A), in which the copper of each gal-



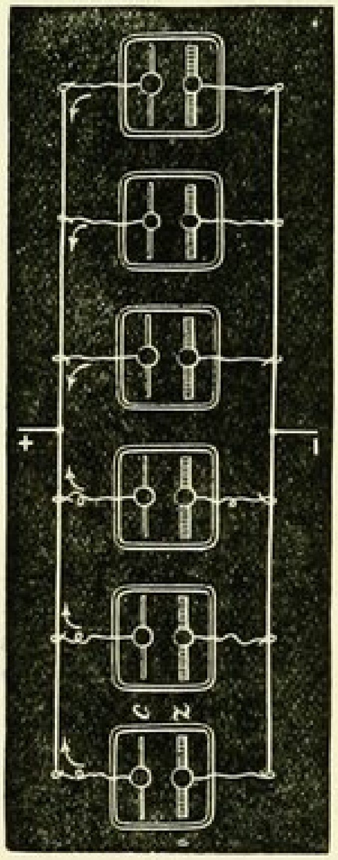
A. B.

FIG. 10.

vanic cell is connected with zinc of the succeeding cell; second, in groups of two cells, each group being formed by uniting two zincs (B), and two coppers, or carbons, of every two cells and then by connecting the zincs of each group of two cells to the copper, or carbon, of the next group in line; or we may arrange them in groups of three cells (C), or of any desired number. The third system is that in which all the zincs are united together in parallel, all the coppers together, and is the usual method for producing the heat current for thermocautery, because we may in this way reduce the internal resistance to its smallest amount, and so obtain the full current strength of a given form of battery (D). We may, also, arrange so that we may decrease the tension and at the same time increase the effective quantity in a given circuit; for instance, we may use in combination two of these arrangements, one of which is "coupled" for quantity and the other for tension; and we may thus arrange for a quantity of ten cells with a tension of six, or of any desired combination.



C.



D.

Fig. 11.

It is, oftentimes, desirable to use a current which may be nicely graduated to increase, or diminish, the original electromotive force, at the pleasure of the operator. The principle of the laws of resistance, as above described, may be mechanically arranged, so that we may place more or less resistance in the circuit. It can, of course, be seen, if these principles have been properly explained and correctly understood, that it will make no difference in what part of the circuit we may interpose the resistance, because its obstructing effect will be manifested in every part of the circuit.

One of the earliest and simplest mechanical forms of resistance coil, or Rheostat (flow-arrester), is that which was invented by Wheatstone (illustrated in Fig. 12).[1]

In this instrument a longer or shorter piece of wire, made of a feeble

[1] Ganot's Physics, 1869, p. 817.

metallic conductor (German silver alloy), is interposed in the external circuit by winding, or unwinding, from one brass spool on to another spool made of insulated material like hard rubber. This coarse method of interposing various amounts of resistance will not produce very nice or accurate means of measurements, nor is it a convenient instrument for practical work; it has, therefore, been superseded by other more compact forms of mechanical arrangement which will be obvious from their description, but the principle of these instruments remains the same. It is not so necessary for medical uses to have an accurate measurement as to have some contrivance of easy application. None are perfectly accurate,

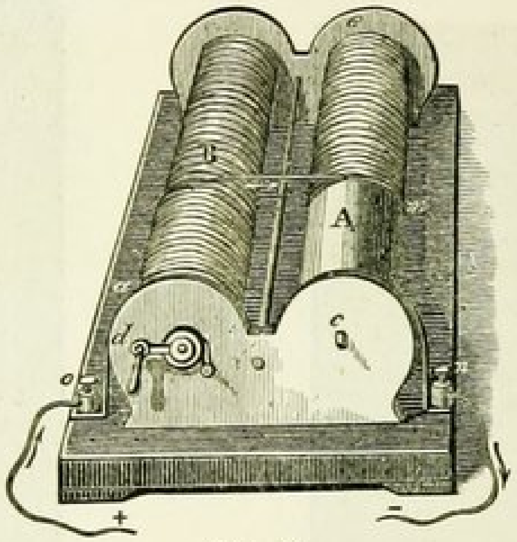


FIG. 12.

and the nearer they approach accuracy the more costly they become. A resistance box which can be made to interpose measured units of resistance, within an error of one-hundredth of the whole amount used, is sufficient for all practical purposes, because the variations in the conductibility of the human body are so great, that an error of an hundredth is comparatively very small.

Oftentimes, a fluid rheostat will answer the purposes equally well; though the action of this form of interposed resistance is objectionable, because it has the disadvantage which arises from a varying amount of corrosion, which attacks the metallic conducting surfaces, and will thus produce irregular obstructions to the transmission of the electrical current. A liquid rheostat can be extemporized out of a short piece of glass tubing, which may be filled with water to produce high resistances, or, with a solution of sulphate of copper which acts as a moderately good conducting fluid (the stronger the solution the better conductor, and *vice versâ* for less resistances.) In the use of a liquid rheostat the conducting points of the wire should be immersed in the column of liquid, these points being approximated to increase, or being separated to diminish, the resistance to the circuit. For medical uses, however, where variations in the current passing through living tissues are not uniform, a rheostat of the kind presented in the illustration (Fig. 13), answers a very good

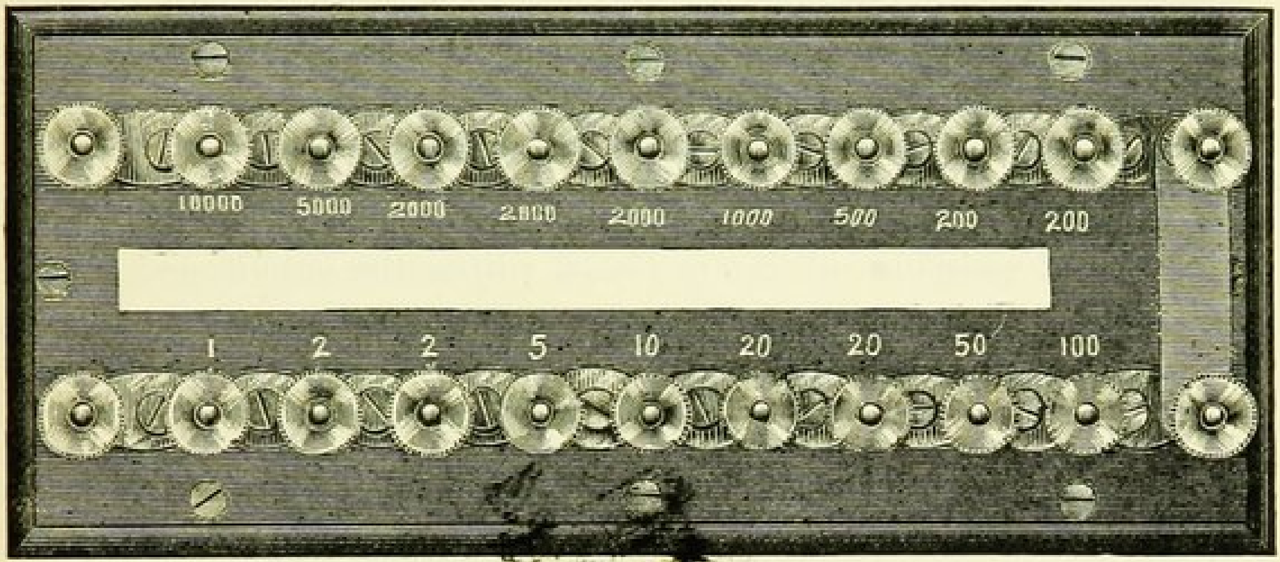


FIG. 13.

purpose. The introduction of the various resistances from one ohm to 20,000 ohms is made by unscrewing the thumb screw connecting adjacent brass plates, to each of which is attached German silver wire from the resistance bobbins, which have measured resistances; each of these adjacent brass plates have resistances which differ from each other by a fixed value, so that

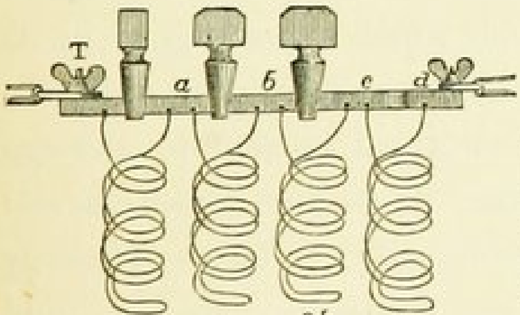


FIG. 14.

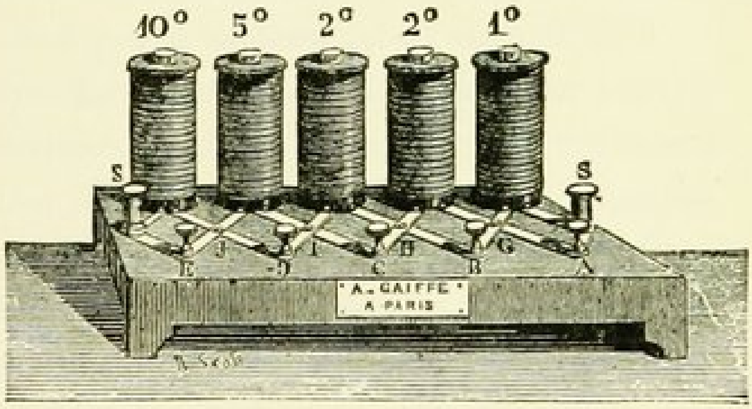


FIG. 15.—Set of resistance coils. Measured resistances are introduced into the circuit by placing into it the coils marked 1, 2, 2, 5, 10. *S S*, binding screws for rheophores. *A*, *B*, *C*, handles for putting the resistance in and out of circuit.

the attachment of the resistance wires to the several bobbins (Fig. 15) are separated, unless the connecting screws of the several divisions are screwed home to make a contact over each separation between the brass plates. The accompanying illustration is borrowed from De Watteville. This figure (Fig. 15), represents a set of resistance coils from one ohm to ten; these coils are made of German silver wire because this metal gives approximately accurate measurements, which are not dependent upon atmospheric or thermo-metrical changes

In most boxes the contact between the brass plates is accurately made by nicely fitting and tapering brass plugs; to these plates the terminal wires of the several resistance bobbins are soldered carefully with resin; after all the mechanical work is finished, the amount of resistance of the several connections is carefully measured and compared with a standard measurement The constant error of a rheostat of this style may vary .0001 of the units of resistance which are placed within the circuit, and may be adjusted even more accurately than this; thus, with a resistance of 20,000 ohms the error would be about two ohms; for a similar resistance given by the preceding instrument the error would be about 200 ohms. When the resistance is formed in the external circuit by metallic conductors, in which the amount can be easily reckoned and allowed for in a physical experiment, the electromotive force resulting will be found simply by a mathematical calculation; but, when the human body, in part or as a whole, forms the conductor of electricity the resulting factor is not always so easily found; because the conductivity of the body is variable; added to this are physiological problems which the current itself sets in action by secondary electrical disturbances. These are caused by chemical action in the living tissues of which the human body is composed.

The human body, used as a conductor of electricity, should be considered as a large fluid whose conductibility is hindered or increased according to the various chemical compounds which are contained in its solution. Moreover, it should also be considered as a chemical fluid, the compounds of which are influenced by the electrical current to undergo decompositions, and to form new combinations. These decompositions and reformations of chemical compounds are accompanied by forms of energy and dissipation of energy, both of which may produce in this semi-fluid conductor the display of electrical disturbance, which may hinder or favor the conduction of electrical force which is transmitted through them by an electrical generator outside of the body. We must suppose that the alterations of chemical compounds will result in the formations of potentials of different degrees, some of which by dissipation of energy are of an intermediate character on account of the varying degrees of potentials between the chemical elements. Estore has presented certain experiments[1] to determine the variation in the resistance in the human tissues. In all of these experiments the positive electrode was placed upon the cutaneous surface of the sternum, and the negative on the surface of some point on the forearm. The strength of the current was sufficiently feeble to be conveniently endured for some time, ten cells. The exact moment was noted at which the current was closed, as also the number of degrees of deflection of the galvanometric needle; the readings of the deflections of the needle were observed at their maximum deviation. From the many experiments which were made he determined the occurrence of two kinds of variations: "first, as usually happened during these experiments, the maximum of deviation will vary; second, the maximum of deviation will be attained at unequal periods of time." Vigoroux has shown that in the hemi-anæsthesia of hysterical patients the conductivity of the tissues is less on the affected than on the sound side. He confirmed the results of his experiments by placing the positive electrode in the axilla, in order to prevent the transmission of the current through healthy tissue, and the negative electrode was placed upon the forearm. The electrodes were small and of a flat shape to insure close contact with the skin; every precaution was taken to avoid accidental errors. The details of his observations were as follows:

No. of Case.		Right.	Left.	Maximum deviation. Time Right.	Maximum deviation. Time Left.	Remarks.
1.		25	18	1 min.	3 min.	L. side (12 elements).
2		Similar results.				R. side.
3	1st.	50	40	12 "	9 "	L side.
	2nd.	55	55	At once.	2 "	
Anæsthesia diminished and disappeared on left side and then on right.						
	3rd.	40	50	11 "	12 "	
4.	1st.	65	65	6 "	8 "	L. side (16 elements).
	2nd.	70	70	9 "	4 "	Changed to L. Hyperæsthesia.
5.	No difference, not a case of true hysterical hemianæsthesia.					

In order to test the resistance of electrolytes many kinds of apparatus have been devised, and the following method deserves mention:

[1] A. Estore. Note sur la resistance electrique de tissues, etudiée au double point de vue physiologicale et practicale. Gaz. Hebd. de Sc. Med. Montpel., 1882, IV., 277.

Der Stromverzweiger[1] (literally "the current divider").

Kohlrausch's former experiments were made by the means of a rheostat whose resistance equalled that of the electrolyte. In substituting the telephone for the dynanometer excursions, it is preferable to have a resistance mechanism with continued variation in preference to the (*Stoepselrheostat*) resistance wire rheostat.

Kohlrausch used instead of a very thin or long wire, one which was coiled. Such a coil he considers very convenient. The machine is made in serpentine form to rapidly equalize alterations of temperature. It is 45 c.m. long and 100 mm. in diameter. On the cylinder is cut a screw in 10 spirals. In the groove is wound a new silver wire 0.2 mm. thick and 3 m. long. As in Siemen's universal galvanometer, the movable contact is a small roll. Its motion is from a rod standing parallel to the axis of the cylinder and is pressed by two springs against the wire coil. As in the old rheostat of Jacobi, the circumference of the small roll (or disk), has a traveller by which it follows the movements of the wire. The small roll and its support are of new silver to avoid heat currents. The springs attached to the rod of the small roll conduct the current from the latter. The current is carried from the machine by the brush contact as in the modern induction machines. In the wooden base of the instrument are four resistances of 1, 10, 100, 1,000, QE, so connected that they may be used separately or in combination; thus a resistance of 0.3 to 3,000, QE, may be measured. Besides five metallic pole-cups there are two others which conduct the wires from the coil. Between two of the end pole-cups the electrolyte wires can be inserted, and the others disconnected except from the coil which is used as a comparison.

The vessels to contain fluids whose resistance is to be measured, have a conducting tube 100 mm. long. Of course, for different fluids different lengths are needed, whose measurements are in relation to their conducting power. If the narrowest tube has a diameter of 8 mm., the best electrolyte gives 30 QE. Tubes of 14 to 25 mm. may be used, and for feeble conductor one which has a curved length of 45 mm. Electrodes should be made of platinum or plated silver, with insulated gutta percha handles. The vessels are held in a wire stand, and this latter is immersed in a water-bath to procure the proper temperature. The resistance of the vessels is

[1] Einfache Methoden u. Instrumente zur Widerstandsmessung insbesondere in Elektrolyten. Verhdl. d. Phys. Med. Gesellsch. in Würzb., 1881, XV., p. 94–100.

determined by that of a known fluid, E.g., t equals temperature; K, conducting power; with dilute H_2SO_4 30.4 per cent. (sp. gr. 1.224), K= 0.00006914+0.0000045 (t−18°). With solution sodium chloride (NaCl), 26.4 per cent., (sp. gr. 1.201), K=0.00002015+0.00000045 (t−18°). With solution magnesium sulphate ($MgSO_4$) 17.3 per cent., (sp. gr. 1.187) K= 0.00000456+0.00000012 (t−18°). $C_2H_4O_2$ 16.6 per cent., (sp. gr. 1.022) K=0.000000152+0.0000000027 (t−18°).

A fluid in the vessels has a resistance of WQE.; the resistance of the vessels for mercury is O°y=WK. If another fluid has the value W, we find its equivalent for unit of mercury to be $K=\frac{y}{w}$.[1]

Instead of the vertical galvanometer of Siemen's and Halske in these experiments, Wiedermann's is substituted; also a Pohl's current reverser. The current was of constant strength. When a prism of coagulated egg-albumen of a given size is connected with the poles of a battery (20 Grove's cells), the following results:

o=closure, t=time, ordinals represent scale divisions of the current strength; t_1=2t, dropping most in 10 to 20 minutes. Current reversed,

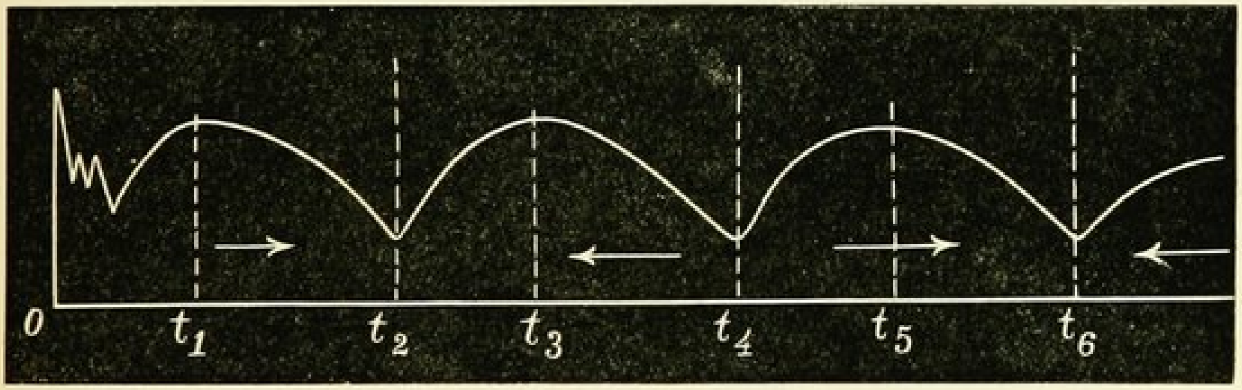


FIG. 16.

a small negative deflection until at t_3,=t_1, and then a drop. This is due to the resistance produced by the action of one current being suspended by the action of another.

It may thus be seen that the tissues of the human body, like other electrolytes, should be considered as a conductor containing various chemical substances in solution, and, in consequence of this, being a body of high resistances, the current strength must be varied to suit these circumstances. The resulting strength of a battery as well as the tension of

[1] E. du Bois Reymond. Ueber den secundaeren Widerstand, ein durch den Strom bewirktes Widerstand phænomen. an feuchten poroesen Koerpen. (On the secondary resistance, a current phenomenon in moist porous bodies.) Moleschott. Untersuchungen, 354, viii., 1862.

the electrical current, will depend upon the power resulting from the transmission of the current against a resistance which is in the circuit. The quantity is different from the electromotive force, and is measured by the amount of chemical work which is accomplished in the interpolar circuit. It has been shown in chapter third how the quantity and tension of a battery may be arranged so as to provide for a combination by which we may obtain the best effects for a given purpose. We may now understand why we cannot obtain a very large quantity of electrical force, no matter how many cells may be connected, when the resistance in a given circuit is very great; for the same resistance will act throughout the whole circuit, and will decrease the original current strength of the particular form of battery which has been selected for our work. The quantity of electricity which can be obtained from a frictional machine for the purpose of decomposing water is by no means comparable to the amount which is produced by a piece of wire one-eighth of an inch in diameter, and dipped into dilute sulphuric acid to the depth of half an inch. It should always be remembered that an increase in the area surface of the metallic elements of a galvanic cell will increase the quantity of electricity, but not its tension; while an increase in the number of these cells will increase the tension, but not the quantity. By this mode of reasoning, we must inevitably arrive at the conclusion that the amount of chemical action in the human tissues to be accomplished by electricity is not so much to be sought for by the use of a battery which possesses great power, as by the use of a feeble current which may be continued for a longer time in those cases where it is desired to produce an increased amount of physico-chemical action. This application of electricity to electrolysis of living tissues requires a clear explanation, since the use of the terms, "quantity and tension," are so often misunderstood.

To make this matter clearer it will be advantageous to compare the transmission of electricity through conducting mediums with that of the movements of liquids, always remembering, however, that electricity is not a fluid but a force acting through matter. Let us suppose that a quantity of water is stored within a cistern, from which it is conducted by means of pipes or conduits having different diameters, lengths and outlets; in this case the flow of water will be governed by the relation of these diameters, lengths, and surface friction, and will depend upon the size which each bears to the others. Following this analogy, it is easy to understand that the transmission of an electrical force from its point of origin will be regulated by, and will be proportional to, the resistance offered by the conducting medium, and to the escape of the current from this conductor, as well as the strength of the current which is dependent upon the difference in the potential energy of the original electricising bodies.

As in the case of the flow of water, the currents of electricity will also be in a measure affected by the number of the various conductors, as well as by their relative conductivity; in other words, there may be several conductors for the same current. . . . This divided system of currents is called the system of derived currents, and is illustrated by Figure 17, which is borrowed from De Watteville.

The current[1] is supposed to originate from the battery E and to pass through two conductors, DRGE, and DR′GE; in the former channel

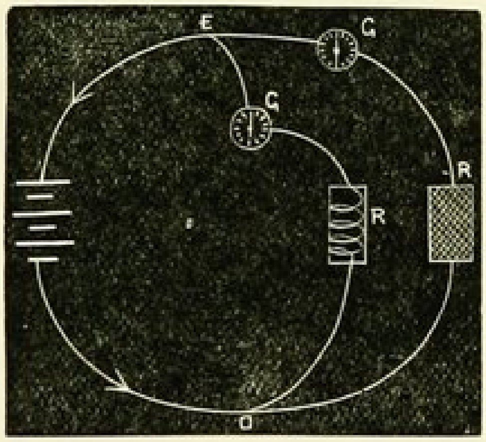


FIG. 17.—The use of this method in electrotherapeutics was first advocated by me in a paper in the *Medical Times*, Sept., 1877. It has since been applied to the investigation by Tschiriew and myself of the excitability of cutaneous nerves (*Brain*, 1879) and to that by Waller and myself of the Electrotonus of man. (*Philosophical Transactions of the Royal Society*, 1881.)

a resistance-box, R, is in circuit; and a galvanometer, G and G′, is placed in the path of each derived current, or circuit. If the resistance of the human body, R′, is in circuit, as R′, and taken at 2000 ohms, a resistance of 2000 ohms produced in the rheostat, R, in the first circuit will be equal to that in the second circuit; but, if the resistance in the rheostat be increased to 3000 or 4000 ohms, the deflections of the galvanometer needle will show a stronger derived current in the circuit through the body, of a ratio of 2:3 or 2:4; if, on the other hand, the resistance produced by the rheostat should be diminished to 1,000 or to 500 the deflections of the galvanometric needle will show that the current is weaker in that circuit

[1] Op. Cit., p. 40.

which includes the human body, or as 2:1 or 2:$\frac{1}{2}$. Finally, a galvanometer which is placed in the circuit EBD will show that the current will be equal to the sum of the other two derived currents.

The application of these phenomena to the case of the human body alone, in the external circuit, will be obvious; for the human body is formed of various kinds of tissue some of which present a much higher resistance than others to the transmission of the electrical current, and the sum of the derived current being always equal to the current which flows through both rheophores between the body and the battery, the derived currents which traverse the body tissues will be in an inverse proportion to the varying resistances of the different kinds of tissue which act as conductors, thus passing more readily through the blood vessels and through tissues largely composed of saline materials held in solution.

Another complication by which the distribution of the electrical force through the human body is affected, is that relating to electrical *Density*. The word density is derived from its use in frictional electricity, in which is represented the quantity of electricity per square centimeter on a charged conductor. In its application to electricity which is derived from chemical decomposition in a galvanic cell, it is used to specify the proportional charge of electrical force between opposing bodies, and is measured by the quantity of electricity which is transmitted per second of time through a unit of the sectional area of the substance conducting the electricity; if two conductors having a difference of potential energy are brought together in contact, a redistribution of the charge must occur, which will produce the resulting intermediate potential of the two conducting mediums. This unit quantity of electricity is that on a sphere having a diameter of two centimetres, and which receives the electricity delivered from one pole of a battery, formed of 268 Daniell's cells, arranged in series, the other pole of this battery being connected with the earth. This unit of quantity is called a *Farad*. An ampère is equal to one tenth of a farad, and represents a current which conveys that unit quantity of electricity [a farad] during a period of one second's time; one thousandth of an ampère is known in medical electricity as one milliampère. The terms, weber and milliweber, are now obsolete, because these absolute units were not used for a measure of electrical quantity passing in a unit of time, but were intended to express an absolute measurement. The unit of resistance is styled an ohm, 1,000,000,000 absolute units. The unit of capacity [also, quantity] is styled a farad, $\frac{1}{1,000,000,000}$ of an absolute unit. The unit of current is one farad per second, but in general use the time is omitted, it being called simply a farad.

The use of absolute units for measurement is not generally approved by the best writers on electricity, and instead of these units of measurement per units of time are generally employed, as for instance,

ampère, milli-ampère;
volt, micro-volt;
ohm, micr-ohm.

The question of density will enter into the matter of the diffusion of current passing through conductors. Without attempting to give a detailed description of the laws of diffusion, which the reader can obtain from any good text-book upon electrical measurements, it will be sufficient for our purposes to note how the human body, as a conductor of electricity, is affected by the result of these laws.

That form of tissue which opposes the most resistance to the transmission of electricity is dry skin, and that which is perforated with fewest sweat-and sebaceous-ducts. If one portion of the subjacent and subcutaneous tissue is more fully charged with blood than another, equal currents of electricity passing from an electrode, closely adapted to its surface, will meet with less resistance and, consequently, will transmit electricity more freely than others which are less fully charged with blood. It should be remembered that an electrical current will select through various conductors that one which offers the readiest conduction. If the skin be thoroughly moistened with hot salt water, and an electrode then applied to this moistened surface, the electrical current will pass to the subcutaneous and deeper tissues, and will pass with the more readiness when the condition of electrode and skin surfaces are more thoroughly saturated with moisture. Again the larger the surface of electrode and skin thus moistened and brought in contact, the more readily the current will pass to the deeper tissues. This latter effect can be better understood by remembering that the resistance of a conductor is in inverse ratio to its diameter, and hence the larger the surfaces of the contact, within proper limits, the larger becomes the capacity of the conductor. So also the more perfect the contact, that is by pressure of the electrode nearer to the skin, the better the conduction, or in other words, the less the resistance. Even under the best of circumstances the resistance of the human body as a conductor will vary from 1,000 to 12,000 ohms.

The same effects of polarization of the tissues of the human body occur as in the polarization of liquids or of substances in solution around the electrodes, and secondary effects of polarization are set up in opposition to the first. In consequence of this effect the electro-chemical action in the tissues, to which the electrodes convey the electricity, is of a complicated character not by any means fully understood in respect to living tissues.

The laws of diffusion of the current are, however, better understood because these laws are founded upon the same principles as those derived from observations upon other mixed conductors. The human body, being composed of various tissues whose conduction depends upon the proportion of water and saline materials of which these tissues are composed, will convey or transmit the current according to the conducting power of these various tissues. In the succeeding chapter the composition of these tissues will be described in accordance with the teachings of physiology. No table of the conductivity of the human tissues in relative order would be of any value, since these tissues themselves would vary according to many circumstances, such as the relative amounts of saline materials and fluids contained in them; and in most cases the conduction would be modified by the laws of diffusion of currents, which would control this question of conductivity of the tissues, much more than the property of conduction inherent in themselves. But by diminishing the resistance offered by the skin by means of moisture and a close coaption of the electrode, we may reduce the resistance to one half; so that in the first instance if the skin's resistance should be 5,000 ohms, we may reduce this resistance to 2,500; and since this number forms the largest part of the denominator in Ohm's formula, it can be easily seen that by this means we have greatly increased the tension of current.

By the words *Diffusion of Current* is meant the distribution of electromotive force through a conductor. We have seen in the case of the thin platinum wire that the current does not pass through this conductor without producing perturbations in the molecules by which the current is transmitted. When we have a conducting medium, composed of different properties of conduction, we have seen that there are derived currents; and these influence the path through which the current will follow. Electricity of one kind will always go in the direction from the higher to the lower potential.

Consequently where the conducting medium is composed of substances having various potentials, the currents of distribution will have many directions, but will finally emerge in one direction; and the current of emergence from the conductor must always be equal to the current of entrance into the conductor; since we have seen that the sum of the derived currents must always be equal to the original current.

In the human body the diffusion of the current is from the point of contact of one electrode, and out at the point of contact of the second electrode: now the distribution of the current between these two points is not by any means in a regular uniform path: some of the current will pass by an easy channel, some by one less easy, or in technical language

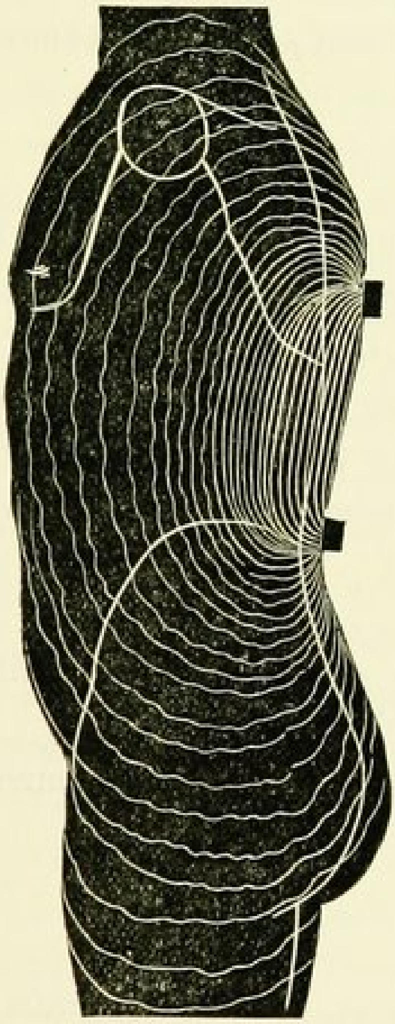


FIG. 18.—If A and B are the positive and negative poles respectively, the bulk of the current flows in more or less curved lines from A to B through the tissues enclosed between them. Externally to this interpolar region, the direction of the derived currents proceeding from each electrode is opposed to the main current in the region, A to *a*, and B to *b*. We assume here that the body is made up of a uniformly conducting substance. The thick lines denote the region of greatest current density. The occurrence of cerebral symptoms (giddiness, flashes of light, the galvanic taste) when one of the electrodes is applied to the upper part of the back, is due likewise to the diffusion of the current upwards.

the current passes through substances which are not equi-potential; thus the current will pass more readily through the blood and the blood vessels, through the nerve tissues, etc., and less readily through the bones and tendons. The current does not pass directly between the two points included between the electrodes, but will be diffused in unequal proportions through the whole body, owing to the production of differential and intermediate resistances of the component parts of the living tissues. The diagram borrowed from De Watteville represents this more clearly.

This law of diffusion of currents applies as well to electrolysis. A sufficient number of cells will increase the electromotive force. Each cell that is added of course interposes its own internal resistance, but with the large resistance offered by the human body, the internal resistance of each cell is insignificant. The quantity of the electricity which will flow through the resistance of the human body will increase with the number of cells; for we have seen that according to Ohm's law

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

Illustrating this law in the given case of the human body, we will take the tension of a current coming from ten Leclanché cells, each having an electromotive force of 1.4 volts, and each an internal resistance of .4 volts; by connecting these in series we have a result of 14 volts divided by 4 volts, or 3.5 volts, for the electromotive force of the cells with their own resistance which, passing through a human body of 2,000 ohms, will give a current strength of

$$\frac{3.5}{2,000} \text{ or about } \frac{1}{700} \text{ volt,}$$

whereas, if we take one cell, the resulting current strength will be only

$$\frac{1}{2,000} \text{ volt.}$$

It will thus be seen that, in order to obtain the strongest effect of the action of a battery, where electrolysis is to accomplish its work through a great resistance of the human body, the galvanic cells must be theoretically coupled in battery in series for tension. In this way the resistance may be overcome by forcing the current at a high tension through the obstructing resistance. The same object may be accomplished by passing a current of lower tension for a longer period of time, and a further advantage may be gained from the latter method; the current will not only produce less pain at the points of resistance in contact with the electrodes, where the resistance offered by the tissues is greatest, but will also produce less inflammatory action in these tissues. This latter may stimulate the growth of abnormalities, or may even cause a dangerous inflammatory process in neighboring tissues, such as the serous membranes, which may be a worse condition than that which the physician was called upon to relieve. It will be remembered that the amount of physical action any current may produce, provided that it is strong enough to overcome the resistance offered by the circuit, is simply a question of time; for a given amount of electricity will decompose a certain amount of a chemical compound, whether it be of low or high tension; and a slow action in mixed organic structures, such as that furnished by living tissues, is more desirable than a rapid action; because the slower processes of retrograde changes are less likely to be followed by the inflammatory effects which follow rapid or sudden destructions of healthy tissues, as, for instance, the action of burns either from chemical or mechanical agents. This view of the matter will explain the experience offered by Ciniselli [see chap. VII.] who advised the use of batteries having a feeble or slow action for the cure of aneurisms. The mistake of using too strong currents is very often made by those who have not learned by experience that "haste makes waste." The use of too strong currents is often caused by the fact that the operator finds his battery is not working at an uniform rate, and consequently undertakes to correct one error by increasing the current strength; he thus falls into the other error of using too strong a current which may then be followed by local inflammations and suppurative processes. Other writers than Ciniselli have cautioned against this danger, but too little stress has been laid upon it in the larger works on electricity. This injurious effect of strong currents has been pointed out by a very experienced as well as a bold operator, Neftel of New York, who has applied the continuous current for the electrolysis of uterine and abdominal tumors; in some of his cases it would appear that the inflammation consequent upon the operation might be explained by the supposition of the use of too strong a current, or by the fact that there was a latent inflammatory process in the serous membrane which was aroused from its quiescence by the electrolytical treatment. The attention of the reader is called to the reports of cases which are presented in detail in the chapter on the applications of electrolysis to therapeutics.

In this way may be explained the small suppurative sores which are so apt to follow the use of electrolysis in the treatment of hypertrichosis. In this case, where the operator has to deal with a very sensitive skin, or where the needle-punctures are too close together, the neighboring tissue seems to be the seat of an inflammatory process which is often followed by a suppuration, and sometimes by a scar; this may leave a red mark for a long time, and often will deter some patients from continuing the treatment, for fear that the scar will be permanent. It is undoubtedly true that, owing to a want of proper knowledge of this portion of our subject, the use of electricity as applied by means of the electro-puncture has not been more largely employed in medicine. It is to be hoped that a more extended knowledge of the principles which govern the practical application of electrolysis to the destruction of abnormal tissue-growths will result in a more successful treatment of certain cases, in which the knife cannot be conveniently used.

Following out these general laws in reference to conducting mediums, their application to the use of electrolysis in the tissues of the living body should be carefully studied, if we desire to know how we may best avoid the evils of this therapeutical agent, and how we may best utilize the benefits to be derived from it.

We have seen in the first part of this chapter, that the difference in potential between two points in a conducting medium of electricity will establish the display of electrical energy, and that the amount of this energy will be in proportion to the amount of this difference in potential. Under the law of conservation and dissipation of energy, this difference in potential must be represented by some work, either that of chemical change or of its transmutation into heat or of some other force; we will lay aside for the present any discussion of what are called vital or catalytic changes, because these terms only represent, but do not explain any physiological phenomena.

It must be recognized from the physiological experiments, as well as from physical experiment, that a polarization of the tissues is established in the interpolar region, that is, between the points of contact between the two electrodes,in the structure of the human body subjected to the action of the electrical current. Now, with the understanding which we have obtained in regard to the laws of resistance and of diffusion of the electrical current, it is quite clear that this condition of polarization is really a new galvanic cell which, acting in opposition to that of our original battery, will diminish its force and thus reduce the original electro-chemical action. Moreover, we can easily comprehend why the intensity of the interpolar current will be expended upon those tissues which offer the most opposition to the transmission of the current through and beyond them; in other words, at those points where the difference between these potentials is greatest, the strength of the opposing current will be greatest, and the amount of chemical action or its correlative will be the most active. In the application of this teaching we can conceive that the difference in conductivity between the skin and those tissues which produce the polarization more readily, or the opposition of a current going in a direction opposite to the original electro-motive force, will be more marked.

To illustrate this in a practical manner, let us suppose that we are passing a current of constant action though a portion of the skin, which has been moistened with hot salt water for the purpose of increasing its conducting power, and make the outgoing current pass back to the galvanic battery by means of the best metallic conductor obtainable, platinum or gold; these metals, offering the property of the best conductor for the human tissues, are introduced through the skin and into the underlying muscles or other tissues, which are plentifully supplied with saline fluids. We shall see in such a case by means of a properly arranged galvanometer that the current employed almost immediately after the establishment of the circuit, will be weakened; in other words, the interpolar circuit is the seat of an incomplete polarization. The effect of such a circuit will tend to exhaust most of the electrical action upon the cutaneous covering, that which offers the highest resistance to the transmission of the electrical force. If this incomplete conductor were composed of an unchanging physical formation its resistance would be a constant factor, and the only effect it would have upon the electrical circuit would be to obstruct the electro-chemical action in the battery; but it is composed of alterable chemical combinations, and its action upon the electricity in circuit will produce a variable current, which will be in accord with the varying amount of succeeding effects produced by the polarized condition of the tissues.

It has been proposed by some of the physicians who have employed the methods of electrolysis in living tissue, to cover the needles used for this purpose with an insulated coating of rubber; but the best observers have found that the difficulties of the consequent polarization were not thus overcome. It has been proposed by such good observers as Ciniselli to use steel needles, which should first have been oxidized by passing a current through them as positive electrodes. This practice has been repeated by Gröh, as will be seen in the chapter on electro-therapeutics [Chap. VI.]. Gröh has also used zinc needles, on the supposition that this metal combines with the results of decomposition, and thus acts more efficiently as a destroyer of tissue. It can be readily understood that an insulated covering would not answer the purpose of limiting the action of the electrode to its needle point, because this is plunged into a chemically acting solution such as that which is offered by the semi-fluid tissues themselves. The effects of electrical osmosis must not be overlooked.

The presence of needles, or of the material of which they are composed, will set up an electro-chemical action in the tissues by means of the chemical reagents in solution in these tissues; this would appear to cause a better physiological effect of change in the structure of tissue formations; whether this effect is still further enhanced by the conditions offered by the resistance in their power of conductivity may be an open question; and, yet, it would seem that the results of practice in these cases would support such a theory.

It should, also, be mentioned that the physical effect of electrical osmosis, which has previously been referred to in chapter second, is more favorably influenced by those fluid conductors which offer a high resistance to the passage of electricity; the tissues of the human body are conductors of this character, and the reader is especially referred to a re-perusal of that portion of our subject in this connection, as well as to the next chapter on the theory of the destruction of living tissues by electrolysis.

Before, however, passing to the next chapter it would be advisable to call attention to another effect of the diffusion of the current, which has been particularly mentioned by De Watteville. When a current of electricity passes through the human body from a large surface of an electrode in contact with the tissues, the current which is included in the circuit is of a uniform strength, as has been previously stated; and consequently if the electrode which the same current passes back to the battery is much smaller, the current at the latter point must have greater density than at the point of ingress. This physical fact may be more easily understood by a reference to the illustration which is borrowed from De Watteville's treatise.

The diffusion of a current in a conductor is regulated by the laws of derived currents; according to these laws, if the electrical force is transmitted through a conducting medium having a homogeneous substance, the diminution of the resulting force will be in proportion to the length through which it traverses. This result is due to an increase of resistance caused by the increased length of the path of the current. When the conducting medium consists of a substance which is not uniformly pervaded by a current, it may be looked upon, as is truly mentioned by De Watte-

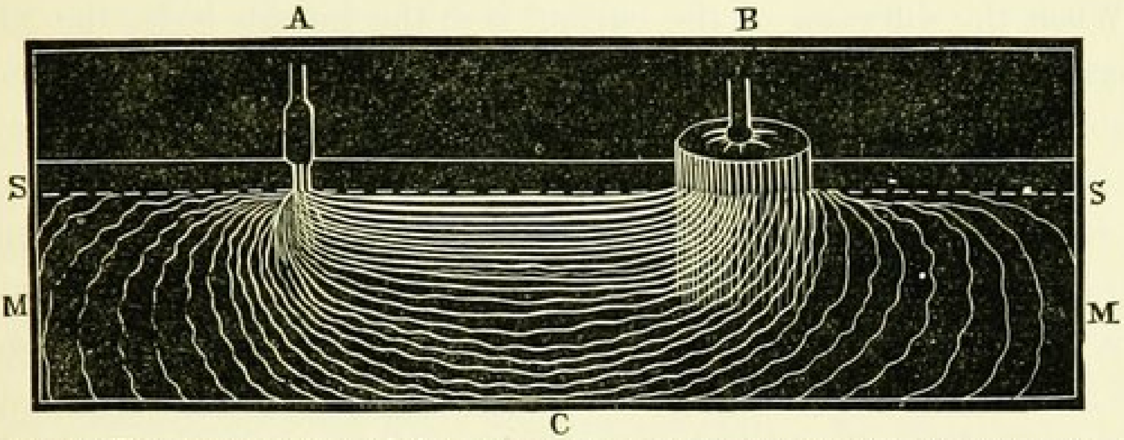


FIG. 19.—This diagram is intended to illustrate the application of two surface electrodes, AB to the skin; the current passing through the interpolar region exerts the most powerful influence where it is the densest, or under the smaller electrode. S is supposed to represent the surface of the skin which overlies muscular or other tissue, M. The shorter the distance of the interpolar region between A and B, the greater will be the proportion of the current flowing through the tissues immediately beneath them; the longer the distance, the more this current will diffuse itself through the whole of M. The amount of internal tissue, which is included between the electrodes, does not materially interfere with the strength of the current (this being regulated by the resistance offered by the epidermis); yet it does govern the distribution of the current, or its density, in that portion of the human body which is traversed. When the interval between A and B is wider, the difference between the extent of the direct path from A to B, as well as the resistance of the more circuitous path, ACB, will diminish in proportion.

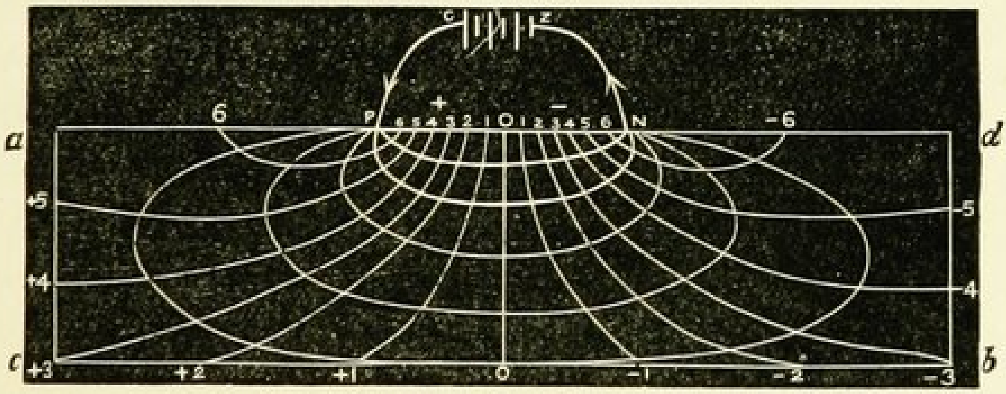


FIG. 20.—The diagram represents a rectangular conductor, *a b c d*, with which the rheophores of a battery C Z are brought in contact at the point P and at N. The whole conductor is then permeated with currents, the general direction of which is represented by the lines joining P N. By means of an electrometer or galvanometer, it can be shown that the distribution of potentials in the conductor is somewhat as shown by the lines + 6 6, + 5 5, etc., 0 0,—1 1,—2 2, etc. If *a b c d* represents a piece of glass covered with a thin metallic film and dusted over with iron filings, when the electrodes are applied at P N, the filings will arrange themselves so as to have their long diameters along the equipotential lines 6, 6, 5, 5, etc., etc. The line of direction P N, should cut the equipotential lines always at right angle, and not as in the figure.

ville, from whom we have borrowed the annexed illustration [Fig. 20], as if it were formed of equipotential surfaces, somewhat like those represented by the curves 6 6, 5 5, etc., 0 0, −1 −1, etc. Now, in order that the electricity should be transmitted from one point to another, there must be a difference in potential between these two points; consequently these latter are present at various parts of the conducting medium. In a cylindrical conductor, like that of a wire, every point of the surface exposed by a transverse section will be at the same potential; this is an equipotential surface.

When the diffusion of the current is in the human body, the whole structure has its potential changed, and the distribution of these changed potentials is not unlike that in rectangular conductors. These equipotential lines are very irregular, as might be supposed from the variability in the resistance of the different tissues, which has been previously mentioned. The diffusion of the current is however throughout the whole body, becoming weaker at the most distant and least conducting tissues, notwithstanding how close together the electrodes may be situated. The illustration from De Watteville on page 97 [Fig. 18] is intended to show how the current diffuses itself throughout the human body, whatever the points of application of the electrodes may be. Absolute localization is impossible.

CHAPTER V.

THEORY OF DESTRUCTION OF LIVING TISSUES BY ELECTROLYSIS.

ELECTROLYSIS being the decomposition of compound bodies by the action of an electrical force, can be applied to the destruction of living tissue by interposing this latter between the terminals of an electrical circuit. This electrical circuit should be furnished by an electrical current which is continuous and has a constant strength. We have seen that it is not necessary that the structure to be subjected to electrolysis should be in a perfectly fluid state. It is also well known that pure water offers so high a resistance to electrical conductivity that most physicists believe it to be undecomposable by electricity; yet, saline and other inorganic substances which are dissolved in water will increase its conductivity, and electrolysis can be accomplished, in a semi-fluid material which contains a large amount of water. According to Gamgee,[1] the normal quantity of water in the blood of man varies in amount from seventy-eight per cent. to eighty-eight per cent. In the former case this percentage would be met with in health, and in the latter, in starvation, a percentage of eighty per cent.; consequently the blood containing such a large proportion of water as well as saline materials in solution would act as a comparatively favorable medium for the conduction of electricity.

Practical experience confirms the above theory that the relative conductivity of the tissues of the human body offers a pretty fair transmission for an electrical current.

In order to understand the property which electricity possesses in causing changes in living tissue by what is termed *Electrolysis*, the reader must carefully have understood the teachings of laboratory experimentation as related in a preceding chapter on the physics of electrolysis, as well as the fact of the property of electrical osmosis.

The laws of physics as determined and translated by the great masters of science should then be applied to the teachings of Biology as

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[1] Physiological Chemistry of the Animal Body, pp. 139 and 339.

known in physiological chemistry and in the histology of the living tissues.

First, let us take up the teachings of physiological chemistry. The tissues are formed of what are called proteid or albuminous bodies. Prof. Gamgee states:[1] "Our very conception of a living functionally active cell, whether vegetable or animal, is necessarily associated with the integrity of its protoplasm, of which the invariable organic constituents are proteids. . . We may indeed say that the material substratum of the animal organism is proteid, and that it is through the agency of structures essentially proteid in nature that the chemical and mechanical processes of the body are effected . . We may confidently affirm of the proteids that they are indispensable constituents of every living, active, animal tissue, and indissolubly connected with every manifestation of animal activity."

It is well admitted that the proteid bodies are non-crystallizable compounds of carbon, hydrogen, oxygen, nitrogen and sulphur, and that these compounds are in a partially solid form or in solution in nearly all the tissues of the body. They are all derived from the vegetable kingdom, which in their turn construct them out of very simple chemical forms which they absorb from the sources of nature. This property of constructing the proteid compounds appears to belong solely to the vegetable organism, while the property of conversion of these compounds into living tissues belongs to the animal organism.

It is also admitted that the sources of nature by which the vegetable organism constructs these proteid compounds from simple chemical compounds and elementary substances are heat and light.

Without necessarily rehearsing the minute details of physiology, we should remember that these proteid bodies are mechanically introduced into the animal organism by the *primæ viæ* and carried through the various tissues by the circulating medium. By this means they are used up partially in reconstructing the slowly wasting structure of which these tissues are formed, and partially are subjected to rapid decomposition or *Metabolism*, which decompositions result finally by the retrograde metamorphoses into carbonic acid, water, and other bodies called organic; these products are more or less the results of oxidation or combustion, and they contain all of the nitrogen which was originally present in the proteids.

These proteids also contain many of the chemical salts originally found in nature, such as, the chlorides, phosphates, sulphates and alkalies.

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[1] Physiological Chemistry of the Human Body, vol. i.

The products of decomposition of the proteid bodies, though not definitely understood by the study of laboratory experiments, are known to be the result of oxidation; these products are chiefly compounded of carbon, oxygen, water and certain nitrogenous bodies, such as urea.

The constructive processes of organic life have not been satisfactorily initiated outside of the living organism, though Dreschel has succeeded in producing urea from solutions of carbonate of ammonia [one of the products of the chemical decomposition of urea in the living body] by means of the use of electrolysis with changing electrical currents.

The cell life in the animal organism is the seat of the oxidation processes above preferred to. The viscous material of which this cell is composed has a very similar character to the egg-albumen, except that the latter when dried may exist for years, while the former rapidly perishes.

The fluid which circulates in the tissues of the living body contains all the elements of which the cell is formed, and by this same fluid the products of decomposition are carried off until the organic processes remove them from the organism. The blood which circulates through the body is subject to coagulation when removed and exposed to the air. This coagulation occurs first on the surface exposed to the air or to the sides of the vessel which holds it. The time required for this coagulation varies from three minutes to twelve minutes, and is due to the separation of *Fibrin* from the *Plasma* of the blood.

According to Prof. Gamgee [op. cit.] coagulation of the blood will be hastened by exposure to a temperature higher than that of the human body; by contact with foreign matter; by the effect of agitation; by the dilution of the blood with not more than twice its volume of water; or by the addition of minute quantities of sodium chloride, sodium sulphate, or other neutral salt, while on the other hand, sufficiently large quantities of the same salts will delay or prevent coagulation.

According to Hammarsten, proteid bodies form more than seven per cent. of the serum obtained from the human blood.

The saline materials of the blood are found in the serum in the proportion of about seven-tenths of one per cent. of its weight. Further, according to Prof. Gamgee [op. cit.] the amount and conditions of gases contained in the blood as a whole, may be summed up in the following six statements:—

"1. The blood, when admitted into an empty space and exposed to the temperature of the body, readily gives up more than half its volume of mixed gases, consisting of oxygen, carbon dioxide, and nitrogen.

"2. The first [oxygen] is present in much larger quantities than could be held in simple solution by the water of the blood, and, as will be afterwards proved, is mainly held in feeble combination by the hæmoglobin of the colored blood corpuscles; only a trace of it is, under ordinary circumstances, held in solution in the liquor sanguinis.

"3. The second [carbon dioxide], whilst not existing in larger quantity in blood than it could do if simply dissolved by the water of that fluid, is partly in a state of chemical combination, but chiefly in a state of simple solution. It is contained in great part in the liquor sanguinis and serum, but in part also in the corpuscles.

"4. The nitrogen is held in a state of simple solution in the liquor sanguinis.

5. Arterial blood of a dog of mean composition yields for every hundred volumes fifty-eight and three-tenths of mixed gases [measured at 0° C. and 760 mm.] composed of 22.2 volumes of oxygen (O), 34.3 volumes of carbolic dioxide (CO_2) and 1.8 volumes of nitrogen (N), the maximum of amount of oxygen observed having been 25.4 volumes (Pfluger.)

"6. As venous blood differs in composition according to the vascular area whence it is obtained, it is impossible to state the mean composition of its gases; the following facts are however correct:—the nitrogen is present in the same proportion as in arterial blood, the oxygen is less in amount (from 8 to 12 volumes per 100 in blood) and carbon dioxide greater (from 40 to 50 volumes per 100 of blood)."

We may quote again from another author.[1] "There are only two ways in which energy is set free from the body: mechanical labor and heat. Wherever metabolism of protoplasm is going on, heat is being set free. In growth and in repair, in the deposition of new material, in the constructive metabolism of the body, in the transformation of lifeless pabulum into living tissue, heat may be undoubtedly to a certain extent absorbed and rendered latent—so that the whole metabolism, the whole cycle of change from the lifeless pabulum through the living tissue back to the lifeless products of vital action, is eminently a source of heat. . . Next to the muscles in importance come the various secreting glands. In

[1] Text-Book of Physiology, by M. Foster London, 1884.

these the protoplasm, at the periods of secretion at all events, is in a state of metabolic activity, which activity as elsewhere must give rise to heat. . . The blood itself cannot be regarded as a source of any considerable amount of heat, since, as we have so frequently urged, the oxidations or other metabolic changes taking place in it are comparatively slight. . . It is evident therefore that the mechanisms which co-ordinate the loss with the production of heat must be exceedingly sensitive . . . Further, though the matter has not been fully worked out, the centre of this thermotaxic reflex mechanism appears to be placed above the medulla oblongata, possibly in the region of the pons varolii. . . Whether we should conclude that the working of this reflex mechanism is of such a kind that cold to the skin excites the centre to a heat-producing activity, or of such a kind that warmth to the skin inhibits a previous existing automatic activity of the centre, may be left for the present undetermined."

These and other considerations tend most clearly to support the view, that the nervous system has a more or less direct influence upon metabolic actions, those of a destructive, as well as constructive, change. This view is well supported in the effects and results of certain diseases: it is hardly necessary to speak in detail of these, but it is well known that diabetes is directly influenced by the nervous system; the case of the atrophy of a gland when its nerves are separated is another example. We should be hardly justified in the statement that the nutrition of tissues is entirely dependent upon the guidance of the nervous system. We may, however, understand that the complicated mechanism known as the nutrition of the tissues is so far dependent upon the nervous system, "that, when those influences are permanently withdrawn, these are thrown out of equilibrium; its molecular processes, so to speak, run loose, since the bit has been removed from their mouths. Pathological phenomena are undoubtedly dependent upon the nervous system; of these phenomena inflammation itself cannot be understood, except when regarded as the result of nervous action. Examples might be mentioned, as the wasting of the tissues which are the result of lesions of the central nervous system: the atrophy and loss of the muscular contractility of muscles, which follow the contusions of nerves more rapidly than after section of the nerves; the appearance of certain lesions of the skin which accompany lesions of the spine or brain; experiments on animals also show that certain destructive changes in the living animal tissues follow after section of the nerves which are distributed to these tissues, though it has been contended by some writers that these changes are rather due to the destruction of reflex action, and that, as a consequence, foreign bodies are left in contact with the mucous surfaces, and thus produce an irritation upon which destructive changes will ensue.[1] Taking all things into consideration, we may venture to say that the numerous phenomena of disease, joined to the facts mentioned above, turn the scale by the amount of evidence in favor of the view that some more or less direct influence of the nervous system on metabolic actions, and so on nutrition, will be established by future inquiries."

If we should incline to the theory that the action of electrolysis is purely of a chemical nature in the animal organism, there is sufficient evidence furnished by the above borrowed facts of physiology to show that: —as the proteid bodies are the result of the conversion of chemical compounds of vegetable origin, so any interference from an outside source which would decompose these chemical bodies into their elementary conditions might interrupt the process of physiological nutrition, and in this way the construction of new tissue might be prevented.

Again, it has been shown that the retrograde metamorphosis is effected by the decomposition of the proteid bodies into carbonic acid, water and organic compounds. Sufficient evidence has been shown, in the chapter on the chemical decompositions of inorganic and organic chemical compounds, to prove that electrolysis can produce the decompositions of a similar nature, and which warrant a theory that the same effects may be produced in living tissue; and that in consequence of this artificial decomposition an increase in retrograde metamorphosis may decrease the tissue formation.

Again, an elevated temperature, as well as dilution of blood with twice its volume of water, will hasten the coagulation, which latter result is the effect of the separation of fibrin from the plasma of the blood. The effect of an electrical current in contact with the blood will, as shown in a previous chapter, result in the formation of a fibrinous deposit on or around the electrodes, and sometimes will increase the amount of water in the blood.

When we add to these facts that oxygen exists in the blood in a feeble state of combination with the hæmoglobin, and that the effect of the presence of an electro-negative needle in contact with the blood results in the collection of hydrogen, we might naturally presume on the establishment of an hypothesis: viz., that the oxygen will combine with hydrogen

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[1] Op. cit.

to form water. Now, this combination, as well as the combination of oxygen and carbon, will produce heat, and this production of heat must do some work. Possibly, and indeed probably, this work is partly explained in the effect of the coagulation of blood; and coagulated blood loses its property of conveying nutrition to the tissues which should be fed by the blood in its active condition.

There is sufficient reason in the above arrangement of causes and effects to account in part for the destroying action of electrolysis on the life of the tissues, but, before carrying this mode of argument further, it would be advisable to obtain some other facts in relation to the natural decadence of the tissues. We can obtain this information from a pathologist of no mean reputation and in his own words in regard to the nature, purposes, and conditions of nutrition:[1]

"It is, further, probable that no part of the body is exempt from the second source of impairment; that, namely, which consists in the natural death or deterioration of the parts [independent of the death or decay of the whole body] after a certain period of their life. It may be proved, partly by demonstration, partly by analogy, that each integral or elemental part of the human body is formed for a certain period of existence in the ordinary conditions of active life, at the end of which period, if not previously destroyed by outward force or exercise, it degenerates and is absorbed, or dies and is cast out; needing, in either case, to be replaced for the maintenance of health.[2] The simplest examples of this that I can adduce are in the hair and the teeth; and in the process which I shall describe, and illustrate with the annexed diagram, we seem to have an image in which are plainly marked, though, as it were, in rough outline, all the great features of the process by which certain tissues are maintained.

"An eyelash which naturally falls out or which can be drawn out without pain, is one that has lived its natural time, and has died, and been separated from the living parts. In its bulb such an one can be found very different from those which are living in any period of their age. In the early period of the growth of a dark eyelash, we find its outer end almost uniformly dark, marked only with darker short linear streaks and exhibiting no distinction of cortical and medullary substance. Not far from its end, however, this distinction is plainly marked. Dark as the

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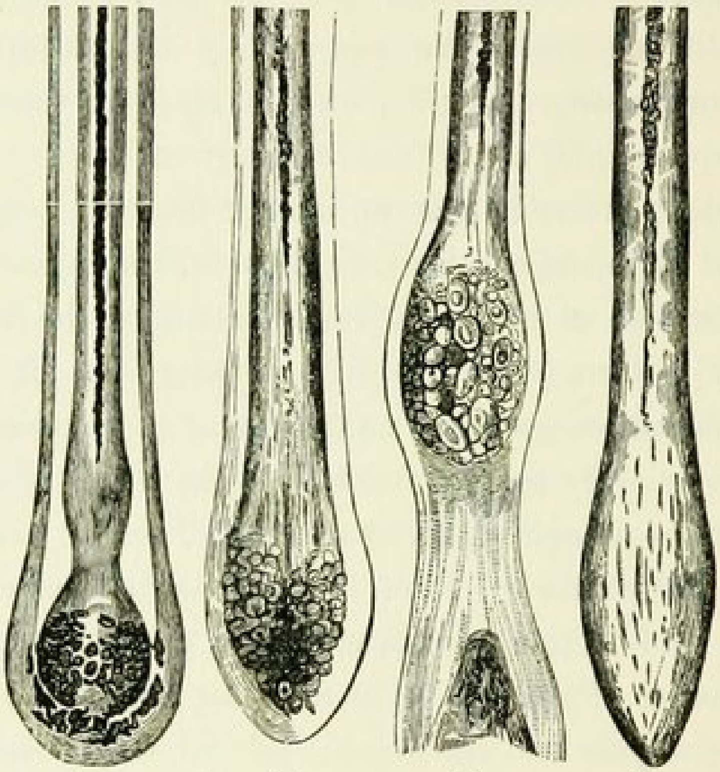
[1] Lectures on Surgical Pathology, Sir James Paget, M.D. Third Am. Ed. Lindsay & Blakiston, Phila., 1865, pp. 286.

[2] Dr. Carpenter, Principles of Human Physiology.

cortical substance may be, the medullary appears like an interior cylinder of much darker granular substance; and in a young hair this condition is continued down to its deepest part where it enlarges to form the bulb (Fig. 21, A). Now this enlargement, which is of nearly a cup-like form, appears to depend on the accumulation of round and plump nucleated cells, which, according to their position, are either, by narrowing and elongation, to form the dry fibro-cells of the outer part of the growing and further protruding shaft, or are to be transformed into the air-holding cells of the medullary portion. At this time of most active growth, both



A. B. C. D.

Fig. 21.

cells and nuclei contain abundant pigment matter, and the whole bulb looks black. The sources of the material out of which the cells form themselves are, at least, two; namely, the inner surface of the sheath, or capsule, which envelops the hair, and the surface of the vascular pulp, which fits in a conical cavity in the bottom of the hair bulb.[1]

"Such is the state of parts so long as the hair is all dark. But as it approaches the end of its existence, it seems to give tokens of advancing age, by becoming gray (Fig. 21, B, C.) Instead of the almost sudden enlargement at its bulb, the hair only swells a little, and then tapers nearly to a point; the conical cavity in its base is contracted, and hardly demonstrable, and the cells produced on the inner surface of the capsule contain no

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[1] Our author here probably refers to the papilla of the hair.

particle of pigment. Still, for some time it continues thus to live and grow, and we find that the vigor of the conical pulp" (papilla?) "lasts rather longer than that of the sheath and capsule; for it continues to produce pigment-matter some time after the cortical substance of the hair has been entirely white, and it is still distinct, because of the pigment-cells covering its surface.

"At length the pulp can be no longer discerned, and uncolored cells alone are produced, and maintain the latest growth of the hair. With these it appears to grow yet some further distance, for we see traces of their elongation into fibres or fibro-cells, in lines running from the inner surface of the capsule inwards and along the surface of the hair; and we can always observe that the dark column of medullary air-containing substance ceases at some distance above the lower end of the contracted hair bulb (C, D).

"The end of all is the complete closure of the conical cavity in which the hair-pulp" (papilla?) "was lodged; the cessation of the production of new cells; and the consequent detachment of the hair as a dead part, which now falls by the first accident; falls, sometimes, quite bare and smooth on the whole surface of its white bulb, but sometimes bringing with it a layer of cells detached from the inner surface of the capsule (D).

"Such is the life of the hair and such its death; which death, you see, is natural, spontaneous, independent of exercise, or of any mechanical external force, the natural termination of a certain period of life. Yet before it dies, provision is made for its successor; for when its growth is failing, you often find, just below the base of the old hair, a dark spot, the germ or young pulp of the new one; it is covered with cells containing pigment, and often connected by a series of pigment-cells with the old pulp or capsule (Fig. 21, C). And this appears to be produced by an increase in the growth of the cells at the bottom of the hair-follicle, which cells Kölliker's observations have shown to be derived partly from the soft round cells of the hair bulb, and partly from the adjacent outer root-sheath. By the subsequent elongation and differentiation of these cells the new hair is formed. I believe we may assume an intimate analogy between the process of successive life and death, which is here shown, and that which is believed to maintain the ordinary nutrition of a part."

Such was the description given twenty years ago by this eminent surgical pathologist in regard to the process by which the growth of a hair is maintained, and from want of which its death ensues. The application of his views and the anatomy of the root-sheath in relation to its surrounding parts will be found in a subsequent chapter. (See Chap. X.)

This foregoing synopsis of the conditions of life and the reconstructive elements of living tissue is briefly recited in order to show its bearing upon the subject before us. We have seen in this brief review, that the blood is the carrier of materials whose purpose it is to reconstruct and repair living tissue, the latter of which is the seat of certain processes which expend the organic material of which it is composed. These processes, which for want of a better word we call vital, are carried on by living cells; these are the seat of chemical changes, commonly called combustion or oxidation, as also the seat of other changes which result either in the reproduction of organic structures, likewise cells, by assimilation of appropriate materials, or which result in the elimination of waste material which they cannot assimilate. In other words, these cells are the seat of constructive metamorphosis [metabolism] and destructive metamorphosis of tissue.

The cells therefore constitute what is called living tissue, and are possessed with functions of life, and when these latter cease the cells perish. It should here be remembered that the blood corpuscles are likewise cells, and are endowed with living functions, and hence are to be considered also as living tissue; disorders of nutrition may affect the latter as well as the former class of cells. If the normal constituents of the blood undergo a change, especially if it be in the direction of retrograde metamorphosis, the cells of the tissues which contain a smaller amount of water, (and in consequence are less likely to allow of motion of the component particles,) will also receive new materials or elements from which to select their peculiar sustenance or with which to carry on their functions of life or of reproduction. Prof. Gamgee[1] states that the normal quantity of water in man's blood varies in amount from seventy-eight to eighty-eight per cent. of its weight; the smaller proportion would be met with in health and the larger proportion in the condition of starvation or after hemorrhage; a percentage of eighty to eighty-two or even higher is met with in the case of anæmia or in an impoverishment of the blood, which is often the concomitant of disease, such as abundant suppuration, chronic diarrhœa, malarial diseases, lead and mercurial poisoning, in cancerous and tubercular affections. A decrease in the quantity of water in the blood

[1] Op. Cit.

occurs in articular rheumatism, in erysipelas, in puerperal fever and especially in cholera. The proportion of water in muscle varies between seventy-four and eighty per cent.

The proportion of water in the nervous tissues is from sixty-four to eighty-five per cent.

The saline materials in the blood vary from seven to nine parts in a thousand, and in muscle about the same, whereas nerve tissue may have only half this amount.

It being understood that electrolysis is not limited simply to fluids, but can act upon substances of which fluids form a large proportion, we can readily understand that the effects of electrolytical action can easily be recognized in any of the tissues above mentioned. Other things being equal, we can also understand why a substance which is so largely composed of water, as blood, muscle and nerve tissue, can itself be the seat of electrolysis, and undergo changes by decomposition and reformation of the original structure.

While attempting to study these changes of living tissue in the human body, we might borrow from recent theories in the department of Botany, in which great advances have been made in the knowledge of the causes which promote cell-formation. Plants grow from the formation of new cells or from the increase in size of the cells already formed. The formation of new cells takes place in the protoplasm of highly active cells, under certain definite conditions; and the process of formation, although differing somewhat in different cases, presents certain definite phenomena. These phenomena have been carefully observed by the aid of very high magnifying powers of the microscope, and by the means of tissue staining; in this process some parts of the cell are more deeply stained than others. These changes, as observed, appear somewhat as follows:—the protoplasm contains a nucleus, a comparatively dense body, which passes through regular transformations; in these transformations this nucleus becomes sooner or later separated by a sort of thin plate of cell-wall into two parts, the thin plate itself forming a common septum between the two halves into which the original divides by the process of segmentation. This nucleus appears to have the power of arranging in regular forms the food-materials, chemical substances, which being placed at definite points would be, otherwise, diffused throughout the protoplasm; the nucleus appears to have the power of making out cf these materials a thin cell-wall, which is situated at a given place with reference to the rest of the cell. The successive new walls are thus produced out of the division-walls which are formed by the segmentation of the older nuclei. These new walls are so disposed with reference to the others that regular forms of the successive organs are developed in their proper order.

Certain of the filaments which are in the nucleus, during its segmentation, form themselves in numerous and orderly arrangement into lines which may be compared to those on the earth's meridian, and constitute what are called by the technical name of karyokinetic figures. These karyokinetic lines, or figures, are the same as those which are formed in the segmentation of cells in the animal kingdom. The increase in the size of the cells is supposed to arise from the deposition of particles of cell-wall which are thrust in between older particles; though some authorities suppose this increase to be caused by the stretching of the existing wall, which becomes thicker by the placing of new particles on the inner surface. The resulting forms of cells are governed, of course, by the character of the organs which they compose; but only by the arrangements in such shapes as would result from their more convenient occupation of the space into which they are obliged to be confined; the shapes of these cells are apparently related to the office they are to perform in the structure. The diversity of these shapes is very great, but is more or less related to the given number of cells which are limited in a given space; the larger the space and the fewer the cells the more rectangular will be the resulting shape, and, *vice versa*, the smaller the space into which a larger number of cells are squeezed the narrower and longer will be the resulting shape.

As essentials to their growth, the cell-structure needs as its food oxygen and a certain amount of warmth. In the plant life the degree of warmth required for a healthy growth varies in different cases; while in the living animal the degree of heat required for the maintenance of health and growth is within a very small range, and must be maintained at the expense of chemical action within the living organism.

In the study of botany many instruments have been devised for the measurement of the rate of growth of plants. The observations of these chronographic instruments show that different plants have precisely the same needs for growth; but that, under the same conditions, the same plant will not always grow at exactly the same rate. While there are certain conditions which are indispensable to rapid growth, there are some internal influences at work in plants by which these conditions are more or less affected in their efficiency; thus, plants exposed to an unvarying degree of temperature will exhibit marked differences in their rate of growth, which are, at present, unaccounted for, and which are not dependent upon any known external influences. Moreover, these differences cannot be explained by any ancestral peculiarity.

In continuation of these modern studies on the growth of plants Prof. Goodale states,[1] that plants not only require a certain amount of oxygen and water, but must also have proper food. It is customary to speak of the food of plants as wholly inorganic; that is, that it comes entirely from the earth and air; yet, it is more in accordance with modern views of physiological students to state the matter thus:—From inorganic materials taken from the earth and air, plants prepare their food, and when thus prepared and ready for use, this food is as truly organic as is the food of animals.

All organic food represents a certain amount of treasured energy; the great difference between plants and animals (excluding a few doubtful exceptions) is this: under the influence of light, plants can treasure up energy at first hand, so to speak, whereas animals have only that which they have appropriated at second hand from plants or from other animals. From this point of view plants should be considered as machines for storing up solar radiance for themselves and for all other organisms on the face of the earth. Plants stand midway between animals and starvation. The animal has all the materials of food that the plant possesses, viz., carbonic acid, water, and the traces of earthy matters, but under no known conditions can the animal directly utilize them. It is not requisite to speak of a few exceptions to this statement, since we are only speaking of the subject in general; every plant which possesses green coloring matter, chlorophyll, which is combined with its protoplasmic contents, can take these inorganic matters and convert them into food, only however in the light.

Any intense white light, for instance the electric light, will answer for solar light, but of course to a less degree. Siemens in England has raised very delicious fruits under the electric lamp. A few plants, mushrooms for instance, have no green matter in their cells, and do not possess the power of creating the food from inorganic matter. They, like animals, must take their food from some prepared supply, as in this case from decomposing matters of organic origin; they cannot subsist upon inorganic matter alone any more than animals can.

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[1] Lowell Lectures, 1886, Boston, Mass.

We are taught that the growth of animals is a growth of the individual cells, which multiply by the segmentation of their nuclei; and the animal cells are fed from the sources of nature which are furnished to them by the work of the vegetable plant life. The source of energy is from the sunshine or from the energy which is latent in the organic kingdom, as well as from that which has been stored up in inorganic chemical compounds. We have seen in a study of the electro-chemical action of these compounds in the galvanic cells, that this energy may be transmitted in the form of electricity, in our present case electrolysis, which by its action must also perform some work, either in constructing or tearing down structures, when passing through the living organism.

We have seen, also that the action of electricity, when passing through its conducting mediums offering resistances, may develop this energy in the form of heat or of light. We also know from the study of disease in the case of abnormal elevation of temperature, that living tissues undergo a loss of substance from the destruction of cell life, and that the products of this definite destruction are found in the form of lower organic chemical compounds or of the higher inorganic compounds. We also know that pathological lesions in the nerve centres are usually marked by disturbance of nutrition in those tissues which derive their innervation from these centres. Now, it seems reasonable to assume that the transmission of electricity through these conducting mediums, whether conducting easily or with difficulty, must be accompanied with some marked effect upon the integrity or functional activity of the structures conducting this energy.

Let us now turn from these studies in botany to some of the more recent investigations of animal cell propagation. It must first be stated that we are progressing somewhat beyond the region of exact science towards the rather doubtful position of speculative theory; but we cannot do otherwise, if we desire to advance our knowledge, for a theory is nothing without its practical application, and will fall by its own weight unless the applications bear out the principles upon which it is founded. The facts of observation are none the less true, whether the resulting theory be admitted or not. Histology has long been occupied with the processes by which the propagation and consequent increase in the number of cells of a given tissue are effected; the principle and fact of the segmentation of the primordial cells is now generally admitted; the details of the method in which these segmentations occur are hardly established.

We have seen in the account which nas been presented by Professor Goodale in his course of lectures on recent progress in the knowledge of cell multiplication in the plant life, that botanists are disposed to admit certain plans of the formation of new cells out of the older nuclei; students of histology of animal tissue formation have also occupied their attention with the details of the process of cell multiplication in the living structures of the human body. In a recent article entitled *Karyokinesis*[1] Waldeyer presented a communication to the Society of Medicine of Berlin in November, 1885, upon the subject of cell segmentation. This author, in mentioning the increasing interest shown in the study of this process in the animal organism, reported some new investigations of a practical nature upon this point.

He states that according to the theory of Remak, which is substantiated by Tilhard, Schultzer, Ranvier and himself, it is believed that when a cell performs its functions of segmentation, the work is done by the nucleolus, which subdivides in two parts, and which process is afterwards continued by the nucleus; this latter ends finally in the division of the cell into two portions. Since the time when the above mentioned process was admitted by histologists as a fact, a new method of segmentation has been recognized, which upon the initial proposition of Schleicher, has received the name of karyokinesis.

According to the recent investigations of Fleuring, of Hertwig and of other histologists, the cell nucleus comprises a kind of limited space (*trame*) which is defined by large filaments; these thrust out slender filaments which anastomose in form of meshes. The nucleus is surrounded by a thin membrane, which is formed, according to the opinion of some authorities, by the terminal expansions of these slender filaments, while according to other authorities, it is a true membrane. A substance (uninucleary of Hertwig) fills the network of these meshes. In the midst of this fluid material (*jus*) are found the nucleoli, suspended to the filaments of this space; and, in the opinion of certain authorities, these latter are only enlargements of the framework.

The above described nucleus is called "*the nucleus in a state of repose.*" When the phenomenon of segmentation begins, which follows the character of karyokinetic, certain methods of peculiar transformations are produced. It must first be understood that the areolar space and the nucleoli,

[1] Nouvelles Archives d'Obstetrique et de Gynecologie, 25 Feb., 1886, p. 113.

both of which are colored by certain pigments, receive the name of *chromatic substance,* in contradistinction to the nucleary fluid (*sic*) *which is not susceptible to coloration by the same pigment and consequently is called achromatic substance.* When segmentation begins, the fasciculi of the space, which were not arranged in any order beforehand. in the state of repose, will afterwards arrange themselves in regular groups (Kalb). The lateral expansions then extend into this space, and the areolar arrangement and the nucleoli disappear.

The large filaments which remain, then form loops with their convexities directed towards one half (*polar*) of the cell, and their concavities directed towards the other half (*polar*). Kalb is of the opinion that this arrangement of filaments in loops had existed during the state of repose, but that it was masked by the lateral expansions; this same writer is the authority for the belief that the nucleus originally contained several isolated filaments; Fleuring and Strassburger, on the other hand, incline to the belief that a single filament only exists and from this the several loops are described.

In a later phase these filaments become contracted in their lengths and consequently are thickened; from this thickening these filaments segmentate in such a manner that several loops spring from a single loop; the same primitive loop will always give origin to the same number of secondary loops. During this second phase the filaments will segmentate as a fundamental phenomenon in the direction of their length (*Fleuring, Hauser, Kalb, Strassburger.*)

The third period is then reached, which is characterized by the fact that the primary chromatic figure of the nucleus will give place to another arrangement, which has been recognized for a long time (*Kowalewski*), and which is named the achromatic figure in spindle shape. This latter figure is formed from very delicate filaments and has the appearance of a regular shaped spindle, which, according to Kalb, occupies an eccentric position within the nucleus, its equatorial line being turned towards the pole of the nucleus. The loops of the chromatic figure face towards the equatorial line of the achromatic figure, and thus become reunited along the length of the equator of the latter. The position of the spindle immediately changes in such wise that its poles suddenly coincide with those of the nucleus. The period of the first stage, called stage of sphericity (*pelotonnement*) is then attained. It should be noted that towards the end of this stage a small corpuscle (*polar corpuscle*) will appear at each pole of the fusiform body; from this corpuscle radiating striæ originate which penetrate into the protoplasm of the cell; this fact seems to indicate that the protoplasm itself shares in the action.

A second stage succeeds to that which has been described above, and to which Kalb was the first to call attention:—The segmentation occurs, as has been mentioned, during the stage of sphericity; at this period the two filaments of the second generation become separated in order to attach themselves each to a pole of the fusiform body; soon the loops are grouped around the poles in a manner to form a stellate figure (*asteroid stage*). Then the filaments of the achromatic figure are drawn within those points, by which the equatorial line of the spindle is defined, and, in this way, prescribe the limit of the area of segmentation; this process of division follows that of the body of the cell. It should be remarked that the limiting membrane disappears during the above described stage, and that a new membrane is formed around each polar mass.

If these two stellate figures be examined during this period, the same configuration will be found as in the primary nucleus:—that is, the loops are curved with their convexities directed towards a pole, and secondary anastomotic filaments will become detached from the larger filaments, and in this way are formed a new plot (*trame*), a nucleolus, etc.

The behavior of the nucleary fluid (*jus*) during these metamorphoses is not yet established. According to the authority of Strassburger, it performs no other part in the work of segmentation than this; while mingling with the protoplasm of the cell at the moment of the destruction of the nucleus, it would assist by this union in giving to the achromatic figure its spindle shape.

Fleuring assumes that the achromatic figure is formed of certain portions of the chromatic figure which are recognized as distinct from the rest by not being susceptible of coloration. Kalb supports this same opinion, but believes, in addition, that the nucleary fluid partakes in the formation of the fusiform figure, and does not change its condition in the protoplasm. There are then some grounds for the support of the hypothesis of Remak in the presumption of a new structure of the nucleus.

We do not know what becomes of the limiting membrane of the nucleus, nor of the part which the fusiform body plays in the process of segmentation.

Waldeyer advances the statement that the knowledge of this method has already furnished its first fruits. He believes that a cell is in condition of segmentation when several nuclei are found in its interior; segmentation should only be admitted as occurring when proof is afforded of the succession of those changes which constitute the process of karyokinesis. Moreover, when these changes are proceeding in several nuclei, which are restricted to a small compass, we may be able to conclude that a tissue is in course of active proliferation directly under our observation.

We see that botanists and histologists, both in each department of microscopical observations, are strongly inclined to the belief of certain movements of the minute organic particles, and that these must proceed in regular order to cause the process of cell multiplication, or proliferation; from their mode of reasoning we are entitled to conclude that any interference with this process of assuming regular motions will interrupt the process of segmentation, which is now generally admitted to be necessary to an increase in the formation of new cells, and, consequently, of new tissue. Without attempting to carry this train of thought into the grand processes of tissue nutrition, we may continue its study in the application to the subject now before us.

It must be admitted from the teachings of chemistry, that every process of building up a higher inorganic or organic structure consumes energy, and that every process of a higher organism, falling to a lower stage from its previous higher form of structure, is accompanied with a liberation of latent energy which may be transferred into motion; therefore in a complicated organism, like that of the plant or animal life, these processes of repair must be accompanied with the consumption of latent energy; on the other hand, decompositions of the higher structures contained in these same organisms must be followed by the liberation of the previous latent energy. We must also admit that motion is the result of the display of a force. We have seen in the latest exposition of the process of segmentation, that this latter is accompanied with the physical property of motion, a motion of a decidedly active and delicate character, which must consume a considerable amount of energy. We know, also, that the analysis of the results of destructive changes of the tissues show a decomposition by descent to lower forms of chemical compounds; these are marked by the presence in the excreta from the human body of these compounds, and they are, moreover, found in larger amounts in the conditions of the body which are concomitant with the waste of tissue.

It has been shown in a previous chapter that electricity is simply a natural force, and that this force is the result of the decomposition of chemical compounds, and is the transmutation of a latent energy. It has also been previously shown that the presence of this electrical force in organic solutions produces their decompositions. It naturally follows from this mode of reasoning that the introduction from without of a force would produce some action upon the complicated processes of tissue formation; impulse would lead us to suppose that the direction of this influence should favor the processes of nutrition; on the other hand, practical experience proves the opposite effect. We cannot assume that the effect of the electrical current acts as it does in the laboratory experiment. We must seek some other analogy. A simple fact is offered from which we may start; the introduction of a sharp-pointed instrument within the medulla oblongata is immediately followed by an arrest of its functional activity, and this is suddenly followed by death. This is a simple act, and there will be no occasion for an elaborate discussion to prove the effect from a cause; the medulla is the seat of the nerve centre which presides over the animal functions of life, the central organ of the motion of the blood circulation, as well as that of respiration; there is no need of entering into the matter of explaining in this connection that probably the medulla receives its reflex impressions from the presence of carbonic dioxide in the blood, because the result which follows the puncture is too rapid to be explained on this supposition. The injury to a very limited portion of this nerve centre produces fatal effects. The illustration is presented to show merely how the simplest interference with the integrity of an important organ may destroy its function.

A simple needle puncture within a living tissue need not necessarily destroy its vitality; indeed, it may stimulate its nutrition by inviting a freer flow of blood to promote its nutrition; the transfixing of a hair follicle by a needle will not destroy its vitality nor impair the growth of the hair, unless it induces an active inflammation which is attended with a loss of the tissue which surrounds the follicle, and from which the hair receives its nutrient material; pulling out of the hair does not prevent another one from growing within the same sheath and from its papilla. A puncture within an hypertrophied growth of tissue does not destroy its hypertrophied cell formation, nor will the puncture from several needles produce a decrease in its extent; yet, an electro-puncture into the hair follicle will, if the electrical current be continued long enough to destroy its surrounding tissue, cause a follicular destruction; the evidence is also sufficient to prove that an electro-puncture into a glandular tissue will be followed by the same result, provided that similar conditions accompany this interference with its integrity. This result is more sure to follow the effect when the tissue is made up of that kind of cell formation which closely resembles the embryonic cell formation. On the other hand, practical experience would appear to show that where the hypertrophy of growth is in that form of cell multiplication which corresponds with a lower scale of vitality, as, for instance, that of cancer, the application of the electro-puncture is not followed by an arrest of this cell formation; so, again, where we have to deal with a collection of the products of decomposed cell formations, as, for instance, that of a fluid contained in a cyst, or with purulent materials, the electro-puncture does not effect an arrest of the products of decomposition.[1]

This position will be more fully understood in the perusal of the cases detailed in a subsequent chapter. Now it would seem that a proper explanation of the causes which effect a decrease in the production of cell multiplication would lie in the direction of a knowledge of the methods in which the particular form of cell is propagated, and which is more unfavorably affected by the electrolytical action. The theory of the karyokinetic configuration and the accompanying segmentation of the nuclei would appear to furnish a basis for the proper explanation of the effects of electrolysis of the glandular hypertrophy; and the most satisfactory way of continuing this study would be in this direction. The method of action of the electrical current in the treatment of cystic tumors is more particularly mentioned in the seventh chapter, in relation to the clinical history of these cases; in the author's opinion this explanation need not rely upon the same basis as that of the cell destruction of hypertrophied growths.

There is another phase of the present question which is not only of importance in our theoretical discussion, but also of paramount importance in regard to the practical application of the therapeutics of electrolysis; the action of a strong current to the destruction of the embryonic cell multiplication is rarely followed by the same satisfactory results, as from the long continued action of feeble currents; especially is this true when the latter have the character of what is known by the name of currents having large quantity, or, what should better be called, by the name of

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[1] We do not here refer to the secondary effects which may be otherwise explained, as the stimulating action to a chronic inflamed tissue which results in the formation of pyogenic membrane.

currents possessed with the property of producing a large amount of chemical action.

Another physical effect of electrical action upon fluids, which has been referred to in these previous pages, deserves more than the passing notice which many writers on electricity in medicine have given to it; viz., *cataphoric action of electricity* (*electrical osmosis*). This physical property is

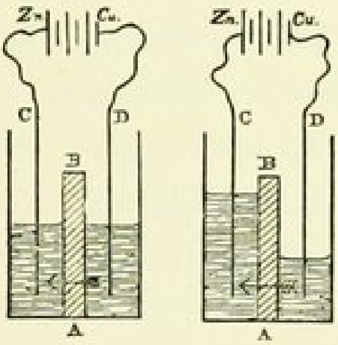

FIG. 22.

so well described in a comparatively recent work that no apology is offered for borrowing this description.[1] "Let a narrow glass cell A as in Fig. 22 be divided by a wall of porous earthenware B, and let electrodes of platinum-foil C and D be connected with Zn and Cu, the respective poles of a 10-cell Grove's battery.

Place pure water in the cell A, so that it stands at exactly the same

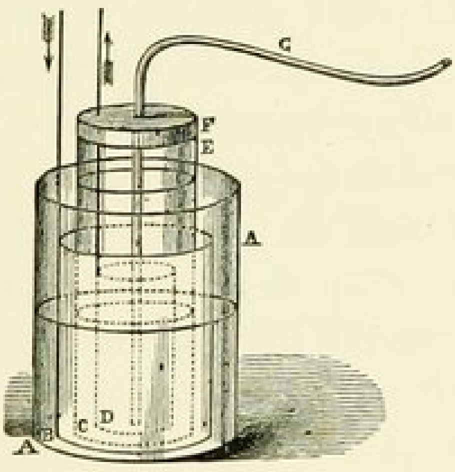

FIG. 23.

level in both divisions. Scarcely any gas will be evolved, the water being so bad a conductor. But in the course of a few hours, the water around the negative (—) pole will be found higher than that around the positive (+) pole (2). With dilute sulphuric acid, or sulphate of copper, the amount of electrolysis is very much greater, but the difference of level is found

[1] Magnetism and Electricity, Guthrie, p. 168.

to be less, while with alcohol and other liquids, which conduct even worse than water, the passage towards the negative pole is greater. A series of exact experiments have been made with the apparatus shown in Fig. 23, which exhibits all the parts as though they were transparent. The outer cylinder A is open at the top. B is the anode in the form of a cylindrical sheet of platinum (or in the case of alcohol, copper). C is a cylindrical porous earthenware cell, fastened above to a short cylinder of glass E of the same size, which carries a cork F.

Through the cork F passes a platinum wire, protected from contact with the cork by being fused into a glass tube, and carrying below the copper or platinum cathode D. Through the cork F also passes tube G, whose inner end dips into a liquid in the porous cell. On connecting the electrodes with the battery, as indicated by the signs, the current passes from B to D, and the liquid moves with it. The whole of the porous cell and glass cylinder, up to the cork, and the tube G, being perfectly full, the quantity of liquid which escapes from C is the same as that which has been moved by electrical osmosis. The gas is evolved in the case of alcohol or sulphate of copper, and an exceedingly small quantity in the case of water; such gas (H) may be collected and measured if necessary. It is found that the amount of electrical osmosis is proportional to the strength of the current of the battery and that it is also proportional to the resistance of the liquid. The total quantity of the electricity which passes through the cell may be measured by interposing a cell of sulphate of copper in the circuit, and weighing the amount of metallic copper deposited on the cathode of the interposed cell."

It will be noticed that the amount of fluid transported to the negative pole by means of an electrical current is proportional to the strength of the current and to the resistance of the fluid conductor; it would naturally follow from this that the movement of fluids within the human body would take place towards the surface upon which the negative electrode is in contact, and that when the resistance is greater from the chemical character of the solution, the movement of transportation will be more active. The clinical experience of von Ehrenstein, Semeleder, Fieber, and others, which is more especially mentioned in chapter seventh, would seem to show that the fluids of a cyst within the abdominal walls will be absorbed and disappear under the treatment of electrolysis, particularly when the combined use of diuretics, hydragogue cathartics, and diaphoretics produce a voluminous discharge of watery materials from the body. It would be unreasonable to attempt to explain the absorption of watery materials from a cystic tumor by the assumption that the cell formations are disturbed by the destructive agency of electrolysis, or that the chemical decomposition of the water or saline substances in its solution are formed into gaseous elements; because the total results of this physiological and chemical action are not commensurate either with the whole effect to be ascribed to the electro-chemical decomposition, or to the whole amount of the resulting absorption of the fluids. It would not be reasonable to suppose that the cataphoric action could account for this large amount of liquid absorption, at least, simply to ascribe this absorption to the physical effects of transportation of the mass of fluid towards the negative electrode; for the strength of the electrical current is not sufficient to account for the rapid effects of the electrical current. In the preceding experiment we have seen that it requires several hours for the transportation of a considerable mass of fluid. On the other hand, it is known that the disappearance of large quantities of fluid, either in ascites or in cysts, from the abdominal cavity has occurred spontaneously, or by the aid of the same medicinal remedies which are above mentioned; yet, it should not be overlooked that these same medicinal remedies frequently have not accomplished the removal of liquid effusions unless the treatment has been combined with that of electrolysis. It must, therefore, be admitted that the action of electricity has a considerable share in effecting the absorption of effusions. As it would require an illustration from clinical experience to understand the method by which these effusions are absorbed, as also the theory which would satisfactorily explain the process, its further discussion will be reserved until after these cases have been reported in detail.

There are, therefore, four methods by which electricity can be supposed to interfere with interstitial nutrition, and in consequence of this interference, destroy the life of the cells, viz.:—

1. By producing a true decomposition of the chemical compounds, upon whose combination the integrity of the living structures depends.

2. By interfering with the natural processes of cell segmentation, by which their proliferation and increase is effected; this interference would thus prevent the repair and multiplication of the cells whose living functions are essential to the growth of the living tissues.

3. By promoting a movement of the mass of fluid in the living tissues towards the negative electrode, and thus interfering with constructive

metabolisms upon which interstitial nutrition depends. In regard to this method, we would refer our readers to the extract from Sir James Paget's lecture to show that, at least in the case of the nutrition of the hair, the increase of the destructive changes, which occur after typhoid and other conditions of disease, may not unreasonably be supposed to effect similar attending phenomena which occur in the natural processes of decay.

4. The acid and alkaline reactions at the positive and negative electrodes, respectively, from which a caustic action upon the tissues is effected through contact of these two different chemical reactions.

CHAPTER VI.

METHODS OF EMPLOYING ELECTROLYSIS IN THE LIVING TISSUES.

Recognizing that the object of the application of electrolysis in the living tissues is that it may be used for the purposes of their destruction, and for nothing else, the methods of its application are theoretically simple. We have seen in the preceding chapters that we have to deal with physiological as well as physical processes, and that the electrolytical action of this form of electricity is to be expended in order to arrest the reconstructive metabolisms. We have also seen that the action of electrolysis is accompanied with the acid reaction at the positive pole and an alkaline reaction at the negative pole; again, that the cataphoric action, whereby a transportation *en masse* of the fluids through a porous septum, occurs towards the negative pole; the fluid condition in these tissues is to all intents and purposes in porous septums, and is undoubtedly under similar circumstances susceptible to the same process of transportation as that of fluids in other porous septums outside of the body. We have also seen that the presence of an electrical force within these tissues may be accompanied with the display of electro-chemical actions, by which the chemical structure of these tissues may be broken up into its elementary characters.

All of these processes of the effects of electrical action are not to be ascribed to that of electrolysis, viewed simply as a chemical reaction, but they are none the less concerned with the subject of this treatise, and deserve the same consideration as the display of simple electrolysis; in other words, since the therapeutical action of the so-called electrolysis has been considered in books on the application of this method of cure in tumors, as well as other conditions of diseased tissues, the study of its action and practical application requires that these different phases of electrical display should be severally mentioned.

The application of this treatment will depend upon the nature of the disturbed condition which we may be called upon to correct; for instance, to take the simplest condition, that of a chronic suppuration of an inflamed tissue, the tract of a sinus or fistula; in these conditions of an unhealthy tissue the indications for treatment, as in those of a chronic ulcer of the skin, is to destroy the results of inflammation or of suppuration, and by a process of stimulation of the inflamed and vitiated surface to substitute a healthier interstitial repair, by means of which the process of healing of this surface may be naturally restored. For this purpose the local action of a stimulating caustic may be employed, and previously to this to cause a removal of the accumulated and vicious secretions; the positive electrode should therefore be applied to the deteriorated tissue, for by means of the cataphoric action produced *from* the positive as well as *towards* the negative pole the watery materials will pass away from this surface; the acid which will collect around the positive electrode will stimulate the underlying tissue, and as a result there will be formed a dry and small scab, under which the reparative processes may be encouraged. This same positive electrode should also be applied to the diseased conditions known as *lupus*, of which some cases are reported in a subsequent chapter.

On the other hand, if the indications are for the prevention of the formations of the embryonic cell growths, by the increase of which hypertrophy will occur, the negative electrode should be selected for application. For this electrode invites the appearance of water around it and will, otherwise, cause the disturbed conditions of the process necessary to the segmentation of the embryonic cells, and in this way, will prevent the constructive metabolisms which cause an increase and multiplication of these cells, and thus produce the hypertrophy.

If, again, we should desire to effect an absorption of a fluid within the cavities of the body, we should then seek to apply the cataphoric action of electricity, by which the fluid is transported towards the negative electrode, and by this means cause the absorption of the fluid by the processes which would convey the fluid towards the periphery, to those tissues which act as absorbents. The combined use of diuretics and other medicinal agents would materially assist in removing by the emunctories the fluid thus transported by the agency of electricity. We must not overlook the fact that the action of rubefacients, vesicants and other similar medicaments are employed sometimes for the same purpose; and possibly we might account in part for the action of electricity as a cataphoric agent by the same explanation of counter irritation; but this will not account for all of the action, because the application of electricity has been followed by absorption of the effused fluid, when the use of the medicinal means, without the aid of electricity, has not been thus successful.

These preceding remarks will suggest that the methods of employing electricity, as well as the other physical properties which are inherent in electricity, will necessarily be varied to suit the purposes of the indication in each class of cases.

To effect the absorption of effused liquids within the cavities of the body a current strength should be selected, which should have considerable tension, as well as a strong chemical action; the galvanic cells should consequently be coupled for tension in series, but the elements would be also advantageously arranged to present a large surface to the exciting solution within these cells; it may even be advisable to combine the system of the arrangement of cells in battery, so that we may employ a mixed combination of two or more groups which combine the parallel, or the multiple, with the series system, as explained in a preceding chapter, or as shown in the accompanying diagram:

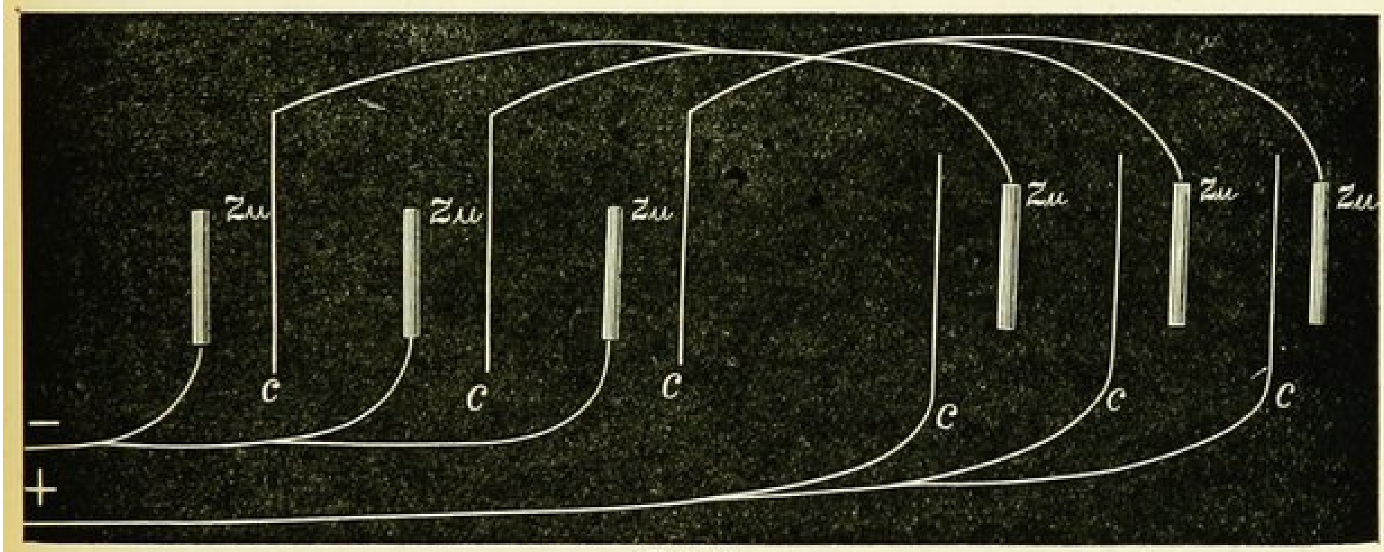

Fig. 25.

When it is remembered that the effusion of fluids into a cavity is the result of a vitiated condition of the tissues, it might be supposed that the use of an agent which has been assumed to effect changes of a destructive character could with difficulty be assumed to act as a curative agent. While admitting the truth of this apparent paradox it should, also, be remembered that the cataphoric action of electricity would have the effect of setting in motion a mass of fluid; as a consequence of this active motion, the processes of absorption would be accelerated towards the porous mediums, and these latter would therefore remove the effusion by the natural process in healthy tissues from the cavity nearer to the emunctory apparatus. The object in using a current of strong chemical power is obvious from the fact, which has already been illustrated, that the cataphoric action increases with this power combined with the resistance offered by the fluid, or partially fluid, condition; a current of very high tension might overcome this resistance and produce other inflammatory effects, which might counteract those of an osmotic character; as a result the local changes in the absorbing tissues might be different from what had been contemplated. To produce the best effects in the absorption of abnormal effusions within the living tissues, the strength of the current should not exceed that of fifteen or twenty milliamperes, and the application of the current should not be prolonged beyond a half hour's sitting, because a current stronger than this produces local inflammatory processes which oppose osmosis. As it is known that the resistance of the human body in different individuals, or in the same individual, varies widely according to the circumstances of the atmospheric condition or of the conditions of the tissues submitted to the electrodes, it is readily seen that the appropriate strength and tension of the current would be a matter of experimental test in each case, as well as at each sitting. This question has not been sufficiently dwelt upon in works on medical electricity, and the attention of the reader is particularly directed to its application in clinical experience.

Where the indications for treatment are simply upon the external tissues, for abnormal growths in or on the skin, the application of appropriate strength of current is not much different from that in the case of effusions. In the treatment of these marks or growths in the skin the action of electricity is simply used for the effect of their local destruction; and proper caution should be exercised to limit the destroying action to the abnormal growth; for, otherwise, the healing mark of the loss of surface may extend over too large a space and be more apparent than the nature of the case may require. As a natural consequence the indications are thus to limit the action of the destroying agent; and, since the electrode should touch the most minute portion of the skin other than that of the abnormal growth, the electrode should, therefore, be made of the best conducting material, should be unalterable to the chemical products of decomposition, and should have a sufficient stiffness, combined with sufficient pliability. Steel and iron have been used, but gold and platinum are so much better conductors that they are preferable. An alloy of platinum and iridium is now a commercial article in the form of fine wire, and can very readily be adapted to our purposes; the platinum has only a sufficient amount of iridium alloyed with it to make the wire stiff as well as partly pliable; this appears not to diminish its power of conductibility. We owe to the ingenuity of Dr. Hardaway, of St. Louis, the application of this alloy to the purposes of electrolysis.

If we desire to remove a warty growth in the skin, and this may have a hard, horny consistence and dryness, it should be remembered that these conditions offer the worst form of conductivity, as compared with the softer tissues of the human body; it will, therefore, be found desirable to use another metallic form of electrode, so that the action of the electrical current may be more extensive than in many cases of skin abnormalities. Zinc presents a good metallic electrode for this purpose, and if it has been thoroughly amalgamated with mercury, it does not very readily become alterable or polarizable. Where one of the electrodes is formed of zinc, and the other of platinum, the action of electrical osmosis is doubled in the same period of time, as compared with the use of electrodes both of which are made of platinum. For these and other reasons zinc furnishes an excellent material for causing a more diffused action in destroying warts, which are often deep-seated and difficult of eradication by chemical caustics; the action of limiting the destructive effects is quite as much within the control of the operator. As we have to deal with a tissue of high resistance, and, as our object should be to concentrate the electrical action, it is advantageous to use a current of high tension, or great strength, equal to that of thirty or forty amperes; but even in this case it is desirable to have a strong chemical action; the arrangement of thirty-two Leclanché cells in eight series of groups of four cells is a convenient arrangement; with such a battery the author destroyed in one sitting of ten minutes a wart which was in the skin surrounding the thumb nail, and which could not be easily removed by the knife or chemical caustic; this wart measured over two centimetres in length and one in breadth; two amalgamated zinc (positive) and two irido-platinum (negative) needles were transfixed through the margins of this hypertrophied growth, and in three weeks the eschar and wart came off without violence. No scar was left on the skin where the wart previously was located. It was observed in this instance that a very large amount of fluid collected at the negative electrode, and that the ebullition was very active, much more so than in cases where other metallic needles had been used. It is absolutely important that the wart shall not be irritated so as to induce the tearing of the adjacent sound tissue, but the dried eschar should separate without being injured by rubbing, scratching or pulling it off from the underlying healthy tissue.

Several cases of the removal of nævus by the similar method are detailed in chapter seventh, as they were reported by Gröh, *and they show the efficiency of the treatment without a blemishing scar or deep destruction of tissue.*

When, however, the object of destruction is that of a fibroid tumor near serous membrane or inflamed tissue the current should have a very feeble strength, less than five milliamperes; but in these cases the feeble current would produce a mild chemical and slight cataphoric action, and the sittings must consequently be of longer duration, perhaps of half an hour to an hour, and repeated at intervals of once in five or six days; in these cases probably quite as much should be expected from the cataphoric, as from the chemical action of electricity; because the electro-chemical action is too slight to have the destruction of the hypertrophied growth attributed to the latter effect of the current.

If the object of treatment be the removal of a cancerous growth, Beard's method of transfixing the base of the tumor by several electro-punctures offers the best means of application of the destroying action of electricity; and for this purpose currents of great strength should be used, for the purpose of thermic effects, in order to produce a rapid destruction and to separate the diseased from the adjacent tissues; the object of this treatment is to thoroughly destroy all the local portions of the diseased mass, as there can hardly be any expectation of removing the cancerous constitutional taint.

If the object of treatment be to reduce a vascular swelling of an hypertrophied growth, like that of some classes of goitre, the strength of the current should be feeble, three to seven milliamperes, and should be continued for sittings of about twenty minutes; local inflammatory action should be especially avoided. On this account, also, the sittings should not occur more than twice a week, and the use of surface and stabile applications should be employed every day; these latter applications are probably of benefit on account of inducing a cataphoric action in the hypertrophied growth, a derivation of water from the deeper tissues to that part of the subcutaneous tissue which can readily absorb the fluids transmitted to its surface by the electrical action; for it does not appear to make much difference in the results of treatment, whether the contact be directly over the cervical ganglions, or at the malar region, provided the negative electrode be of large surface and be applied upon the skin which overlies the tumor. The electro-punctures should not be connected with both battery poles but the negative only. The electrodes should be made of irido-platinum, because the use of zinc will cause too much irritation or even may induce inflammatory action, which may stimulate an increase in the growth of the tumor. One pole should be selected for the puncture; this should be preferably the negative, for the conveyance of water to the cell nuclei may derange segmentation. To relieve the exophthalmos the surface application and negative electrode should be used with currents of moderate strength, about ten milliamperes, the negative in contact with the eyelids for daily sittings of ten minutes' duration. This will drive the water from the deeper tissues behind the orbit to the subcutaneous surface of the eyelids, where it may be absorbed.

In cases of *hypertrichosis* very fine irido-platinum needles (negative) should be inserted to the bottom of, not through, the hair follicle, and the object should be to convey the electrical action directly in contact with the papilla of the hair bulb and the surrounding connective tissue next to the follicle, and thus destroy its vitality and power of reproduction by nucleated cell formation of a second hair. The battery should have the strongest chemical action and be of very low tension. For this purpose a large amount of surface area in a large amount of an exciting solution should be preferred, as in this arrangement the inflammatory action upon the skin may be avoided, and hardly any scar or pitting of the surface will result. The destruction of the skin is in the form of a cone whose apex is towards the papilla, and the base at epidermal surface; hence the reparative process does not generally extend to much depth, unless several adjacent hairs are selected and the destruction of tissue be thus extended.

The strength of the resulting current should not exceed five milliamperes, and in some cases of very delicate skin it should not be more than two or three milliamperes. *If proper care be employed to use these feeble currents, and to strike the papilla, and not to forcibly pull out the hair, no new growth of the hair, and rarely inflammation of the skin, will recur.*

It should be here stated that the healing of wounds in the skin which are produced by the action of electrolysis are rarely followed by deep or pitted cicatrices, and this is explained by the character of the resulting wound which has previously been described.

The theory of the use of electrolysis in the cure of tumors is discussed in detail in another chapter, but it may be desirable to mention some of the reasons for selecting a certain strength of current. The theory is assumed that the electrolytical action is due to the interference with cell proliferation; if, then, the current should be too strong to effect this interference and should excite an inflammation, suppuration will ensue and the action of the electricity as a caustic may be localized upon the parts of the tissue immediately in contact with the electrode. The products of suppuration prevent the transfer of the electrical action to any distance from the point of application. The effect of a localized inflammation in the tissue surrounding a tumor causes the attraction of a larger amount of blood than will suffice for the simple nutrition of the tumor. Consequently as there is an increased amount of nutritive material, the tumor has the tendency to grow larger. For these reasons, the strength of current required to effect the slow absorption of tumors should have a feeble tension and small chemical action, and the duration of each sitting should be prolonged. In this method of using electrolysis the period of time will make up for deficient strength and tension of the current.

RESOLUTION OF TUMORS. Among the earlier recorded papers on the application of electricity is one which is presented as a criticism upon an address by Scoutetten, to whose words reference has been previously made. The criticism offered by Tripier[1] is that the term "resolution" should be preferred to that of electrical absorption, which was used by Scoutetten, as a result of the treatment of tumors by electrolysis.

Tripier claims that he was the first to have called attention to the fact which he observed to follow the application of the electrodes to the region of the nerves of taste:—if the positive electrode be applied to the tongue, and the negative be placed upon some indifferent spot on the outside of the skin, an acid taste is experienced; if the position of the electrodes be then reversed, an alkaline taste is experienced; if both electrodes be then applied to the skin overlying the cheeks, a metallic taste is experienced which will persist for some moments after the electrodes have been removed. In the former two observations the acid and alkaline taste were present only during the passage of the current; the metallic taste noticed in the third case was intensified on breaking the circuit. If, again, a large electrode be applied to a distant portion of the body, connected as positive, and the negative electrode be applied to the skin of the cheek, the alkaline taste will be repeated; reversing the position of the electrodes will develop the acid taste. These observations were made from the use of a current from

[1] Electrolyse und Resolution, in Allg. Wein. Med. Zeitung, 1862, pp. 18 and 35.

a battery of twelve couples, and are well known to every electrician who utilizes this fact for determining the direction of a current in an electrical circuit. It is extremely probable that these effects of electricity upon the gustatory nerves are due to the movements of the fluids through the salivary glands, and can be explained by the physical property of electrical osmosis.

A comparison is offered with the action of anæsthetics, for during the pre-anæsthetic stage and during the post-anæsthetic stage the metallic taste is experienced, and is explainable in this latter instance as being due to the arrest and subsequent motion of the blood in the capillary circulation; the effect is much more marked in the anæsthesia of the so-called administration of laughing gas (protoxide of nitrogen), during which there is a true capillary stasis. This comparison is presented here to show that the action of electricity, even when applied by surface contact, has a decided physical action, which can be recognized by our senses. The osmotic action of electricity is made available in the application of the so-called electrolysis of cystic tumors; the method of application should be properly by the surface contact of the negative electrode over the region of the fluid, while the positive electrode should be formed of a metallic needle of the best conductivity, and this should be inserted within the sac which surrounds the fluid. To guard against the local action of the contact of the metal with the skin the precaution may be taken of introducing the electro-needle through a rubber or ivory canula. Many writers advise the coating of the needles with hard rubber or with shellac for the purpose of insulation; experience of the best operators have shown that this method of insulation is ineffective. The reason of the inefficiency of the hard rubber coating is very obvious, for the collection of moisture around the needle electrode will assist in the conduction of the current to those tissues which we may especially wish to avoid—for instance, the skin and other superficial layers. On the other hand, if the canula of a non-conducting material be employed, the fluid will pass between the needle and the canula, and the cutaneous tissues will remain sufficiently dry to act as an insulating substance; the use of vaseline or the officinal petrolatum upon and in the canula will not impede the escape of fluids, and will assist in the insulation of the epidermis. It is probably on this account that the positive electrode is the most suitable for the puncture into cysts or aneurysmal sacs, for the cataphoric action of electricity transports the mass of fluid away from the positive towards the negative electrode; this action is increased by the coating of the iron needles with an oxide of iron, since the latter compound will introduce a higher resistance than in the case of a gold or platinum electrode, which metals offer a better conductivity. Canulas of this form have been used by the author of this treatise for some time, and have in his experience entirely removed the disagreeable effect of causing pain from the metallic contact with the skin, as well as have prevented the subsequent inflammatory action, which is so liable to follow the insertion of uninsulated needles. His experience has demonstrated that hard rubber coating upon the electro-needles is usually followed by local points of inflammation and of subsequent suppuration, at least in the use of strong currents.

Were it not for the inconvenience in using unpolarizable needles, an illustration of which is presented in the annexed figures (Figs. 26, 27), it

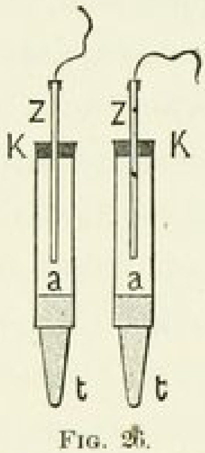

FIG. 26.

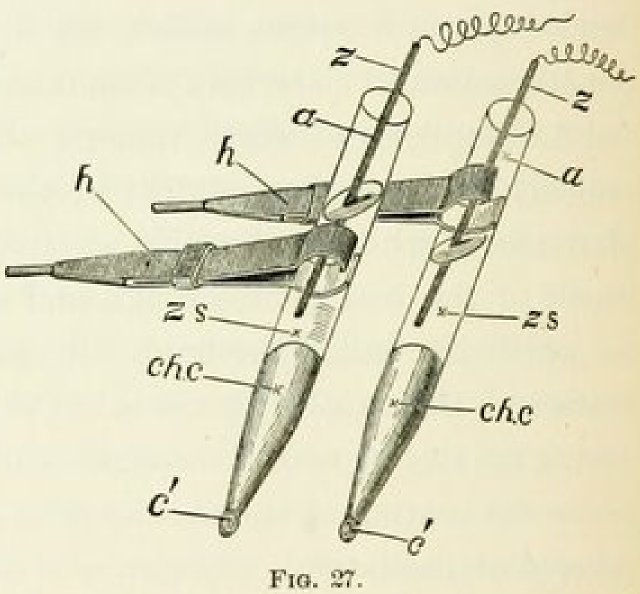

FIG. 27.

FIG. 26.—Non-polarizable electrodes of DuBois Reymond. *Z*, zinc wire; *K*, cork; *a*, zinc sulphate solution; *t*, *t*, clay points. From Dr. L. Landois' Manual of Human Physiology, translated by Wm. Stirling. Phila.: P. Blakiston, Son & Company, 1885, p. 736.

FIG. 27.—Non-polarizable electrodes. *Z*, zinc rods; *a*, glass tube; *Zs*, solution of sulphate of zinc; *h*, clips for holding the electrodes; *ch*, *c*, moulders' clay mixed with solution of common salt; *c'*, *c'*, points of clay protruding from glass tubes for application of the electrodes to living tissues.

would be better to introduce these within the tissue, and thus convey the electrical action to the deeper tissues in which we may desire to concentrate the action of electrolysis or of osmosis.

Extra-uterine fœtation offers the most favorable indication for the electrolytical treatment; this is the more evident in view of the fact that electrolysis in therapeutics should be used for its destructive agency. There are a sufficient number of cases which have been reported to prove that the interrupted, as well as the constant, current has caused the death of a fœtus which has been fecundated within the Fallopian tubes, and this without injury, provided that the current has been of a very feeble strength. It cannot be too often repeated that a feeble current will not cause inflammation, when it is properly applied, and that the same destructive action to the cell life will follow its use, when the period of time is prolonged sufficiently to interfere with the cell proliferation, upon which the growth of living tissue entirely depends. The objection to the use of the interrupted or faradaic current, is its uncertain distribution to the cell whose segmentation we seek to disturb. One application of the electro-puncture should theoretically cause the destruction of the fœtus, whether it is within or without the uterus; but, the puncture should be directed at the seat of the cell segmentation, upon which the integrity of the ovum depends, exactly in the same manner that the life of a hair bulb is destroyed. A current of feeble strength from a constant battery is the most suitable, and this strength should not exceed that of five to thirty milliamperes.

If, however, it is desired to use a current of changing polarity, it should be so arranged that the current strength should be within the control of the operator, and the feebler strength could be employed in order to guard against the evils of inflammatory action which follow the application of currents of too great strength. An apparatus has been devised by Kohlrausch[1] for the measurement of the induced current.

(*Stromerreger*) *Induction Apparatus.*—It should be desirable to make and break the current uniformly. Instead of the usual bundle of soft wire within the helix of the induction coil, a soft iron cylinder is substituted; this should be 100 mm. in length and 16 mm. in diameter; the induction wire is wound around this in six layers of 522 spirals, and the size of this wire should be 0.8 mm. in diameter. One end of this wire is connected with a Neef's hammer, the point of which is coated with platinum and can be immersed in a cup of mercury; the contact is made by dipping into and out of this mercury. The mercury should have a layer of water to protect its upper surface from oxidation by contact with the air. The platinum point should be attached to a steel spring in the usual manner; the spring should vibrate 100 times per second, and thus cause 300 interruptions per second. The spring may be loaded down with a piece of iron weight. This iron acts as an armature and should be adjustable by means of a fine screw. The induced wire is wound over the inner coil, and should have

[1] Einfache Methoden und Instrumenten zur Widerstandsmessung insbesondere in Elektrolyten. Verhd. d. phys. med. Gesellsch. in Wuerzb., 1881, pp. 93-100.

a diameter of 0.4 mm. insulated by a silk covering, and should be wound in 2,800 turns. This last coil is divided into two parts, which, by an appropriate connecting mechanism, can be used separately, in combination, or alternately. The battery for this apparatus may be two Bunsen, or three Daniell, or six Smee cells.

The above-described induction apparatus can be used with the dynanometer just as the rotation inductor. If the two dynanometer columns are not placed vertically, one over the other, the interrupted current is induced from the one to the other and may be a serious source of error. To find the vertical position is not difficult. One column is linked to the inductor, the other to itself; no variation should result. For our purposes Weber's dynanometer may be modified for convenience, by the use of only one attaching wire, the other being replaced by an electrode attached at the base and dipping into dilute sulphuric acid. This makes the instrument more sensitive and more portable. The outer column is divided into two halves, the inner is lighter and vibrates more rapidly. To compensate for the loss of sensibility resulting from the last modification the reduced size is to be considered. One of the simplest means of measuring the current is by means of a Bell's telephone. When an induced current is transmitted through this instrument the disk vibrates and this forms a delicate test of its presence. By the use of this form of induction apparatus currents may be transmitted of a measured strength.

But the method of electro-puncture is preferable to that of any induced current, and should be used with the constant battery; in this way we may limit the action of electroylsis to a selected tissue and not distribute the effect of the current to more distant parts; we may also combine the chemical with the cataphoric action, which we have seen has a definite influence over the matter of metabolisms. It is extremely doubtful whether the induced current acts cataphorically any better than it does chemically.

It is alleged that an urethral stricture can be readily overcome by the use of electrolysis; for this purpose the negative electrode should form the contact within the stricture, because the fluids of the hardened tissue will collect around this pole, and thus render the possibility of stretching without tearing the stricture. The electrode should be made of a metallic catheter, which is insulated down to the tip, and in this way the whole strength of the current will be brought to bear upon the strictures, provided there is no mucous ulcer; in the latter case it would be advisable to apply the positive electrode for the healing purposes. The positive electrode should be preferred in this latter case on account of the fact that this pole will drive away the moisture from the diseased tissue, and thus form a dry eschar under which the natural process of healing would occur; later on, it would be appropriate treatment to employ the negative electrode to the constricted tissue, unless the previous method of application has made this unnecessary. It should not be overlooked that in the removal of the positive electrode-catheter, there would be a tendency for the metallic conductor to adhere to the hardened eschar, and therefore for a moment or two before its removal it would be advisable to change the polarity of the catheter to the negative; this would have the effect of loosening the adherent metal, or rather the cicatricial tissue, and prevent the accident of pulling off the eschar which had been recently formed. The catheter should be withdrawn gently by a rotary motion on its own axis.

ANEURISMS. The treatment of aneurisms by electrolysis has not, up to the present time, met with many permanent cures. The methods of application are empirical, and details of reported cases are reproduced in a subsequent chapter. A study of these cases would seem to show that no particular theory of the action of electrolysis has been followed, except the supposable coagulation caused by means of the positive electrode.

The method which has been pursued by Ciniselli appears to have met with the most promising expectations, but even in his experience, the results of cure have rarely been permanent. His method of treatment is discribed in detail in chapter seventh. Bartholow states in his work on medical electricity[1] that Dr. Duncan, of Edinburgh, has presented a statistical table of the results of the treatment by electrolysis of

	Cases.	Cures.	Deaths.
Aneurism of aorta, ...	37	6	3
Of innominata, carotid, subclavian, .	13	3	6
External iliac, ...	2	1	
Femoral, popliteal, brachial, . .	29	16	3
Smaller vessels, ...	8	6	
	89	32	12

Since Dr. Duncan's report, Dr. Bartholow has collected 21 additional cases of aneurism which were similarly treated; nine of these were reported as improved, but whether permanent cures were effected it is diffi-

[1] Henry C. Lea's Son & Co., Phila., 1882.

cult to determine. We are rather surprised that the above-named author recommends the use of strong currents of high tension, since the experience of Ciniselli was decidedly the reverse of this. Dr. Bartholow appears to follow the lead of Robin, and would apparently favor the use of a current of 45 milliamperes, one which disengaged in a voltameter a cubic centimetre of mixed gases in two minutes.

The method of the use of electrolysis in the cure of aneurisms would appear to offer promises of success, but as yet these promises are unfulfilled; this want of success is undoubtedly due to two reasons: 1, the cause of the formation of an aneurysmal sac is inherent in the faulty nutrition and strength of the coats of the blood vessels, and the appearance of the dilatation at some definite point in the artery may be only in part remedied; while the conditions of the primary cause are not removed; 2, most of the operators who have sought for the coagulating effects of electrolysis have used currents of too great strength; and consequently the local inflammatory action has complicated the result; in some of the cases which have been reported it will be noticed that this inflammatory process has caused a fatal conclusion, and which was due to the use of strong as well as high tension currents. Ciniselli's rule that the strength of the current shall not exceed that of the disengagement of the mixed gases of the decomposition of water in a voltameter to the amount of two or three centimetres' volume during five minutes, is probably the safe guide to the strength of the current; yet, if the cataphoric action (the driving away the water of the blood) is the cause of the hardening of the clot, the current might be somewhat increased, but should not exceed two or three milliamperes, that is, one which will cause the disengagement of 20 to 30 cubic millimetres of the mixed gases in a minute of time; if the weaker current should be employed, the duration of the sitting ought to be prolonged to a period of half an hour. In any case, an insulated canula of a length of half an inch, or less, if the aneurism is more superficial, should surround and protect the electro-needle during the whole sitting; there would then be hardly any pain resulting from the passage of the current.

The method of treatment of chronic and indolent ulcers of the skin should embrace the special indications in each case; for instance, if the surface of the ulcer is covered with moist secretions, the positive electrode should be applied for the purpose of drying up these secretions and for the production of a dry eschar. The process of subsequent healing would then proceed in a natural manner. It would seem as if many of the cases of chronic eczema might be successfully treated by this method. On the other hand, if the ulcer has a dry, scurfy, or scabby surface, the negative electrode should be preferred for application to the points of disease.

The application of these principles to the treatment of fistulous tracts and sinus will naturally follow from what precedes, and will need no further discussion.

Varicose tumors, which contain fluid masses, would naturally require the application of the positive electrode. This should be electro-needles, because the objective point of attack is under the cutaneous covering; the number of electro-punctures will depend upon the extent of the tumor, and they should not be inserted nearer together than one and a half to two centimetres apart. Feeble currents, two to five milliamperes, should be passed for several hours at a sitting, and the battery should be arranged for a continuous and uniform current of as low tension as may be convenient; the pain of the metallic contact with the skin may be almost overcome by the use of hard rubber or ivory canulas, which should fit loosely around the needles and thus allow the escape of the fluids which might collect around the puncture.

The needles should always be carefully withdrawn with a rotary motion to prevent disturbing the hardened coagulum. The patient should be kept perfectly quiet to prevent afflux of blood to the venous enlargement.

It should be remembered that the use of surface application probably utilizes only the cataphoric action of electricity. As a consequence of this transportation of fluid through the tissues the secondary effects of physico-chemical and physiological action are produced in those tissues which are embraced within the interpolar circuit. The application of the electro-puncture will convey the application of the current to the tissues which are in direct contact with the metallic electrodes. The combined effects of electrical osmosis and of the electro-chemical action of electricity would naturally follow the electro-puncture. The surface of contact can be conveniently combined with the preceding effects by the use of another battery of higher tension than is required for the latter action of the puncture, and they will not operate in antagonism. The current for the administration of surface and stabile electricity should not be of a less strength than that of twenty to fifty milliamperes, and can be continued during an hour, provided that the electrodes are well moistened, and that their contact with the same portion of the skin be not prolonged beyond a period of fifteen minutes.

The choice of the position of either or both electrodes will depend upon whether we wish to convey much or little of the electrical current directly to the point selected for electrolysis. If a large mass of the human body intervenes, the current will pass through a larger portion of a resisting medium of various tissues; if the contact of the electrode with the surface of the body be dry rather than moist the resistance will be extremely great; if, however, the body's surface be moistened and the electrode also be kept wet with water, this resistance will be materially lessened. If again the skin and the electrode each be moistened with a hot saline solution, the resistance to the conductivity of the electrical current will be still more materially lessened.

The other terminal electrode can then be applied, either by surface or by insertion through the skin, to the selected point, and the conductivity of the tissues be lessened or increased by the same methods. It will add greatly to the knowledge of the amount of current passing, if a galvanometer of the kind to be described in a subsequent chapter be used to measure the current, and this instrument should be placed in the same circuit with the patient's body.

We have seen that the negative electrode or kathodal terminal is the most convenient agent in resolving the elements whose composition forms the abnormal structure which we seek to destroy. Therefore the negative electrode should be placed upon the surface nearest the growth, and the electrical current may then be made to pass into the body by the anodal terminal, or positive electrode, and out of the body by the kathodal terminal or negative electrode, and so complete the electrical circuit back to the battery. If the galvanometer be placed in the path of the current from the battery terminal (copper or carbon) to the body, the needle will be deflected towards the North pole on closing the circuit, or if a vertical needle be used the needle will be deflected to the left; if the galvanometer be placed in the circuit which goes within the galvanic cells from the zinc to the copper, the needle will point in the same direction as first mentioned.

Now if the current appears to be too strong for the patient to bear with tolerable comfort, a rheostat may be connected with either circuit and thus interpose a resistance which can be increased or diminished at the will of the operator.

This surface method of applying the principles of electrolysis is not very effective, because the resistances offered to the flow or passage of the current must pass through epidermal tissues which of themselves vary in power of conductivity. The current meets with a very poor conductor of electricity, the skin, which in itself feels the discomfort of pain at the point of contact; and if this is not the tissue which we seek to destroy, its effects are there wasted and not carried to the underlying tissue which is our objective point of attack.

To obviate this difficulty a good metallic conductor, made preferably of gold, silver, or platinum, or irido-platinum alloy, may be thrust through the skin and into the very structure of the pathological formation. It is desirable to use a metal of high conducting power in order to use an instrument of small diameter. If we desire to increase the surface of the electrode it is more convenient for obvious reasons to do so by multiplying

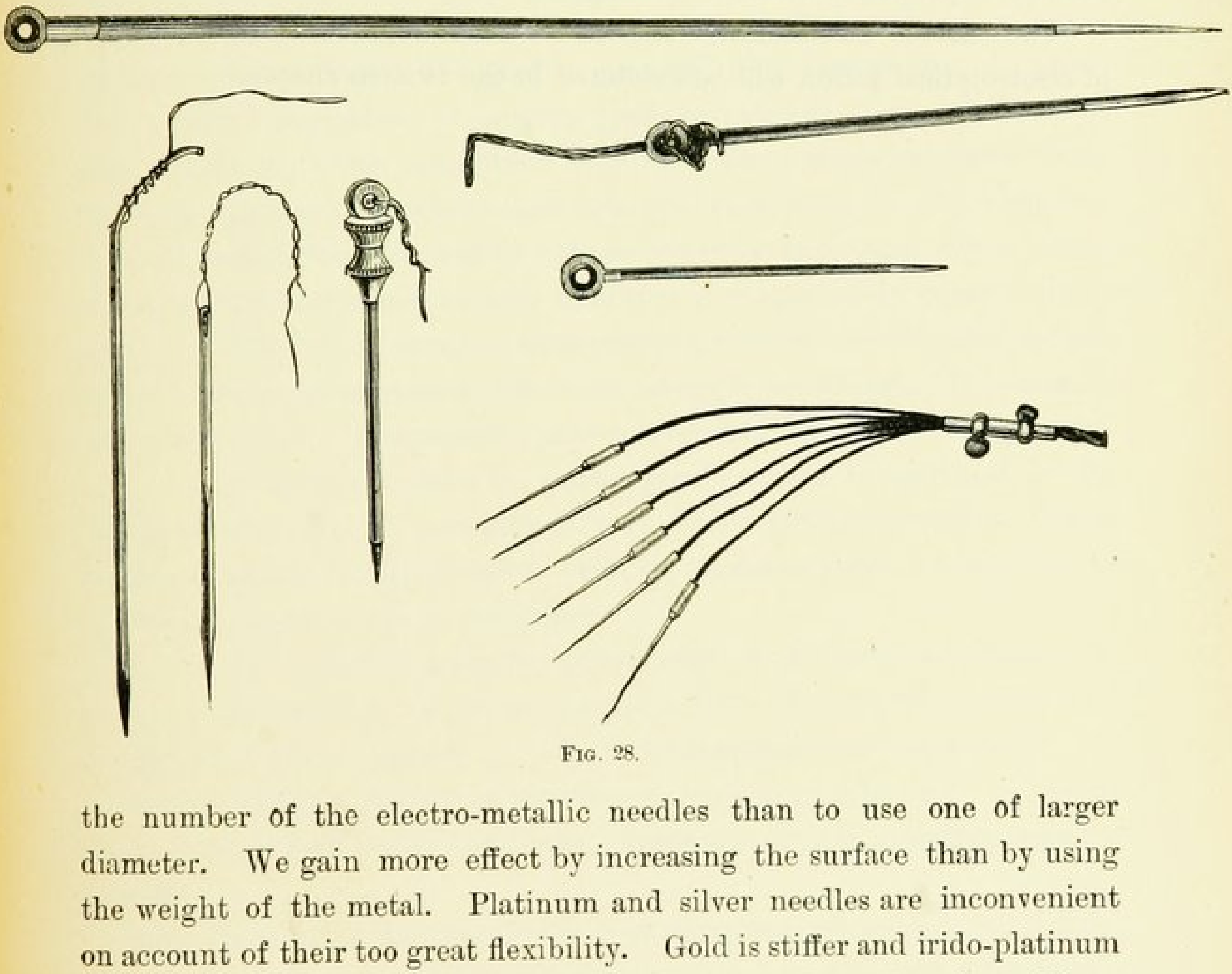

Fig. 28.

the number of the electro-metallic needles than to use one of larger diameter. We gain more effect by increasing the surface than by using the weight of the metal. Platinum and silver needles are inconvenient on account of their too great flexibility. Gold is stiffer and irido-platinum is better yet, on account of the same property and smaller size. These needles are represented in the Figure 28, as also the multiple-connecting rheophore with which we may use any desired number.

Gas carbon furnishes a very convenient material for surface electrodes, and this can be shaped in any desired form; but this material is better suited for use in the contact method of application, and unless we should desire to utilize the burning effects of the contact of this dry metal with the selected tissue, it should have a moistened soft texture, such as is offered by absorbent cotton, chamois skin, or a wet compress, to mitigate the local escharotic effects of the contact.

The application of electrolysis to epilation in hypertrichosis deserves its mention in a separate chapter (chapter tenth), since this treatment has recently become quite extensively employed in this unsightly affection on women's faces, and because it offers a perfect cure in the removal of the hairs.

The application of this same treatment to warty and other abnormal growths is presented in the next chapter.

The various mechanical contrivances for the practical manipulation of electrolytical action will be exhibited in the twelfth chapter.

CHAPTER VII.

THE APPLICATION OF ELECTROLYSIS TO THE TREATMENT OF DISEASES.

THE indications for the use of electrolysis in disease are governed by certain general facts:—where there is an hypertrophied growth due to a multiplication of normal cells of a certain tissue; or where the growth may be due to an increase in the normal connective-tissue structure; or where the excessive deposition of healthy granulations may overlie certain surfaces which on close adaptation will form the definite union of these opposing surfaces; or where a destruction is desired of the boundary between healthy and unhealthy tissues; or in certain cases where under abnormal circumstances healthy structure is misplaced by other healthy structure, which is an unusual transposition; or where an excess of certain healthy tissues are obnoxious deformations to the individual. It is contra-indicated:—where inflammatory action is already seated in these growths, or in their immediate vicinity, unless great caution is exercised by the operator in the use of currents of very feeble strength; and in hypertrophies caused by degeneration cells or neoformations. According to one writer,[1] electrolysis is indicated:

1, In the exudation process, either with or without cell-formation, as in certain hyperplasiæ (lymphomata); and in diseases of cerebral and peripheral nervous system; in tumors, hemorrhages and neuritis;

2, In exudation-process in muscles, in tendon-sheaths and connective tissue; also, within the membrana tympani, and in opacities of the cornea;

3, In diseases of joints and their surrounding parts; in hydrops articulorum, and in plastic infiltration (not caries or arthritis deformans);

4, In goitre, parenchymatous and vascular; in chronic splenic tumors.

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[1] Zancopulos, of Greece, ueber die electrolytischen u. katalytischen Heilwirkungen galvanischen Stroms; in Archiv. f. klin. Med., band p. 562, 1872.

This writer explains the curative effects in the above classes of disease as due to what he calls *katalysis*. This word is so often used to explain some unknown action that it seems hardly wise to apply it to any curative agency. He probably intended by its application to refer to some electrochemical agency which could not well be demonstrated; the use of this word has been deprecated in a previous chapter, and there is no need here for any further comment.

This same writer describes the application of electrolysis to:

1. Aneurisms. In these cases the electric needles should, in his opinion, be insulated nearly to the tip with a coating of shellac.

2. Tumors. He considers that the application in these cases, produces an action like that of a chemical caustic. Strong currents should be used during anæsthesia for a period of time of an hour or more. He quotes the authority of Gröh in support of a statement that a weak current will stimulate growth of cancerous tumors. He proposes this treatment for a destruction of small tumors which are inaccessible to the knife; also, where they exist in anæmic patients or in those who have a great dread of the knife.

It should be remembered that this communication was presented thirteen years ago; and that these statements would be necessarily qualified by the more recent experience of those more familiar with the application and action of electrolysis upon living tissue. The use of strong currents of electricity appears to excite an inflammatory action, especially in those structures of the body which offer the highest resistance to its conduction. The insulation of the needles with a coating of shellac, or even with rubber, does not appear to prevent this local inflammation and irritation of the skin and other structures of feeble conducting power; and it is quite probable that the resistance offered by tissues of low conductivity are so influenced by the action of electrical force, that a current of strong tension may cause an arrest of the physiological functions of metabolism, by means of which the natural processes of tissue changes are quietly conducted, and thus without producing abrupt disturbances of the natural processes of the organism.

The effects of electricity when passing through the body at high tension, like that of high tension dynamo machines and lightning shock, are too well known to produce death of the living organism, both in plant and animal life. Mention has already been made, in Chapter IV. of the fact that electro-chemical changes of definite amounts can be accomplished by the long continuance of feeble currents, as well as by the use of strong currents continued for a short period of time; this is well established both in the inorganic and organic chemical compounds; it is equally true in the living organism as shown by the results of clinical experience. Ciniselli has especially mentioned this fact in relation to his application of electrolysis to the treatment of aneurism. Even this careful observer arranged his battery in series for tension, "as in Volta's pile," and while it is probable that an effective treatment in aneurisms may require certain dynamic actions which really belong to currents of definite tension; yet, it should be borne in mind that, up to the present time, the application of electrolysis to the treatment of aneurisms has produced few radical cures.

Writers on the subject of electrolysis appear not to have paid sufficient attention to the comparative value of the use of currents of low tension continued for a longer period with those of high tension continued for a short period. It is certainly true that the use of a feeble continuous galvanic current can rarely work any serious injury upon the living organism; but secondary effects caused by the irritation and subsequent inflammatory and suppurative processes may provoke, not only an active increase of pathological action in tissues which are the seat of degeneration, but may also induce an extending inflammatory processes in tissues of a lower order of vitality, such as the serous membranes; this may, and has, induced serious accidents and even occasional death. This action is similar to that produced by the local application of medicinal irritants and chemical caustics to growths which are in the vicinity of serous membranes.

It will be perhaps advisable to call the attention of the reader, at the outset of this chapter, to a list of published cases, which were collected and presented in the communication of Zancopulos before referred to. It will be noticed that in the long list of about thirty reporters, the treatment of similar cases by electrolysis was not followed invariably by similar results. An explanation of this discrepancy is suggested in view of these preceding remarks; for instance, one reporter, Chvostek, mentions the treatment of thirty cases of goitre, all of which were cured; another writer, Althaus, mentions eight cases of goitre, four of which only were cured; another writer, Gröh, mentions eleven cases of nævus (angioma) all of which were cured, and Althaus mentions twelve cases of the same disease, seven of which only were cured; again, Althaus mentions two cases of scirrhus, both of which were cured, and Gröh reports one case of carcinoma, also of the breast, which was not followed by a favorable result. Other comparisons can be drawn of a similar nature by a close study of this list.

This table is arranged in the first column with the reporters' names, in the second and third columns the number of their cases reported and the nature of the disease treated by electrolysis, and in the fourth column the results of this treatment. The details of some of these cases are presented in the text, farther on in this chapter; those cases thus referred to are marked with a *.

TABLE I. OF REPORTED CASES TREATED BY ELECTROLYSIS.

No.	REPORTED BY	No. REPORTED	NATURE OF DISEASE.	RESULT OF TREATMENT.
1	Benedikt.	8	Arthritis deformans and ankylosis.	Improved.
2	M. Meyer.	1	Arthritis nodosa.*	Cured.
3	Chvostek.	9	Gonorrheal orchitis.*	Cured.
4	Gröh.	1	Carcinoma mammæ.*	No result.
5	Benedikt.	21	Chronic diseases of joints.	17 cured. 4 improved.
6	Cheron.	7	Chronic arthritic rheumatism.	Cured.
7	Bartholow.	3	Chronic infarctus of uterus.	Cured.
8	Scoutetten.	5	Ganglia.*	Cured.
9	Althaus.	1	Ganglion.	Cured.
10	Gröh.	1	Gonitis rheumatica.	Cured.
		1	Gonitis traumatica.	Cured.
11	Benedikt.	9	Hydrarthrosis.	Cured or improved.
12	Gröh.	1	Hydrosarcocele.*	Improved.
13	Bruns.	4	Hydrocele.*	Not cured.
14	Arcoleo.	9	Hypopion.	Cured.
		1	Corneal abscess.	Cured.
15	Chvostek.	1	Traumatic infiltration in leg.	Cured.
16	Chvostek.	6	Indolent inguinal buboes.	Cured.
17	M. Meyer.	1	Lymphoma.	Nearly made to disappear.
18	M. Meyer.	1	Lymphoma.	Cured.
19	Gröh.	1	Melano-sarcoma	Failed.
20	Rudolfi.	2	Ophthalmia, granular.	Improved.
21	Chvostek.	1	Pannus.	Improved.
22	Wolf & Cheron.	17	Enlarged prostate.	Cured.
23	Birch.	2	Pseudarthrosis.	Cured.
24	Schwann.	2	Extensive chancroid.	Cured.
25	Chvostek.	30	Goitre.*	Cured.
26	Mendel.	2	Traumatic tetanus.	Cured.
27	Benedikt.	2	Trismus.	Improved.
28	Wiesner.	2	Prosopalgia.	Cured.

TABLE II. OF REPORTED CASES[1] IN WHICH ELECTROLYSIS WAS USED.

No.	REPORTED BY	No. Re-ported	NATURE OF DISEASE.	RESULT OF TREATMENT.
1	Ciniselli.	23	Aneurism thoracic aorta.*	4 cured.
		1	Ascending aorta.*	Cured.
2	Petrequin.	1	Aneuris traumatism of temple.	2 cured.
3	Gröh.	11	Angioma* (nævus).*	Cured.
4	Althaus.	1	Angioma, lower lid.*	Cured.
5	Juenken.	1	Angioma.*	Improved.
6	Manfredini.	1	Villous cancer in leg.	Cured.
7	Neftel.	1	Cancer.	Cured.
8	Gröh.	18	Cancer.*	14 cured.
		1	Condyloma.	Cured.
9	Fieber.	1	Ovarian Cyst.	Destroyed.
10	Lincoln.	1	Erectile tumor in supra-orbital fossa.	Cured.
11	Klaine.	1	Fibroid of left trochanter.	Cured.
12	Gröh.	1	Hemorrhoids.	Cured.
13	Billroth.	1	Prae-patellar Hydrops.	Failed.
14	Billroth.	a few	Hydroceles.*	Not permanently cured.
15	Dittel.	1	Hydrocele.*	Cured.
16	Scoutetten.	1	Lymphoma, neck.	Cured.
17	Demarquay.	1	Submaxillary.	Cured.
18	Groh.	1	Scrof. lupus in upper lip.*	Cured.
19	Hilton, Fagge and Durham.	1	Hydatid liver.	Cured.
20	C. Foster.	1	Hydatid liver.	Failed.
21	Gröh.		Myxo-sarcoma.	Cured.
22	Althaus.	11	Nævi.	7 cured.
23	Ehrenstein.	1	Osteo-enchondroma of clavicle.	Cured.
24	Bruns.	3	Pseudarthrosis.	Failed.
25	Nélaton.	5	Pharyngo-nasal polypi.	3 cured.
26	Bruns.	1	Polypus of fauces.	Cured.
27	Althaus.	8	Goitre.	4 cured.
28	Gherini.	7	Cystic goitre.	Cured.
29	Althaus.	2	Scirrhus mammæ.	Cured.
30	Gröh.	4	Sarcoma.*	All cured.
31	Bruns.	2	Urethral stricture.	1 cured.
32	Tripier and Mallez.	40	Urethral stricture.	All cu'd or improv'd
33	Couriard.	12	Urethral stricture.	10 improved.
34	Althaus.	16	Sebaceous tumors.	15 cured.
35	Billroth.	1	Telangiectasis of cheek.	Failed.
36	Dittel.	5	Varices.*	All cured.

In addition to the above list which is thus transcribed, Ciniselli first employed electrolysis to effect a cure of a neuroma in the leg.

Broca reports its use and cure in a case of an erectile tumor of the lip.

Nélaton reports the cure of a polypus in the naso-pharyngeal space.

Chvostek reports six cases of the cure by means of electrolysis of indolent bubo, after the failure of other treatment.

Neftel reports a case of a tumor in the left mamma of a man, aged fifty-six, which was pronounced to be a cancer by several surgeons; among them was Marion Sims, by whom it was originally removed by the use of

[1] Details of these cases are presented in this chapter further on.

the knife; another similar tumor appeared in the right mamma which was treated by means of the method of electro-puncture by Neftel, who used gold needles with strong currents at weekly sittings which lasted from two to ten minutes each. Though the tumor at first increased in size, it afterwards became softer and more elastic, and the general condition of the patient gradually improved. There was no fever following the great pain of the operation, and the tumor began slowly to grow smaller by degrees until at the end of three months there was only its vestige remaining; the last report is that of a complete cure.

Thirty-two cases of aneurism were collected by Boinet in which treatment by electrolysis was followed. Twenty-one of his cases were failures and ten were followed by successful cures. There was no report in one case. Other methods of treatment had been unsuccessfully tried.

Ciniselli collected in 1856 fifty cases of this treatment in aneurism. These aneurisms were located in nearly all the large arteries, aorta, carotids, subclavian and popliteal. Twenty-three of these cases are reported as cured.

Writers, who have had experience in the use of the electro-puncture, report that frequently eschars will form in the superficial tissues, and this in spite of every known precaution; there is, also, danger that a similar inflammation will occur in the walls of aneurismal sacs. Broca claims that this interior and local inflammatory action may be avoided by the use of currents of low tension and of large quantity. It is difficult to understand exactly what he means by this statement, because where we have such high resistances as those which are offered by the living tissues, we can hardly expect to convey through them currents of large quantity; for by a reference to the former discussion of this subject in the preceding chapter, the reader will comprehend that currents of large quantity can only pass through a conducting medium which has a large section area of low resistance, and the human body is not a conductor of this character. Probably Broca would refer to weak or feeble currents, which could be readily conveyed by mediums of conduction, in which the transmission of the electrical force would be effected slowly and with feeble chemical or physical .action. It should always be remembered that the resistance in either the internal circuit of the battery, or of the external path of the conducting medium, along which the electricity flows back to the opposite pole of the battery, will affect the rapidity of the electro-chemical action in the battery. This author may, however, have referred to the local effect of a strong current which would produce a severe caustic action at the points of contact of the electrodes with the skin; the same action would, however, be caused by a long-continued contact with feeble currents. Ciniselli states that no cure of aneurisms is possible without some inflammation in the aneurismal sac.

Electrolysis is equally useful in telangiectasis, venous tumors, etc., because its local action can be so readily circumscribed.[1] Wilheim[2] reports a case in which he first tapped an ovarian cyst, and after a second tapping, he inserted an electro-positive needle to the depth of two inches, and completed the circuit by means of a flat metallic plate (current from five cells for five minutes), which was followed by great pain and by no improvement or reaction; the cyst refilled. A second application was made this time with the negative pole connected with a battery of ten cells, and kept in place for ten minutes; this was followed by no improvement and produced considerable pain; an increase in the dyspnœa necessitated tapping, and six pints of a frothy albuminous liquid were removed. Death occurred two days later. Post-mortem examination revealed peritoneal cancer and ascites. In regard to the foregoing case, it should be remarked that cancer of the peritoneal surface would naturally be attended with inflammatory action of this tissue, which is of a low order of vitality. The increase of inflammation which would follow electro-puncture, producing also the irritation which naturally would be expected from so strong a battery power, would increase this inflammatory action.

Male, aged thirty-six years, with chronic hydrocele; this was situated on the left side; a platinum needle connected with the negative pole was inserted into the sac. The escape of the contained fluid, although prevention was attempted, was unavoidable. Subsequently, the amount of fluid diminished and parenchymatous inflammation ensued, but, later on, the hydrocele returned and was subjected eventually to ordinary treatment.

Female, aged forty-eight, cellular polypus of uterus; (this patient was also under treatment for paresis of legs); the polypus was accompanied with hemorrhage. The positive pole, a needle, was inserted to the depth of half an inch into the polypus, which protruded from the cervix uteri, and the negative pole was placed on the surface of the thigh. A current from a battery of ten cells was continued for five minutes. The

[1] Consult Ciniselli's, Broca's, and the writings of the other authors, previously referred to.

[2] Die Electrolyse u. ihre Labredner, 1877.

color of the tumor changed from red to green, and emitted the odor of sulphuretted hydrogen; after three sittings of this same treatment the tumor became shrivelled and gangrenous; but after the last sitting parametritis ensued and the patient remained weak and sickly for six months. She became finally cured.

Female, carcimona uteri: two applications with no favorable results.

Female, aged fifty, hygroma præpatellare: the circumference of the tumor measured two inches. In this case the two electrodes were applied upon the surface of the skin, electro-puncture not used; this treatment was followed with no favorable result. Afterwards, bipolar electrolysis, both electrodes being electro-puncture, was tried for a sitting of twenty minutes; the current was derived from a battery of ten cells (Bunsen). This current strength is equal to twenty volts, or a total amount of four hundred volts during twenty minutes. Taking into consideration the resistance of the tissues in the interpolar circuit, the resulting current would be equal to .20 of this original strength. This treatment was followed by inflammation of the joint around the punctures. After three weeks of this method of treatment for relief of the inflammation, which confined the woman to the house, the tumor was reduced to one half its original size.

Five cases of lymphatic tumors. In one of these cases Frommhold's method of insertion of the negative needle-electrode only, was used. The tumor, which was situated under the lower jaw, was hard and unyielding. All the tumors grew softer under that treatment, but did not disappear. Two cases of chronic ulcers of the leg, treated by surface application of the electrodes, met with no success comparable to that of transplantation. A flat platinum disk over the ulcer was combined with the application of the other electrode upon some indifferent spot; this was attended with pain, but treatment was continued for a period of five months.

Colley[1] mentions the introduction of electrolysis into medicine in Russia thirty years ago. This introduction resulted from the studies of G. Crusell, of Finnland, who being favored by Pirogoff, founded a hospital in Moscow. Colley ascribes to Crusell the first application of the "hydrolytic" current of measured strength, and of the "heat development" of galvanism in therapeutics. 152 patients were treated in his hospital, of whom 8 died and 64 were cured. Electrolysis was found useful in the

[1] Die Electrolytschen Heilanstalt in Moscow. Med. Zeitung Russlands, iv., p. 2041, 1847.

treatment of scirrhus, fungus hæmatodes, fungus medullaris, gangrene, primary syphilis, urethral strictures, tumors, and ulcers; also, in leucoma and cataract.

Billroth[1] was so much impressed with an oral statement of Socin, that he employed electrolysis in the treatment of a case of hydrocele. He used a Stöhrer's (bichromate) battery formed from twelve couples. The sac of the hydrocele at once grew tympanitic and in three or four weeks a cure was effected. The whole procedure involved but little pain. Billroth did not consider the cure permanent, as in one of these cases the hydrocele soon returned. In hydrops bursæ præpatellaris the same treatment resulted in suppuration, which required free incision for the escape of pus.

Dittel[2] reports a case of hydrocele which was situated on the left side, and was of two years' duration. This case was treated by electro-puncture (positive electrode). The needles were inserted into the sac. The negative electrode was applied by means of a sponge on the surface of the scrotum. Very little pain accompanied the puncture. On removing the needles some serum escaped and an œdema of the scrotum ensued. The patient complained of pain in the region of the vas deferens, and the temperature was slightly elevated (38.5 C°) and the pulse became 92. The insertion of three needles (positive) was continued at the second sitting for thirteen minutes, a platinum plate being used for the other electrode. Closure of the wound was followed by pain, which continued for five days; the temperature varied from 37.4 to 38.6 C°. After a week the swelling diminished. At the third sitting a battery (Grove's) of two couples only, was used for the current strength in place of the three which were used at the first sitting. Five days later, the sac was shrivelled and was as small as after treatment by iodine injection in eight days. The patient was discharged with the tumor one-fourth its original size.

Male, aged thirty-seven, with bilateral varicocele. Four needles were connected with three Grove's cells and these were thrust into the right veins. A sponge electrode was placed upon the surface of the right groin; the veins grew smaller at once, and the scrotum became shrivelled and its surface corrugated. No local rise in temperature occurred, and the veins shrunk in the course of three days to a small, hard and painful knot. The pain was relieved by cold applications, and in three weeks the previously swollen veins appeared as hard empty strands. There was no fur-

[1] Open letter Th. Billroth to Prof. O. Weber. Deutsche Klinik, xviii.

[2] Œsterich. ztschr. f. prakt. Hlkde., No. 17, 1869.

ther sign of the varicocele. The patient ran away to avoid treatment of left side. The needles were inserted into, and not through the veins. The writer did not notice formation of a thrombus and did not consider the cure permanent.

Female, aged sixty-one, with varicose ulcers which had existed for sixteen years; these were in the left leg and there was a varicosity of the saphena major. Three needles were connected with a current from three Grove's cells, and these were inserted for sixteen minutes. The veins were compressed above and below the needle puncture; moderate burning pain followed the application of the electricity; the coats of the veins became thicker and their width narrower. The patient was discharged improved.

A similar case is reported in a man of forty-two years who had varicose ulcers, which had existed for fourteen years; this was similarly treated and the treatment was followed by the same result.

Male, aged sixty-five; similar case and treatment. The ulcer healed and the vein was narrowed.

Male, aged forty-two years, with varicose ulcer of twenty years' duration. Two sittings with the electro-puncture. After the first, the patient had pain which was accompanied with a chill (temp. 39.2 C°); the ulcer was cured in about two weeks.

Male, aged twenty-seven years, with cavernous subcutaneous tumor. This was situated just below the tuberosity of the tibia having the size of a walnut. It could be increased in size by pressure upon the saphena above; four needles were inserted into the tumor. This grew harder but soon returned to its original condition; after the second sitting, the periphery became hard and small. When the patient was discharged hardly a vestige remained.

Scoutetten[1] reports the use of electrolysis in the following nine cases. This was applied by the use of electro-puncture.

1. Four cysts in the wrist, one of which was in a young man and the others in young women. These all completely disappeared in a very short time.

2. Two cases of hydrocele, which had existed seven and twenty-six years respectively. The later case required two sittings and, in the former, one sitting was sufficient. There is no report of the recurrence.

3. Sebaceous tumors of head. Two of these cases were in men, and

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[1] Sur la methode electrolytique dans ses applications aux operations chirurgicales. Bull., Acad. de Med., Paris, 1864–5, xxx., p. 969.

one in a woman. Each case required two sittings of fifteen minutes duration, and a cure was effected.

4. A cyst on the outer border of the left eyebrow was not successfully treated.

5. A cancerous tumor in a male, aged sixty-six years, continued to grow, notwithstanding the application of electrolysis for six sittings; finally death ensued.

6. Three soft lymphatic ganglia of the neck were successfully treated.

7. A fibrous tumor situated under the jaw, right side, of a man, aged thirty-seven. All of these latter were unsuccessfully treated, for five sittings, with a current derived from three Bunsen's cells.

8. An indurated ganglion on the anterior portion of the auditory meatus, left side, was successfully treated by a current of the same strength as in case seven. Scoutetten gives no other details of apparatus used by him. It is not improbable, as has been before remarked, that inflammatory and suppurative processes existed in his cases. The use of too strong current in tissues previously inflamed and degenerated may have increased the local inflammation, and so have hastened death in the case of the cancerous tumor above reported.

Onimus[1] produced a softening in several cases of lipoma, but the treatment of electrolysis was discontinued on account of objections from the patients. In one of these cases, the lipoma disappeared after several sittings. The treatment of this case was attended with oily discharges, which was followed by an interstitial abscess caused by emphysema.

A venous tumor in a man of twenty-one years of age was treated by the same method; this was situated in the forearm. A current strength from fourteen Daniell cells, probably arranged for tension, was employed for one minute with no apparent effect. At the second sitting, a battery of twenty Daniell's employed during three minutes apparently produced no effect. At the third sitting the use of thirty of these same cells was followed by complete coagulation of the blood in the venous sac.

It may be well at this point to present certain results of experiments on animals reported by Abeille.[2] Eleven of these experiments were on animals, one sheep and ten dogs. In the first experiment on the dog the

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[1] Quelques faits chirurgicales relatif aux acu-punctures electriques. France Med., xxiv., 769.

[2] L'electricite appliquée a la therapeutique chirurgicale. Par M. le Dr. J. Abeille.

crural artery was pierced by the electrodes; the operation was successfully performed without isolating the blood vessel; the duration of the current was for five minutes. On the next day, an unsuccessful attempt was made to pierce the left crural artery. The animal was killed two days later; the right artery was found to be occluded by a firm clot, which was adherent to the sides of the vessel, and the coagulation was arranged in concentric layers.

In the second experiment on a large dog, an electro-puncture into the blood vessel caused so much struggling that the needle became disengaged. This operation was followed by spurts of blood. On again being introduced the hemorrhage was immediately arrested, the blood "boiling and coagulating" around the electrodes; the duration of the current was for five minutes. A hard body was felt in the track of the artery at the seat of the operation. On the next day a similar attempt was successfully performed on the corresponding artery of the opposite side, and twenty-four hours later the dog was killed. Both arteries were found to be occluded, the passage of a stylet being impossible; the clot presented the same concentric layers. The second clot was red, and the first rose-color; the color appeared to depend upon the length of time after the operation at which the animal was killed. As in the third experiment, when the animal was killed later, the clot was paler, and its color was still paler in the fifth experiment, in which the animal was killed at a later period. In the last experiment the color had completely disappeared, except at a central spot, which proved that decoloration proceeds from the circumference to the centre. The other experiments on dogs, the details of which are not given, produced similar results. The experiment on the sheep was conducted with difficulty; four attempts were made to find the artery, and it was thought in none had the electrode pierced the vessel. The animal was killed fifteen days later, however, and after careful search among the hardened tissues, four inches of the vessel were exsected. The artery was found flattened like a ribbon and would not admit of the passage of the stylet; in the interior of the artery a remnant of a clot, which adhered to the walls of the vessel, was found. It was remarkable that the clot formed so rapidly. According to these authors, it is supposed by many physiologists that the result of the coagulation of blood should be attributed to the effect of heat; but this theory cannot be true, from the fact that the clot is so firm and so adherent to the walls of the blood vessel that it can only be removed by violence. The action of heat alone would in their opinion result in an embolus. The action of electrolysis differs from that of heat in causing no direct inflammation. This may be explained on the ground that the walls of the blood vessels, being bad conductors, insulate the current from adjacent tissues. Neither, according to this writer, can simple needle punctures in the vessels produce the same effects; because, unless these needles act as electrodes, experiment shows that similar coagulating results cannot be obtained. Other observers claim that the blood of the lower animals is more plastic than that of man. because some authorities have shown that a clot will form in the animal at the opening of a divided artery. Amussat has, however, shown that the same will occur in man, and that, at the most, the only difference lies in the fact that a longer time is required for its formation.

With the introduction of these detailed experiments the application of electrolysis to the treatment of aneurisms and venous enlargements may justly be compared. Abeille presents the following case of aneurism treated by electrolysis:

Mlle. P. de G., æt. 65, the aneurism was situated in the left subclavian artery. When first seen it had the size of a pullet's egg; the pulsation was expansile and was synchronous with the heart's beat. The tumor had a medium hardness, and was partially emptied by digital pressure, at the same time giving a trembling sensation to the fingers; compression of the subclavian above the tumor arrested the pulsation. Compression of the axillary artery increased the size of tumor. The diagnosis of aneurism was confirmed by several physicians. The bulk of the tumor was visible between the scaleni muscles. Operation.—Patient was etherized in the recumbent position, and the head was turned to the right to render the tumor more prominent. Four needles were introduced to a depth which, from the diminution of resistance and increased freedom of their movement, showed that they had penetrated the sac. Duration of the current was for thirty-seven minutes; the tumor grew hard and pulsation ceased, as shown by palpation over aneurismal sac and in radial artery. Several small drops of blood followed the withdrawal of the needles and light eschars formed in the skin around these needles. At the close of the operation there was apparent absence of pulsation over the aneurismal sac; but the bruit was the same. This was formerly distinctly audible. On very careful palpation a feeble pulsation could be detected in the axillary and radial arteries. The wounds from the puncture were covered with a wet compress of cold water, and a weight of one kilogram (about two pounds), was placed over the subclavian artery above the tumor, where it remained for ten hours.

On the second day there was light vibration, but no radial pulse; the hands and fingers were cold; and there was loss of muscular power in the fingers. On this and the day following the compress was kept in place, and the patient slept well.

On the third day ointment was applied to the wounds of the punctures and the compress was removed.

On the fourth and fifth days pulsation reappeared in the radial artery, though small and feeble. The tumor was very hard and incompressible, and its shape was regular and oval. The patient had intense headache, flushed face and injection of conjunctiva. During the next two or three days the hand regained its normal warmth and usefulness.

On the thirteenth day the tumor had diminished to more than half of its original size.

On the seventeenth day after the operation the skin was no longer elevated, and strong pressure developed the sensation of a hard metallic plate. The artery above the aneurism was enlarged and gave off three distinctly visible branches, which were supposed to be the inferior thyroid, the vertebral and posterior scapular.

The following cases were reported by Gröh:[1] 1. Aneurism of right subclavian artery. In this case six zinc needles were used for one electrode, while the other was applied on the skin over the aneurismal sac, and the battery was formed of six zinc elements. After duration of the current for thirty minutes there was no pulsation to be perceived by palpation in the aneurism; but the subsequent history of the case was uncertain.

A case of aneurism of the arch of the aorta is reported by Rivet:[2] Man, aged forty-five years, was admitted to the hospital in February, 1878, with a large aneurism in the ascending portion of the arch of the aorta, which communicated with this vessel by a narrow orifice. Two negative electrodes were applied on the surface of the chest and thigh. A needle, positive electrode, was thrust into the second intercostal space seven centimetres from the median line to a depth of five centimetres; a second needle was thrust into the third intercostal space. The duration of the current lasted for ten minutes.

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[1] Die Elektrolyse in der Chirurgie, Wien, 1871.

[2] Aneurisme de la crosse de l'aorte traité par l'electro-puncture. Med., Paris, 1878, xxv., p. 241-3.

On the second day the subjective symptoms were somewhat more favorable, as well as the objective symptoms.

On the thirty-second day three needles were inserted during thirty minutes. For the next few days the symptoms were greatly relieved, the arterial impulse was diminished and venous stasis, formerly very marked, was also relieved; the bruit, though sometimes absent, was about the same. At the date of writing (one month later), the author does not specify the result.

Bucquoy[1] reports the following case of an aortal aneurism in a woman of fifty-eight years of age: The measurements of the aneurism were eight centimetres in the vertical line, ten to twelve centimetres in the transverse diameter. There was no vestige of the second, third, or fourth ribs, or their cartilages. The first sitting was on June 12, 1878, in the presence of Dujardin-Beaumetz. Two needles were inserted, which were connected, one at a time, with the positive pole into the most prominent part of the tumor to the depth of two and half centimeters (one inch). The negative electrode was applied to the thigh; the current was applied for twenty minutes; great pain and inflammatory swelling followed this application. These symptoms, however, disappeared at a later period. At the second sitting, two weeks later, there was further improvement. After three more sittings the tumor was in great part solidified, and the patient left the hospital for the purpose of resuming work. The tumor again reappeared two months later, but not in its original dimensions. After four applications the aneurism was reduced to a hard fibrous character. This case appeared to the author to present every reason to hope for a permanent cure. He thinks the method of treatment would be of great benefit when the aneurism is in communication with the artery by a narrow orifice.

Ciniselli[2] divides his cases of aneurism into two classes: nine of the cases were between 1846 and 1866, and fourteen cases were between 1868 and 1870. The former cases were those treated without experience, the latter were treated in the light of the former results. The first cases were voluminous tumors, in one of which the blood had begun to escape; all of the cases were threatened with rupture and gangrene, and were thus very far advanced, being beyond the reach of nature and art. Three cases were ameliorated. In one the result was

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[1] Bull. de l'Acad. de Med., 2me., viii., p. 55, 1879. [2] Op. cit.

not known, and the remainder died of rupture. As this first series was experimental, the improper methods used, probably, had something to do with the results. Thus in two cases the induced or faradaic current was employed, which subsequent experience shows to be the worst possible form of current. In other cases, Bunsen's and Wallaston's elements were used, giving too great current tension, and causing phlegmonous inflammation, gangrene and fatal hemorrhage. From an analysis of twenty-three cases, this author is convinced that when the aneurism is still within the cavity of the chest, is of medium size, lateral to the artery, and communicating with it by a limited opening, and when no complications exist menacing life, galvano-puncture offers fair prospects of success.

Of the second series, seven were characterized by bulging of the intercostal spaces only, the remainder in addition being attended by more or less erosion of the chest walls; seven were uncomplicated, three being in the ascending aorta, three at the arch, and one in the innominate. They were diagnosed to be lateral to the artery, except one which had an uniformly enlarged bulging on both sides of the sternum. This latter required two applications of electrolysis while one only sufficed for the others. The other seven were complicated with secondary external aneurisms, three being in the ascending aorta and four at the arch. These communicated with the vessel by wide orifices. Aggravated subjective symptoms usually were present.

Ciniselli used the previously described voltaic pile; this pile was formed of thirty couples; the zinc and copper plates were each ten centimeters square, each disc-element being separated by cloths wet with salt water. He used the poles alternately to avoid the local effect of either the alkaline or acid reaction, which belong to each respective pole. By this method the author considered that no accidents would occur from the predominance of either reaction. In one case only was it necessary to use anæsthetics.

The local irritations due to the contact of the electrode were always easily controlled by ice and lead water. Ciniselli considered that the local cauterization is produced by too long-continued application of the electrode, or to a chemical action which is too great. The irritation should never be more than superficial and slight. The first seven cases showed immediately apparent improvement; this was marked by a diminution of extent of pulsation, by increased consistence and firmness of the tumor, and decrease in size; there was increased regularity of circulation. The general symptoms of neuralgic pain and dyspnœa diminished or disappeared; the patient was able to lie in positions that were formerly impossible, and decided improvements recurred in tranquil sleep and in muscular strength.

This author states in regard to the recurrence of aneurism in his experience:—in six of these cases there was no return for seventeen months, eight months, four months, three months, and three months, respectively.

In the first case a second operation was required twenty months after the first temporary cure; the walls of the chest were eroded and the tumor was of immense dimension.

Another case recurred in four months, but was still confined within the walls of the chest; a second operation was a complete success, and there was no evidence of the aneurism at the close of eight months later.

In the seventh case there was marked and prompt improvement, but a rupture of the sac caused death eighteen days later.

The same methods of procedure were followed in the six remaining cases. Two of these cases required a second operation, immediate results of which were the same: viz., increased consistence and firmness, and diminution of the size of the tumor, with improvement in the general constitutional symptoms. There was no general constitutional disturbance and very slight local irritation. The greatest advantage possessed by this operation as compared with other means of treatment is its short duration. In two of the cases the tumor was of considerable size, which subsequent to the operation became suddenly enlarged and softened; gangrene, rupture and death resulted in forty-two and fifty-two days respectively after the operation.

In the seventh case the occurrence of gangrene and hemorrhage resulted from local cauterization which was caused by a current of too great strength. *Post-mortem* examination showed in some of the fatal cases organic alterations which would preclude success; while in the others the beneficial effects of the operation were shown by consistent clots.

Ciniselli draws some conclusions from his experience in this method of treatment of aneurisms. Before presenting this summary it would be well to call attention to the large number of cases from which his experience was gathered, and to note in advance of his conclusions, that many of his cases presented more unfavorable aspects of treatment than some of those which are quoted from other authorities. It would be well also to remark that the voltaic pile, used by him, gives a galvanic current of very low tension and a feeble chemical action. The current from this pile has not the property of a tolerably constant action for long-continued use. The batteries most generally employed for electrolytical treatment of aneurisms on the European continent, as well as in this country, appear to be those which afford strong currents of a high tension.

The conclusions of Ciniselli are summarized in the following valuable suggestions for the indications and methods of treatment of aneurisms:

The favorable indications for the use of electrolysis are: entire enclosure of the aneurismal sac within the cavity of the chest, the only external manifestations being a pulsation and bulging of the intercostal spaces; the seat of the aneurism should be lateral to the arterial wall; the aneurism should not be too extended nor have formed in a very short period of time. There should be no evidence of disease in the organs of respiration or of the circulation other than that shown by the symptoms of the aneurism itself.

The above symptoms demand the use of the electro-puncture. As the most common cause of aneurism is that of atheroma of the arteries and its tendency to progress, the permanence of the cure will depend upon the progress of this arterial lesion. If the aneurism should recur, and if the same favorable symptoms persist, the operation should be repeated.

On the other hand, in the case of peripheral aneurisms, and of those which show a tendency to progress very rapidly, and in secondary aneurisms, or in those complicated by erosions of the thoracic walls, the electro-puncture is contra-indicated. It is useless and may be followed by dangerous consequences.

He would especially caution against the use of too strong a current (of high tension). In his opinion, the best form of battery is furnished by the Voltaic pile. One serious objection to this form of battery is the fact that its electro-chemical action is not continuous for a sufficient period of time, and consequently the force of the current decreases very rapidly. If another form of galvanic cell is used in battery, the current should not have a greater force than that of the initial strength of the Voltaic pile. The strength of the current should be equal to that which will decompose a mixture of sulphuric acid and water in the proportion of one part of the acid to thirty of water, and which will give in five minutes two or three cu. cent. of the mixed gases resulting from the electrolysis.

He recommends polished steel needles which are one millimetre or more in diameter. These should be inserted, to the number of two or four, not nearer together than an interval of one and a half to two cent., nor to a depth of over two to four cent. The current should be reversed at regular intervals in order to obtain a firm clot, and abrupt shocks may be prevented by having pins in the handles of the electrodes. At first the negative should be applied on the surface of the skin by means of a wet compress, and the electro-positive needles should be connected one after the other in such a manner that each needle is connected first with the positive and afterwards with the negative electrode, when the direction of the current is reversed. The needles should not be allowed to connect with the negative electrode until after they have been acted upon by the positive. His reason for this precaution is that he desires to coat the needles with oxidized iron so that they are practically insulated before being used to convey the negative electricity. The current, after acting upon the skin should be changed, so that the former positive needle shall be used as negative on changing the direction of the current.

The current should be reversed as soon as a little black circle shows itself at the positive pole, as this indicates the commencement of the caustic action. The appearance that indicates that cauterization is about to take place around the negative pole (which has formerly been positive) is the substitution for the red zone surrounding the black circle of a pale and subsequently a cadaverous hue. This will inevitably be followed by an eschar and ulceration unless the action of the current be terminated. The sittings will last from 30 to 45 minutes, according to the number of needles and the number of times each is employed.

Dujardin-Beaumetz[1] refers to a later collection by Ciniselli of thirty-eight cases of aneurism. In no case had a permanent cure been effected. In eleven cases the cure persisted for 48, 27, 23, 21, 17, 16, 7, 7, 6, 4, 1 months respectively. In seven cases the amelioration persisted at the date of writing (28, 16, 12, 8, 6, 3, 3 months after the operation). This quotation is from a letter of Ciniselli to Dr. Bacchi. Dujardin-Beaumetz puts a case on record witnessed by Dr. Bernutz. This was an aneurism of the aortal arch. The patient after apparent cure from the treatment returned to work at the forge, and died suddenly two weeks later. There was no post-mortem examination in this case.

Another case is reported by Dujardin-Beaumetz which was in a man aet. 37; aneurism of ascending portion of the arch, with insufficiency of aortal valves. When admitted March 17, 1877, the patient stated that he

[1] Note sur un cas d'aneurysme de la crosse de l'aorte traité par l'electro-puncture. Bull. gen. de therap., xciii, p. 1.

never had syphilis, nor had he been addicted to alcoholic excess; no report of rheumatism; his father died of cerebral hemorrhage, his mother was living and in good health. This patient had apparently from the reported history an attack of parenchymatous nephritis at the age of fourteen years, which was not recovered from for six months. Four years ago he was suddenly attacked with violent pain in chest, which disappeared after some days. Two years ago without appreciable cause he was attacked with pain which radiated into the arms, especially the right; this was soon followed by a palpitation so severe as to compel him to stop work. Decubitus on the left side caused intense dyspnœa. About one year ago he noticed a pulsation on the surface of the chest, between the fourth and fifth ribs. He was treated for this symptom at a hospital in Bordeaux by ice and iodide of potassium. On examination visible pulsation was most marked in the third intercostal space. A bruit could be heard at the apex on the mammary vertical line in the sixth intercostal space. Iodide of potassium and refrigerants were tried unsuccessfully, and as this case presented the favorable symptoms for treatment by electrolysis mentioned by Ciniselli, this method was determined upon. Gaiffe's battery of twenty-six couples was used, producing 2c.c. of mixed gases in five minutes from the acidulated water of Ciniselli. A rheostat was available so that the current strength could be increased at will. Needles were varnished for one half of their length. One positive needle was inserted at a distance of three cent. to the right of the sternum, the second needle was introduced at a distance of four cent. from the sternum. The positive needles were used singly and in succession. To avoid shock the current was diminished each time a needle was inserted; each needle was twice acted upon in the way recommended by Ciniselli. The sitting lasted half an hour. An ice bag was applied after the withdrawal of the needles. Four hours later, the force of the impulse beat of the tumor had diminished, and its increased consistence showed that a clot had formed. This author concludes that, if Ciniselli's directions are followed, two-thirds of the cases will be ameliorated.

In the Gazette des Hopitaux[1] Dujardin-Beaumetz reports the continuance of the treatment in this same case; second sitting, about one month after the first. Three needles were inserted in the fourth intercostal space, which was followed by an amelioration even more marked than

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[1] Paris, 1877, p. 1004.

before. The pulsation was perceived only (and there with difficulty) at the borders of the tumor; but in proportion to the improvement in the aneurism the cardiac symptoms increased in severity, dyspnœa, enlargement of the liver, and œdema appearing. Death took place one and a half months after the second operation. Post mortem showed a pear-shaped aneurism, of the first portion of the vessel; this aneurism rested on the liver, mounting to the third intercostal space. There was insufficiency of the aortal valves; the sac was lined by a clot one cent. in thickness. The author thinks that it would be impossible to produce complete occlusion of a cavity of such a size by electro-puncture. Some erosion of the chest walls was also present.

Ciniselli[1] says that formerly he used varnish to prevent cauterization, but found this to be useless, as the tissues were cauterized by "the electricity acting by induction across the intervening stratum." Also that cauterization takes place around negative needles, but not when they have previously been positive. It is more difficult to obtain a clot with the negative pole applied over a wet compress. He has shown by experiments on animals that the negative pole does not dissolve a positive clot. On the contrary, it produces an increase in its consistence and renders it a better conductor. These clots are chemical and can be prevented by the use of oxidizable electrodes. The best insulator for the tissues is the black circle of oxide formed on a steel positive needle, and this is the reason for never using a needle as the negative electrode which has not previously been positive. Induction will, however, take place after a while around this circle, and the sign of this is—pallor replacing the redness that formerly existed around the dark circle. He now employs, first a positive needle, second the negative, and third positive for 8-10 minutes. This ensures a better clot, of a drier character, and prevents hemorrhage. A light compress is placed over the vessel and an ice bag on top of that.[2]

Male, aet. 44, thoracic aneurism. Four new silver negative needles were inserted in sac and positive leather-covered electrode moistened applied on skin. Pain and discomfort at once lessened, improvement continued for several days.

Male, aet. 45, aneurism of thoracic aorta. Seven positive needles introduced into sac. A current from thirty Daniell's cells was applied for

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[1] Letter to M. Dujardin-Beaumetz. Bull. gen. de therap. xciii, p. 177.

[2] Z. de Kauer. Galvano-plastischen Behandlung der aorten Aneurismen. St. Petersburg Ztschr., xv, p. 29.

eighteen minutes; temporary improvement ensued. The operation was repeated seven times, and the patient died.[1]

Heidenreich states that the current decomposes blood thus: at the positive pole, albumen, fibrin and fat, acids (HCl, etc.); at the negative pole, watery and alcoholic extracts, alkaline and earthy bases, iron, pigments, etc.

ANGIOMA (Nævus).

The treatment of nævus by the use of electrolysis has been attended with great success, and, like almost all those resulting from the local action of electricity, the scars on the skin are of so slight a character that hardly any visible blemish remains. The treatment of this class of skin deformity by the use of chemical caustics, or by means of skin transplantation is most generally followed by white scars; these leave ugly cicatrices and, consequently, are very objectionable. A number of these cases were successfully treated by Gröh.[2]

1. Male child of five months. The size of this nævus was that of a walnut and situated in the skin of the left cheek. It was cured in one sitting.

2. Male child of six months with a cavernous nævus of the same size as in the preceding case; this was situated in the skin of the left upper eyelid and extended to the temple, where it was flat and of the size of a silver dollar. This was cured by electrolysis in three sittings.

3. Two cases of nævi were cured in five minutes and three minutes respectively. One of these was situated at the left angle of the mouth and had the size of a bean; the other was below the right clavicle and was the size of a pea.

4. Another nævus in a child eight months old was equal in size to a pigeon's egg; this was situated upon the upper lip. It was cured in three sittings.

5. Another case of cavernous nævus was situated near the left eyebrow and was the size of a walnut. This was cured in three sittings.

6. A child of ten months had a cavernous nævus situated on the left side of the neck over the region of the larynx; this was twenty-one lines

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[1] Frommhold. Ueber coagulation des Eiweisses durch Electrischen Stroeme mit Beziehung auf die Heilung von Aneurismen und ueber Aufloesung von Harnroehren Stricturen durch Electricitæt. Oest. Ztschr. f. prakt. Hlkde. vi., 1860, p. 514.

[2] Op. cit.

long and fifteen lines broad. This nævus could be diminished by pressure, and was increased with muscular efforts of the child. A long and thin needle (positive electrode) was connected with Frommhold's battery.[1] The negative electrode, a steel needle, was inserted parallel to the surface of the skin first above and then below the transfixed positive needle, and then in other parts of the tumor. In eighteen minutes the whole mass was a slough. The positive needle was held so firmly by the tumor that it was allowed to remain. The slough separated in eight days, and its only remains was a linear cicatrice.

8. Another case of cavernous nævus was situated in the skin of the cheek, involving also the right eyelid; this was treated by electrolysis; the dimensions of this nævus were eighteen lines vertically and twenty-one lines transversely. The patient's age was six months. As it was the author's intention to produce obliteration of successive portions in the hope of preventing a distorted scar, a battery was used of twenty-two couples, the elements of which had an area of 160 square inches. The applications extended over seven sittings and the treatment was followed by favorable results.

9. A female child of five months presented a very large nævus on the right side of the face, which extended forwards six and a half centimeters (two and a half inches) from the tragus and six centimeters (two and a quarter inches) in a vertical line. This case was cured after a number of sittings.

10. A nævus in a boy of thirteen months, a walnut's size, situated below the umbilicus, was cured after two sittings.

These blood tumors were either cured by the coagulation of the blood or by the production of a slough. Gröh had a practical difficulty in procuring insulated zinc needles. A number of zinc needles were used for the purpose of procuring a distribution of several points and these were used for the positive electrode. The negative electrode was formed of a moistened conductor applied on the surface of the skin or by needles inserted into the growth. To produce a shrivelling of the growth the needle should remain only for a few moments. In order to produce sloughing the needles should remain for a longer time. Gröh, from his experience, ascribes great value to the treatment of angiomata (nævus) by electrolysis.

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[1] This battery has been described in chapter iii.

The following case reported by Wilheim, assistant, was observed and reported in Fieber's[1] Clinic. Though it presents an unfavorable result as compared with the experience of Gröh, it should be observed that this nævus was not treated by his method nor by an operator who placed much confidence in cures by electrolysis. The nævus was situated below the left clavicle of an hysterical girl; a gold needle, used as a positive electrode, was inserted into the tumor; the negative electrode was applied over the surface of the skin in the region of the deltoid muscle. The current was derived from a battery of six Bunsen's cells. The treatment produced no favorable result.

Two cases of leucoma were reported by the same observer, one of which was partially and the other wholly cured.

1. Leucoma (a white opacity of the cornea), was situated on the left eye of a woman. In this case a needle, as the negative electrode, was placed in the centre of the opaque spot for a little less than two minutes. This was followed by a cure.

2. In this case of leucoma the negative electrode was a wet sponge which was placed over the eye; the positive electrode was held in the hand. There was no cure. It will be observed that in one of these cases which was followed by a cure, the electro-negative needle was directly applied to the spot; the other case which was treated by surface contact of a moistened electrode, was not followed by a cure. The nævus which was treated by the insertion of an electro-negative gold needle into the growth was followed by a cure. The impartial reader will naturally infer from the preceding cases that nævus can most generally be removed by proper application of treatment by electrolysis.

It is not right to assume that every case should be treated in the same way, or by the use of only one kind of electrode. These electrodes should be adapted for each especial case. Generally speaking, the destroying action which follows the insertion of an electro-positive gold needle is slower than that which follows the insertion of the electro-negative gold needle, and the accompanying inflammation in the former case is greater, perhaps from the acid reaction or exosmosis. The use of zinc electrodes would appear to be followed by a more rapidly destroying action. Gröh assumes that this result is on account of the formation of a destroying caustic action produced by a caustic zinc compound, or else by promoting chemi-

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[1] Die Elektrolyse und ihre Lobredner. Allg. Wien Med. Ztg., xxii, pp. 30, 40, 56, 93. 1877.

cal decompositions by establishing a subsidiary electro-chemical action by the decomposition of zinc within the tissues. (See Chap. XIII.)

The Action of Electrolysis in Tumors.—The following cases of the action of electrolysis in promoting the absorption of sacculated tumors are quoted:[1]

A laborer, aged thirty-nine years, with a hydrosarcocele, which had existed for many years, was six inches long by two inches broad, and was situated near the external ring.

First sitting, a varying number of cells was used for sixteen minutes; this was followed by much pain; the firmness and consistence of the tumor was softened.

Second day "feels well."

Fourth day the tumor is smaller.

Fifth day, patient was discharged from the hospital with the tumor reduced to half of its original size.

Female, aged twenty-three, with a tumor of medium size. In this case[2] the tumor extended a distance of seventy-eight centimeters, from one iliac spine to the opposite.

Two needles, separated ten centimetres apart, were connected with a current from a Bunsen battery and were inserted during ten minutes. As fever, abdominal pain and other symptoms of peritonitis developed the operation was not repeated. There was no immediate signs of diminution in the size of the tumor.

Ovarian Cysts.—The following eight cases of ovarian cysts treated by electrolysis are reported by Ehrenstein:[3]

	Abdominal measurement.	
	Before.	After.
1.	178.62	89.75
2.	110.75	60.75
3.	90.00	60.75
4.	79.75	56.37
5.	127.12	87.50
6.	75.25	58.25
7.	109.75	87.75
8.	77.25	63.75

The following case is reported by Fieber[4] of an ovarian cyst of the size of a man's head. The age of the patient was thirty years, and the diag-

[1] Gröh., op. cit.
[2] Scoutetten. Gaz. d. Hop., Paris, 1865, p 354.
[3] Allg. Med. Cent. Ztg., 1876, 603.
[4] Wien Med. Presse, 1871, p. 372.

nosis was confirmed by Carl Braun. The cyst was multilocular with non-fluid contents and was not suited for an operation. A battery of twenty Daniell's cells was employed. A gold needle, connected with the copper element of battery (positive electrode) was thrust into the tumor. This treatment was repeated at eleven sittings, and ultimately reduced the size of the tumor to that of a small apple. Negative electrode was applied to surface of skin.

The same author reports[1] another case of a tumor of the left ovary which had existed for three years; this was first punctured after a consultation with Spath, and four litres of fluid removed; then, percutaneous faradization was employed; but the cyst refilled. Afterwards, the patient was treated at four sittings with the galvano-puncture. This was followed by a little pain, and after some weeks the tumor was reduced to the size of an apple.

The use of electrolysis in the treatment of ovarian tumors has been the subject of a careful and critical study by Dr. Mundé of New York. The general tone of his article would appear to lend support to the belief that he was disposed to consider this method of treatment so much inferior to that of the more popular ovariotomy that it should hardly ever be used in place of the latter capital operation. We do not desire to make any comparison of the two methods; it would scarcely be in keeping with the purposes of this treatise, which is simply intended for a description of electrolysis, and not a treatise to defend this treatment, which should stand upon its own merits, even in those cases of disease whose details have been given in this chapter. The history of the reported cases should simply be used for the purpose of illustration, and their study will furnish us with information such as may be usefully employed to obtain a knowledge of the most appropriate means to be used in the application of this remedial measure for the treatment of diseased tissues, no matter in what part of the human body they may be found.

In this article of Dr. Mundé's we find a collection of fifty-one cases of abdominal cystic tumors which were treated by the method of electrolysis or by "*electro-catalysis.*" Twenty-eight of these cases (55 per cent.) have been completely cured; nine of them ended fatally, and four of them were followed by dangerous symptoms. We can hardly forbear mentioning in this relation that the first few years during which the capital operation of ovariotomy was practised, the mortality from it was so great that but

[1] Allg. Wien Ztg., 1876, p. 432.

few surgeons would undertake the risk of operating. At one time, in the early period of this operation, if memory is correct, about four out of every five cases of ovariotomy performed ended fatally; and yet, in spite of this record, the great skill and care of the eminent surgeons who brought the rate of mortality down to nine per cent. might have been far otherwise, if the objections which are now urged by Dr. Mundé against electrolysis of cystic tumors had prevailed to stop the efforts of Spencer Wells and other surgeons from studying the best means of performing ovariotomy with successful results.

In a letter which is given at length in the article before us from Von Ehrenstein, it is stated that the latter had treated two hundred and twenty cases of abdominal tumors having liquid contents, and that all of these were cured with the single exception of one patient who left before the completion of the treatment. In some of these cured cases, about thirty or forty, after two to five years, the tumors returned, but were invariably removed a second time when the treatment was administered in his establishment. One case of recurrence, on the other hand, which was treated by a North German physician with electrolysis only, without regard to Von Ehrenstein's method, terminated fatally under his care. This physician especially cautions against the use of tapping prior to electrical treatment, and also against employing both electrodes as electro-puncture; he employs for the latter only the "*cathode or positive pole,*" (?) and uses sulphite of magnesia or magnesia sulphurosa to prevent any suppurative fever. Though it may be somewhat out of place to discuss this particular form of treatment, the details of which are especially withheld by Von Ehrenstein from our knowledge, yet it seems to be advisable to make a little digression, in order that the obscurity may possibly be cleared while the question is still before our thoughts.

Reference has been made in a previous chapter (see chapter second) to the cataphoric action of electricity, electrical osmosis, and it should be remembered that the effect of this action results in a transmission of the fluid, acted upon by a current, *en masse* towards the negative electrode. From the information incompletely furnished above from Von Ehrenstein, it would appear that his method required the insertion of only one pole, the positive, into the sac which contained the fluid. While the negative was applied to the surface of the overlying skin; the effect of this manner of application of the electrodes would resrlt in pushing the contained fluid towards the secreting membrane of the sac, and would probably help the natural absorption of this fluid. It should also be noticed that the administration of an active hydragogue cathartic, like sulphate of magnesia, which is also a diuretic, would increase the physical osmosis from the abdominal tissues. In this way we may suppose that the fluids which are contained in the pelvis may be drained out of the body. This mere hypothesis is certainly not established; and yet it is a well-known fact that ascites is frequently relieved by the active medication of diuretics and cathartics; moreover, the spontaneous disappearance of cystic abdominal tumors is sometimes accomplished in the same manner. In support of this supposition we would refer to a few details of some of the cases which are reported in Dr. Mundé's article.[1] In regard to Case III., which was published by Von Ehrenstein:[2] "After the third sitting an unaccountable profuse diuresis took place, accompanied by a marked decrease of the abdomen. No cystic fluid escaped through the abdominal walls at any time, but the originally tense abdominal parietes became lax, after the third day, particularly in their upper portion, so as to render the formerly hidden points of the false ribs easily palpable, and a splashing motion became perceptible in the abdomen of the patient at each movement. These attacks of profuse micturition were repeated during the whole month of August, at intervals of twelve hours to three days, without, however, producing debility; because the development of a strong appetite rendered the patient better able to bear the drain on her system, and the improved condition of the blood prevented the rapid refilling of the cyst by transudation of its watery constituents. The usual (sic) diaphoretic tendency did not appear in this case, but on August 29, an intense itching of the abdominal epidermis showed itself, unaccompanied by an eruption, or by a change of temperature or color. But the dry hand or a dry warm plate of glass applied to the skin at once demonstrated the presence of a continuous, almost imperceptible moisture, which was neither actual perspiration, nor transudation from a puncture, and could be looked upon as nothing else than so-called "perspiratio sensibilis." The beneficial diuresis having ceased in the meanwhile, Ehrenstein restored it by a mixture of squills, digitalis, and oil of juniper. The results of eight other cases are mentioned by Ehrenstein, but the details of the symptoms of treatment are not given. They all completely recovered.

Another case (No. XIX.), is reported in detail by Dr. Mundé, in which

[1] Transactions of the American Gynecological Society, vol. ii. p. 377. 1877.

[2] Allg. Med. Central Zeitg., 1876.

the tumor recurred two years later and resulted fatally, that reported by Dr. Hayes of Chicago. The chief point of interest to us in this case is, however, that a subsidence in the size of the tumor, each time during its treatment by electrolysis, was marked by a previous appearance of diaphoresis and diuresis.

Dr. Semeleder, of the city of Mexico, publishes[1] eighteen cases of abdominal tumors which he treated by electrolysis. His method was the insertion of positive steel knitting needles into the sac of the cyst, and the negative electrode was applied to the surface of the abdomen. He used a Calland's battery of twelve elements of zinc and copper, the surface of the zincs measuring two by sixty square centimetres. For the battery solution he used water in which sulphate of copper was dissolved. The elements were arranged in series for tension. Four to twelve galvanic cells were employed as his battery in different cases. The negative electrode was formed of carbon, or of sponge, or of wet blotting paper. Twelve of his cases are reported as cured, one with no especial result, two were improved, and three died. Two other cases reported by him were not treated with a sufficient number of sittings to furnish any especial matter of interest. His sittings occurred almost daily, and lasted from five to ten minutes. The number of these sittings was from six to one hundred and three, and the time of the whole treatment lasted from one to six months.

TUMORS.—Wilheim reports a case of ganglionic tumor in the wrist joint treated by electrolysis.[2] After this treatment, points of gangrene supervened and the hand became œdematous, and lymphangitis occurred, which required treatment for six weeks. It should again be remarked that this writer used currents of too great strength, and probably did not exercise the same careful use of electrolysis that other operators of larger experience had especially observed in their cases. Too much stress cannot be laid on this subject of the use of feeble currents continued for longer sittings. It should always be remembered that the same chemical effects can be produced by the long continuance of feeble currents as by the use of strong currents in a short period of time, and without the danger of exciting inflammatory action; this chemical effect and law has been mentioned in the statement of the behavior of electrolysis in the decomposition of inorganic chemical compounds, and is equally true for the electro-chemical action in the living tissue. This same author reports two

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[1] The American Journal of Obstetrics, July, 1882, Vol. xv., No. 3, p. 513.

[2] Op. cit.

more cases of the use of electrolysis, in which he notes a failure of cure: one, a thickening of the false vocal cords, and the other a case of sarcoma in the larynx.

Tripier[1] quotes the following three cases reported by Ciniselli:—

1. A hard round cutaneous tumor in the right leg of a woman, aged twenty. Forty couples of discs, each ten cent. square, were arranged in Voltaic pile and were separated by pads moistened in sulphuric acid diluted (1 to 20). A positive electro-needle was inserted into the tumor and the negative electrode was applied to the surface of the skin on a wet compress on the leg. Great pain followed this treatment, but the tumor came away with the eschar in eight days, and a smooth cicatrix was left in twenty days.

2. A tumor of the size of a hazel-nut in the left arm of a boy of fourteen years of age, was electrolyzed with a current from a voltaic pile of thirty couples. The discs used were half the size of the preceding; in other respects the application of the treatment was the same. The patient complained of the attending pain. The eschar separated on the thirteenth day leaving half of the tumor; at the second sitting, electro-puncture, platinum for positive and steel for negative were employed for five minutes, and the remainder of the tumor separated on the tenth day, producing a complete cure.

3. An erectile tumor, of the size of a large walnut, was situated on the nose of a child of eight months' age. One electro-positive platinum needle and two electro-negative steel needles were inserted into the tumor, and these were connected with a current from a voltaic pile of fifty couples for ten minutes. The local inflammation and fever which followed this treatment ceased on the sixth day, and the separation of the eschar on the ninth to the twelfth day. Erysipelas supervened and the child died on the nineteenth day. It should be noticed that the current used with this third case was not only four times the strength of the preceding case, but even still stronger. It should be remembered that, after the current has counterbalanced the resistance offered by the human body, the addition of added couples will practically increase the tension of the current by that of each additional pair.

Tripier[2] reports a case of a multiparous married woman, in whom an interstitial fibroid tumor, with metrorrhagia, was appropriately treated

[1] Archiv. gen. de. Med., 1866, vii., p. 48. [2] Op. cit.

for the relief of the hemorrhage. After this had ceased acute bronchitis occurred and continued throughout the winter, which, in the opinion of her attending physician, was caused by tuberculosis. In March, 1881, Tripier discovered a fluctuating tumor in the margin of the side of the anus, which was two and a half cent. in diameter and bulged out to an extent of one cent. This was punctured with a trocar, and on the withdrawal of the trocar a little pus, blood and a large quantity of tenacious pus was spontaneously expelled; the depth of the cavity measured five centimetres. A sound was then introduced and the interior of the sac was subjected to the action of a current equal to ten milliwebers (milliamperes?) for twenty minutes duration, the closure of the circuit being formed by an electrode placed on the surface of the thigh. There was no dressing applied to the opening of the wound; cicatrization occurred on the fourth day, and there was no return of the abscess.

Dr. Neftel[1] reports cases of tumors, mostly cancerous, which in his experience were treated by electrolysis.

1. In a man of fifty-six years of age, atheromatous, lately troubled with rheumatic neuralgia. His maternal aunt died of cancer. The man had noticed for some years an induration in the left mamma, which he supposed was caused by a local irritation, because a blister was applied some time previously. After which three boils had appeared, two of which had since healed; the third remained in an ulcerated condition and subsequently had become painful. The diagnosis was formed of a scirrhous cancer, which involved the axillary glands, as well as the cervical glands; this diagnosis was confirmed by Nélaton, Marion Sims and by several European physicians. Dr. Sims removed the diseased structures, after which healing occurred by first intention, though the general condition was not much improved. A year later, the glands had enlarged to a considerable size. Dr. Sims removed these enlarged glands, the subsequent cicatrization of which was retarded by the appearance of erysipelas. Later on, a tumor as large as an orange was found in the right mamma. The patient was then too much reduced to admit of an operation by the knife. Dr. Neftel proposed the use of electrolysis, which he applied for eleven sittings; the negative platinum needle was introduced into the tumor, and the positive electrode was applied as a wet compress

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[1] Die electrolytischen Behandlung Boesartiger geschueltste. Reprinted from Virchow's Archiv., lxxv.

on the skin. A labile application[1] was made for fifteen minutes. At the second sitting, an electro-positive gold needle was introduced into the tumor, the circuit being closed by the application of a surface electrode, and the full intensity of a current from fourteen Siemen's (Krueger-Hirschmann) battery was continued for two minutes.

Three days later, two negative needles were introduced.

Four days later and five days later, electro puncture was used as negative electrode, and the positive electrode was applied by means of a broad surface to different points of the skin, with a current derived from a battery of thirty Siemen's couples, during a period of five to fifteen minutes; a frothy foam appeared around the electro-punctures. The pain attending the operation was intense, and immediately after the tumor increased in size and became softened. The patient continued the use of weak currents, from a Daniell's battery of two cells, which he applied himself daily for fifteen to twenty minutes. After the second introduction of the needles the tumor began gradually to diminish, and in three months had entirely disappeared. The patient continued the applications of the weak currents to himself for a longer period. He was seen three years later by Neftel, Sims and Mott, of New York, and no evidence could be detected of the return of the tumor, or of enlargement of the glands; the skin over the mammary region was soft and movable. The patient died of some other disease at Washington.

Dr. Neftel states that the electro-punctures with strong currents into cancerous tumors will not suffice for a cure; but the subsequent and continued application of weak currents are, also, necessary. His reasons for this statement are based on the supposition that strong currents attack the tissues violently around a small space, while weak currents will radiate with the production of a milder local action. It has already been noticed by the writer of this treatise, as well as upon the authority of Ciniselli and other observers, that the use of strong currents by electro-punctures in the tissues will cause an irritation and inflammation at the point of application, which may even extend to the adjacent tissues, and provoke suppurative processes; these may induce the spread of the cancerous degeneration beyond its original seat. Moreover, even if suppuration does not follow the electro-puncture, the irritation may act as a stimulating cause for the enlargement and further growth of non-cancerous tumors,

[1] Labile application is made by the continuous movement of the electrode; the stabile method is made by keeping both electrodes stationary.

which are forms of neoformations. Dr. Neftel states, further, that the electro-puncture affords the best possible conductor of the current into the deeper tissues, and that the tumor will soften at these points of application. He would advise that the order of procedure should be:—first, to provoke an energetic decomposition, and second, to induce a slow absorption by the application of surface contact of the electrode to the skin through the long-continued action of weak currents. He presents the history of the following recited cases to show the inefficiency of the use of strong currents to effect a cure of cancerous affections:—

1. Unmarried woman of fifty years; the growth of the patient had been stunted; kypho-scoliosis; menstruation had been absent for twelve years. The right mamma had been amputated on account of a scirrhous tumor. Two months after this operation the axillary glands began to enlarge. He began treatment of these enlarged glands, six months' after the amputation of the breast; he employed the electro-negative puncture into the axillary glands, closing the circuit by means of a broad positive electrode applied to the surface. The current was gradually increased to that from fifteen Siemen's couples, applied for fifteen minutes, and then gradually diminished. At the next three sittings, at intervals of a week, the current from twenty couples was applied during fifteen minutes; then, that from twenty to thirty couples (Siemen's) for fifteen minutes. The same electrodes were employed as in the preceding sitting, and in the same manner. The enlarged gland, which had previously been as large as an egg, then disappeared from the axilla gradually during the next two months, as well as the cervical glands which had been treated in the same way; the patient's condition was good and she went home. In less than a month she returned for advice on account of a diffuse hardness in the right subclavian fossa; this tumor had the size of a walnut. A current from twenty Siemen's couples was employed, as before, during twenty-five to thirty minutes for four sittings. This treatment produced so much irritation that a confluent slough appeared which covered the place of the tumor; this afterwards disappeared and the tumor diminished in size; the axillary swelling also decreased and the patient went home. Four months later she again returned with nodules of the size of a pea on the anterior wall of the thorax; there was, also, diffuse induration in the axillary space. At eight sittings, each nodule, one only at a sitting, was punctured by the electro-negative needle with a current from twenty-five to thirty Siemen's couples for thirty minutes. He was intimidated

from inserting the needles in the axillary space on account of the numerous vessels. The axillary induration gradually increased in that region as well as an œdematous condition of the whole forearm. This case illustrates the rapid disappearance and rapid recurrence of the cancerous condition under this treatment.

2. Married woman of fifty-two years of age; menstruation had ceased two years ago; her maternal aunt had died from cancer of the breast. In the present case there was a hard knot in the right mammary gland of the size of an hen's egg, which he had noticed within the preceding six months. There were also swollen glands in the right axillary region. Both the tumor and glands were extirpated, after which pleuro-pneumonia of the right side developed. Cicatrization was followed by a stiffness and pain in the right arm, and the fingers were immovable. There remained two hard nodules under the cicatrix. These latter became hard and inflamed. Three electro-negative needles were inserted during anæsthesia into these nodules, the circuit being closed by the surface contact of the positive electrode on the skin of the breast; a current from thirty Siemen's cell, arranged for tension, was passed through the circuit for twenty-five minutes. On recovery from anæsthesia there was no pain and no local inflammation, and the patient felt much improved. Three days later, at the second sitting, the insertion of the same needles caused no pain; the hardness was less.

Third sitting, same treatment was repeated.

For the next two months a current from thirty Siemen's couples was applied by means of surface contact of the two electrodes for twenty minutes, but without electro-puncture. The patient regained the use of her arm and hand. Six weeks later the induration had returned and was rapidly increasing; four needles were then introduced with a current from forty Siemen's couples for twenty minutes, which seemed in a few days to soften and reduce the pre-existing induration; the hardness of the cicatrix still remained, as well as the enlargement of the cervical glands of the right side. Strong currents then became unbearable, as they caused great pain and vertigo; consequently, only a current from eight to ten couples was used. Præcordial pain and an irregular pulse followed even this mild current application, and death occurred after a collapse. The post-mortem confirmed the original diagnosis.

3. A married woman of forty years of age received a blow upon the breast, which was followed soon after by the appearance of a tumor in

the mamma (left) accompanied with lancinating pains; the skin was involved with, and adherent to the tumor; the pain extended over to the other (right) arm; the patient had a cachectic appearance. Of late the tumor had increased to the size of an orange, and was accompanied with indurated glands in the axillary region. The electro-puncture from a battery of thirty Siemen's couples was applied in the same manner as in the preceding cases, and under chloroform, for thirty minutes. Great improvement in the patient's condition followed the first applications of electrolysis, and the use of daily and weak currents were then, immediately, begun; these currents varied in strength from six to ten couples, and, in duration of application, from fifteen to thirty minutes. Under this method of treatment the tumor gradually decreased in size and finally disappeared entirely. This author insists upon the imperative rule, that the applications of electro-puncture should be made at short intervals, and should be followed up by the application of weak currents; because, if the intervals between these applications are long, the effect of the electrolysis will be to stimulate the growth of the tumor.

4. A married woman of forty-eight years of age; the patient's family history was good. She had received a blow on the breast (left); soon after this a tumor had appeared which was accompanied with lancinating pains. When seen by Dr. Neftel the tumor involved the whole breast, and was adherent to the surrounding structures as well as to the skin. The axillary glands were also enlarged and there was pain accompanying voluntary motions of the arm. Under chloroform, a current from thirty Siemen's couples was applied for twenty minutes by the method of electro-puncture, as in the other cases, but through three needles used as the negative electrode.

Four days later the tumor was softer and smaller; the electrolysis was repeated in the same manner and with the same current strength.

Twenty-three days later the tumor had still further decreased; electrolysis was again repeated; the decrease in the size of the tumor was followed by a subsequent increase in size.

Eight days later, as the patient had been suffering rheumatism for the past four months and was somewhat worse, Dr. Neftel did not like to proceed with the electro-punctures, and, therefore, applied the surface contact daily for thirty to fifty minutes with a current strength of twenty to thirty couples. Later on, he employed the electro-puncture fourteen times, during a period of thirty minutes at each sitting, with a current strength of forty couples. The surface application of the current was daily continued for the following eight days with a current strength from twenty to thirty couples, and, later, with that from four couples. The patient began to improve, and the electro-puncture was then resumed. This treatment was followed by varying methods of electrical treatment, and at the date of the report the patient was in a very unfavorable condition.

5. A married woman of thirty-eight years of age with a good family history; the tumor in this case was situated under the surface of the left breast, and was of the size of a pigeon's egg; in a few months it had involved the whole gland. At present all the adjacent tissues were involved and the axillary glands formed one hard swelling. The mammary tumor was in size as large as a child's head and the breast itself was hard; a peripheral ulceration extended under the tumor. The case was recognized as cancerous by several consulting physicians. Under chloroform one electro-positive needle was inserted vertically into the breast, and four electro-negative needles were inserted into the tissue around the periphery at intervals of half an inch; these needles were connected with a battery formed of forty couples (Siemen's). The electro-negative needles were re-introduced, one after another, until the whole mass was undermined; the tumor became livid, the next day it was black, and in nine days it sloughed off; after this the pain was gone and the patient could sleep; her general health improved greatly. Strong and medium currents were continued for a year; but it was evident that the disease was not, and could not, be cured, and the patient gave up treatment and went home. When last heard from she was in a feeble condition.

These cases are given in detail, and, certainly, as the author specifies, do illustrate the dangers of using currents for electro-puncture of too great a current strength. We have the authority of Bruns for the statement that, though the case reported [1] by him had a relapse after a period of three years, he has since cured others by electrolysis. In his opinion, if the primary affection of cancer be treated by this method, and before it should become a constitutional infection, after Virchow's views, the cancer will not recur. Bruns believes this to be true, as he has seen it proved in his practice, because electrolysis extends somewhat into the tissues which surround the electro-puncture. Ciniselli [2] claims that the caustic

[1] Op. cit. [2] Op. cit.

action of electrolysis is of some importance in the treatment of malignant tumors and their relapses, either as curative or palliative. Gröh[1] recommends the most powerful currents for the treatment of cancerous affections, and advises the battery arrangement of the couples in batteries for currents of high tension; he speaks favorably of his own experience with the use of four large and four smaller Grove's cells. He urges the use of these strong currents to extend the action, as with extirpation by the knife, to as far as possible into the tissue surrounding the seat of the cancerous degeneration. He succeeded best by undermining the tumor by the use of curved needles. In smaller tumors he advises that a zinc needle should be used with which to perforate the base, and that steel needles should be employed to puncture the surface. The electrolysis must, in his opinion, be continued until every portion of the affected and adjacent tissues have been completely destroyed.

He presents the history of the following cases:—

1. Epithelioma of the head, having an area equal in extent to twice the size of a silver dollar; this was cured in two sittings. He employed, as the negative and positive electrodes, three zinc needles attached to each electrode. This case was in a young woman.

2. Epithelial cancer of the size of a walnut directly under the lip; this tumor was destroyed in one sitting of twenty minutes.

3. A case of epithelial cancer, which was very extensive, situated in the under lip of a man aged seventy-four. Gröh attempted to destroy this tumor by passing a curved electro-negative needle under its base, the circuit being closed by surface contact of a sponge positive electrode, and a battery of twenty couples (Grove's?). Though this strength was well tolerated by the patient without anæsthesia, it was not sufficient to destroy the tumor. Then zinc and steel needles were used, respectively, in place of the curved needle and the sponge electrodes. The operation was once repeated for a slight return, after which a cure was effected.

4. Epithelial cancer in middle of the lower lip of a man of fifty-six years of age; three applications, similar to the preceding treatment sufficed for a cure.

5. Case similar to the preceding in a man of sixty years of age was cured by four applications. This cancer afterwards recurred with a terrible relapse. The whole of the gum, lower lip, and chin was a mass of cancer; his teeth were loose and the submaxillary glands were also in-

[1] Op. cit.

volved. The patient requested a repetition of the previous treatment; and a positive curved zinc needle was inserted at the right angle of the mouth and beneath the bone across to the opposite side, the electro negative being formed of three steel needles which were inserted about three lines apart; the electro-punctures were continued from the periphery to the bone; a current was employed from four large and four smaller Grove's cells. The action of electrolysis was very powerful, the whole mass swelling from the development of gas in the tissues and from the local inflammation of the parts.

The swelling subsided in an hour and the swelling of the submaxillary glands disappeared in six days. The sitting lasted an hour under chloroform. The disease reappeared a second time, and required another sitting. A battery of thirty Frommhold's cells was used with the same electrodes as before; three needles were inserted for fifty-eight minutes, and subsequently for three more sittings of thirty minutes each. As a result the whole of the lower jaw over the seat of the disease was exposed, followed by rapidly spreading and healthy granulations, and a cure resulted with brilliant effect.

6. A case similar to No. 4 was cured in four sittings.

7. A case of epithelial cancer in a man of seventy years of age; this cancer involved the whole of the lower lip. A Frommhold battery having a surface of two hundred and ten square inches was used under chloroform; an electro-positive zinc needle, two and a half inches long, was inserted through the middle of the tumor, and an electro-negative curved steel needle (forming a segment of a circumference of a circle having a diameter of three inches) was also inserted at the margin of the tumor at the angle of the mouth; a frothy foam developed rapidly over the surface of the diseased tissue. The sitting lasted for twenty-five minutes, and effected a permanent cure.

8. A case of epithelioma which involved the chin, lower lip, and alveoli of a man aged sixty-four; the positive electrode was formed of three long zinc needles, which were inserted from the left side to the centre of the tumor; the negative electrode was formed of three other needles, which were inserted also into the cancerous mass; the current was continued for seventy-three minutes. At the second sitting, the facial artery was punctured and a severe hemorrhage followed, which was stopped by inserting the positive electrode at the point of the flow of blood; the patient then absconded much improved, but not permanently cured.

9. A case of epithelioma in right lower eyelid extending over the zygomatic region. The patient refused more than one application.

10. A case of epithelioma in the left cheek of an old woman, which was equal in size to that of a hazel nut. A cure was effected in one sitting of twelve minutes.

11. A case of flat epithelial cancer in the left cheek of a woman of forty years of age. Five needles were inserted into the cancer about three lines apart, which he has since concluded is too wide a separation and now places the needles closer together. The positive electrode was a thick zinc needle. This patient was cured in one sitting.

12. A case of cancer of the parotid (on right side) as large as an apple in a woman of the age of eighty-four years. This patient was much exhausted by her age, by suppuration, and by hemorrhage. Each electrode was formed of three needles, which were inserted parallel to and alternately, the positive placed from behind forwards, and the negative from before backwards. A current from thirty-two Frommhold's cells was employed for forty-four minutes. The cancerous affection was much improved, but the woman died of colliquative diarrhœa.

13. A case of a man, aged forty-eight; there was epithelioma of the tongue, including the lower jaw and the floor of the mouth, the enlargement of submaxillary glands; there was some sloughing from the cancerous mass. A battery of thirty-three Smee-cells was added to the Frommhold battery, previously referred to, thus making the whole surface of the couples exposed to the action of the exciting fluid equal to four hundred square inches.[1] Gröh was averse to the use of chloroform in this case from the fear that the collection of mucus in the air passages might interfere with respiration. This collection of mucus was very abundant and had to be frequently removed by the use of sponges and forceps during the operation. Two zinc needles were fixed into the middle of the tongue for the positive electrode, and the electro-negative needle was formed of steel; the latter was used to separate the healthy from the diseased tissues. Two electro-negative steel needles were thrust into the floor of the mouth, and between these a zinc needle, connected as positive, was also placed. The first sitting lasted six minutes, but

[1] It is doubtful whether this combination of two batteries would give a very much stronger current than either one used alone, because the junction of different kinds of cells is apt to complicate the electro-chemical action in each, and the result of their combined effect is disadvantageous.

was interrupted by the falling out of two steel needles; then two zinc needles were inserted into the tongue and a third in the lower jaw; six electro-negative steel needles were arranged in a circle at various points, each receiving the current for a period of fifteen to thirty seconds; when this had continued for three minutes and a half, the sitting was interrupted by the cessation of action in the battery. Then a battery of thirty-three Smee-cells was employed, and with this current a long and curved zinc needle was inserted into the tongue, and another similar needle of the opposite pole was thrust into the floor of the mouth, during six minutes. This was followed by a cessation of the pain, and afterwards sloughing ensued. As there was some induration remaining, a second sitting was required during which two zinc needles were inserted for an hour at three different points; a battery surface varying from fifty to two hundred square inches was used. The size of the glands decreased, but a relapse recurred which required another sitting; at this third sitting two zinc needle-electrodes were used for twenty-seven minutes, the negative being inserted at three different points, and the positive being held firmly fixed in the tissue. This was removed afterwards in the evening by gentle rotation. At the fourth sitting, which lasted seventeen minutes, for the treatment of some nodules which had appeared near the lower jaw, the same plan was followed, after which granulation and cicatrization occurred; this was, however, followed by another relapse in three weeks. The patient very naturally refused to submit to any further use of the strong currents, so that only those of a weak character were employed with the hope of retarding the rapid advance. The final result is not stated.

14. A case of scirrhus which involved both mammary glands, and which was accompanied by swollen glands in the axilla; on the left side there was a disseminated mass (lenticular) which included also the skin. The first three sittings were occupied by the employment of the surface contact, without any electro-puncture, using weak currents with moist electrodes. Then in a series of frequent and consecutive sittings, the cancer of the right breast and the adjacent nodules were destroyed by the electro-puncture. No anæsthesia was used because only weak currents were employed. After the sloughs had separated, cicatrization was hastened by dusting the surface with fresh gypsum. Though during this time the tumor on the left side did not progress, death occurred six months later from the disease.

15. A case of cancer nodules in a cicatrix from an amputated breast; in this case one zinc needle was inserted in the nodule of the mammary cicatrix, and three steel needles in the nodule in the axillary region. A Frommhold battery was used, having a square surface of one hundred square inches, for one sitting of fifty-eight minutes. Both of the nodules were destroyed. The only distress shown by the patient appeared to be chiefly from fright.

16. In another case, an extensive cancer which included the uterus and vagina, the electro-puncture produced so much pain that the treatment was stopped, and the patient was discharged unimproved.

17. A case of extensive cancer in a man of fifty-two years of age, which was situated in the rectum and was surrounded with infiltrated tissue around the anus, and which extended two inches up the gut; no anæsthetic was used. Electrolysis of the external growth was accomplished by the current from a Frommhold battery which had a surface of ninety square inches, the treatment being continued for forty- two minutes. Immediately afterwards a number of electro-negative needles were used, instead of the one which was employed at the first sitting, during forty-two minutes; this treatment was followed by the relief of the previousy existing great pain, and his sleep and appetite returned; the offensive odor of the discharges was also much lessened. At the second sitting, which lasted for thirty-three minutes, a larger Frommhold battery was used having a surface of one hundred and thirty to one hundred and sixty square inches, with the insertion of electro-positive zinc needles, the puncture was made through the base of the rectal tumor, and parallel to it. Half an inch apart from these, electro-negative steel needles were inserted, removed, and reinserted, into the tumor, until the whole circumference of the mass was completely destroyed. Subsequently, an old-fashioned brass electrical conductor was placed in the rectum and an electro-positive zinc needle was inserted into the anal tissue; this was accompanied by a great deal of pain, but the patient was discharged cured.

These seventeen cases of cancer treated by Gröh are presented in all their details, for the purpose of illustrating the destructive action of currents, having high tension, acting as a mild thermo-cautery upon cancerous tumors. The attention of the reader is again called to what has been previously mentioned in this book, that electrolysis is liable to increase inflammatory action, especially the suppurative processes, which may have already been established. Consequently it is not desirable to attack such a diseased condition with electro-puncture, unless this be used to separate the healthy from cancerous tissue. If these and the other cases be examined with especial reference to this view of the matter, it would seem as if the local inflammatory condition would act as a contra-indication to the use of electrolysis in such cases. It is, moreover, doubtful if the use of weak currents will cause the destruction of cancers, which are undergoing a process of inflammation and suppuration. This part of our subject has been so particularly discussed in the chapter on the action of electrolysis of the tissues, that it is hardly worth while to mention it further in this place.

Gröh in the work from which we have so largely quoted proceeds to a report of the practical effects of weak currents. Their long-continued action, in his opinion, produces startling results. He recommends the use of the Daniell's cell for obtaining a constant action of electricity with weak currents. This cell has been described in chapter third, in which its electro-motive force was stated to be about one volt, or two-thirds of that furnished by the Leclanché, or one-half of that furnished by the Grove's on an open circuit. The chloride of silver cell would, however, supply the same amount of electromotive force, and though its internal resistance is high, about seven ohms, this would not be of much account in reference to the very high resistance which the human body presents in the external circuit. As but few cells are required to produce weak currents the transportation of the Daniell's cells need not deter their use in this object. It should be remembered that, to obtain any chemical or physical effects on the living tissues from the continued use of weak currents, the action of the battery should be maintained at a constant point. The electrodes should be of such a kind as could be easily handled by the patient himself, and which would not easily get out of order. The advantage according to Gröh to be derived from the use of weak currents:—

1. That of avoiding the expense to the patient of frequent consultations at the physician's office.

2. The avoidance of the pain which accompanies the use of currents of high tension and of great power.

3. That many diseases may be subjected to the slow action of a weak chemical current, which would otherwise not receive any treatment, except at great expense or with great pain.

Gröh first attempted this method in 1851 for the cure of varicose ulcers. He reports three cases treated in this way:—

1. Myxo-sarcoma in a man of thirty-two years of age. This was situated in the left leg and was in size equal to a child's head. There was suppuration and hemorrhage from two points of the ulcer. The tumor was very painful and the patient was much reduced; the ulcer covered an extent of two and a half inches in one direction by four inches in another, and was twelve inches in circumference. Heroic treatment was thought to be contra-indicated on account of the patient's weak condition. A Daniell's battery of six cells was suggested, and for rheophores, or conductors, insulated copper wires which ended in spirals of thick copper (about two millimetres thick) measuring three cent. in diameter. The two ulcers were filled with zinc filings and the copper discs placed in contact with these filings and then covered with more filings; then each ulcer received the current from the Daniell's battery; a moderate burning sensation was experienced which soon disappeared on closing the circuit; the current was continued constantly for twenty-four hours. There was then found on the electrode connected with the zinc pole of the battery (positive) at the end of this period a reddish-brown froth; the other (negative) electrode was dry; on removing the filings of the latter a horny white slough was noticed; on removing the zinc electrode the cavity appeared black but was not sensitive; the copper disc was almost eaten through. On the next day the electrodes were applied in the inverse order; twenty-four hours later the conditions of the ulcers were reversed. On the third day the middle of the tumor appeared to be destroyed, and the general condition of the patient was much improved. At the fourth visit electro-puncture was employed, the electro-positive at the lower and the electro-negative at the upper part of the varicose swelling; the pain from these punctures was so considerable that the number of the cells was decreased to four. The slow action of electrolysis was then resumed for twenty-four hours, as before. When, at the end of this period, the electrodes were removed, there appeared at each of them about one and a half inches of slough, together with, at the positive, a greenish-grey froth, and at the negative, a greyish-white firmer tissue. The appearance was that of an excavated ulcer. The slow method of electrolysis was again repeated until the swelling was entirely gone. The patient was discharged with this ulcer nearly healed. Gröh remarks that this treatment took fifteen days and was apparently attended with no discomfort to the patient.

2. Osteo-sarcoma in the right thigh of a woman of twenty-two years of age. This tumor was larger than a child's head and was situated on the

outer side and on the lower third of the thigh; it measured three and three-quarter inches on the vertical line and five inches transversely. This patient was very much reduced by hemorrhage and suppuration. Nine fine and seven thicker needles were thrust into the tumor to a depth of over two inches; the thicker needles which were introduced from below upwards, were connected with the positive for the purposes of providing for corrosion, and the fine needles, as the negative, were inserted into the upper portion. The tumor was destroyed in three days, but did not heal for three and a half months. The tumor showed no tendency to reform, but an annular ulcer with healthy granulations remained, which was two and a half inches in diameter.

3. A case of a cancerous nodule which formed to the size of a hazel nut in the cicatrix of an amputated breast. As in the other cases of electrolysis four fine electro-positive and six thicker electro-negative needles destroyed this nodule, and in half an hour's time.

A careful examination of these last three cases reported by Gröh will show that the local action of a weak current of electricity will accomplish a destruction of tissue with as much facility as the stronger currents, though the action must be longer maintained. It is perfectly comprehensible in view of the original truths laid down by the physicists, who have declared and confirmed by experiments that the electro-chemical action in a galvanic cell will develop an equal amount of chemical action in the external circuit, provided this circuit be formed of chemical compounds in solution in this circuit; the resistance in the circuit can only affect the result by weakening the current, and, in consequence, the original electro-chemical action in the battery. It is rather a matter for regret that Gröh did not record the measurement of the currents actually used by him in each case; this would furnish a basis upon which other operators could compare their experience with his. His report was, however, presented in 1871, when the matter of measurements of currents was not so much in vogue.

Gröh reports four cases of sarcomata which he treated by electrolysis; all of these were successfully destroyed.

1. A case of myxo-sarcoma,

2. And a case of melano-sarcoma, both of which were cured in sittings of fifteen minutes each.

3. Sarcomatous epulis, excrescence on the gum, of the size of a hazel nut; this was electrolyzed by two positive zinc and one negative steel needle.

One sitting effected only a temporary cure, as the excrescence recurred four months later, the patient having complained of being sensitive to draughts of air during this interval. The size of the tumor had meanwhile increased. Thirty-three Smee cells were then added to the previously used Frommhold battery, thus giving an area of four hundred square inches of surface. In this second sitting the whole mass was destroyed in seven minutes, the excrescence sloughing off with a thin lamella of bone.

4. A case of fibro-sarcoma in the nose which had developed from the nasal septum and from the wall of the left nasal cavity. This case, which was in a girl of sixteen years of age, was temporarily cured in one sitting; but it recurred nine months later and was then permanently destroyed in a sitting of five minutes' duration by the use of platinum needles used as electrodes. There was no further recurrence in this case.

Gröh reports two cases of lupus which were successfully treated by electrolysis.

1. The lupus in this case covered the space of a square inch on the upper lip; the electro-positive zinc needle and seven steel electro-negative needles, was connected with, at first, ten, afterwards with thirty-two cells. These needles were arranged around the circumference of the ulcerating surface at one sitting of nine minutes, and they were separated three lines apart. This sufficed for a cure.

2. This case, in a boy of fourteen years, involved the upper lip and nose. Six electro-negative needles were inserted into the mass, separated two lines apart, the positive electrode being formed by a wet sponge. The lupus was punctured again and again, the needles remaining in the same place for twenty seconds. The diseased growth was destroyed in twelve minutes; after two weeks had elapsed only a few small hard knots remained at the periphery. This case was reported cured.

A few cases have been reported where electrolysis has been used for inciting a healthy growth over a suppurating surface. In these cases care should invariably be exercised to use the current only for a very few moments at a sitting; and it would seem advisable, even then, to employ this treatment only in those cases where the suppuration has been sufficiently prolonged to be called a chronic abscess, or only in those cases where there is a sinus or a fistulous tract.

1. A case of anal fistula in a woman of twenty-three years of age. This fistula dated from four years before, and after her confinement; the

pain was so troublesome that it prevented sleep; forcible dilatation had never been tried. The patient reported that many kinds of cauterization had been tried, but that all had failed to relieve her. Ciniselli[1] made an examination and found an elliptical ulcer on the right margin of the anus, which was one and a half inches square; he performed an operation for a superficial galvanic cauterization lasting for three minutes, with a current strength of fifteen milliwebers (milliamperes?); in one week after this operation the patient reported that there had been a steady diminution of her pain, though this had not entirely disappeared; a tender cicatrix was then present. One week later the pain had completely ceased and the cicatrization was perfect.

Tripier[2] reports the treatment by electrolysis in two cases of chronic abscesses of the axilla; the suppuration of these glands is often a very tedious affair, one after another undergoing inflammatory and suppurative processes. These abscesses were operated upon by his method of tubular cauterization, which has been previously described in this chapter, and cicatrization occurred within a few days. There was no return of the abscesses. He advises the use of this method in the so-called cold abscess, and especially in Pott's disease; he does not attempt in the latter to evacuate the contents of the abscess at one sitting, but to make of this "a means of treatment of the affection."

This same writer reports the beneficial results in improving the condition of an ulcer in the cervical canal of the uterus; also, for the enlargement of the calibre of this canal in a case in which it had become so obliterated that the uterine sound could not be passed. He recommends this method in the case of wens and in the opening of buboes, in the latter of which he endorses it as the best treatment. He advises the employment of electro-negative electrodes as the better pole for the introduction into lachrymal tumors and fistulas. This may also be used as a means of cauterizing the opening into the Eustachian tube, as also, some portions of this canal. He would recommend its employment for the removal of cutaneous tumors, and as well also in the dilatation of urethral strictures.

Tripier reports also a case of fistula in ano, which he treated by electrolysis. The details are thus given by this writer:—

Three months after the second labor of a young woman an abscess appeared at the right margin of the anus, and eleven months later she pre-

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[1] Op. cit.

[2] Op. cit., 1881.

sented herself for the treatment of a fistula, three centimeters (one inch) long, which communicated with the rectum; an olive-pointed sound was employed as the positive electrode with the hope of healing the opening of the fistula into the rectum, and it was therefore passed as far as possible within the tract, and the negative surface electrode was applied upon the skin of the thigh. A current strength of eight milliamperes was continued for ten minutes; an examination seven days later showed only a sero-purulent discharge without any admixture of fœcal matter; on this same day the procedure of the previous week was pursued; ten days later the fistula was in about the same condition, as also at an examination a fortnight later. Another application of the same current strength was tried for five minutes, and again one week afterwards for eight minutes; eleven days later the same strength of current was repeated for three minutes, the electrode being inserted to the depth of eight millimetres, and a month later to a depth of one centimeter. Frequent repetitions were made, but with apparently no further benefit to the patient, as she left for the country.

A comparison of this case of fistula, with the report on a previous page (p. 192), will show that Tripier did not employ a current of sufficient strength to obtain the cauterization by means of the positive pole (ACID), which is especially mentioned by Ciniselli as the proper method for the use of electrolysis in the repair of suppurative surfaces of long standing. It will be noticed that the current strength used by Tripier was only half of that used by Ciniselli, and in the cases reported by Gröh for the healing of indolent ulcers the current was even much stronger than that used by Ciniselli, or else was used for several hours' duration.

Before closing this chapter which has been devoted to the clinical applications of electrolysis, it should be mentioned that no allusion has been made to the action of the galvano-cautery, except as for comparison with the special subject of which this book treats, for the reason that:—

Galvano-cautery, like thermo-cautery, deals with the destruction of the tissue by a cutting edge; while electrolysis acts upon the tissue by disturbing the chemical or physiological integrity which maintains the composition of the structures of which these tissues are composed.

It probably has been noticed that Gröh employed zinc and steel electrodes for the destruction of the degenerative tissue of cancerous and similar growths. The effect of the contact of these metals, endowed with opposite polarities of electricity, appears to have produced very extensive destruction even in tissues in which the inflammatory and suppurative action had already existed. His experience is so different from that of other operators by this method of electrolysis, that his results may have been influenced by the materials of which the electro-needles were formed.

This subject will be more fully discussed in the final chapter, but it may be as well to anticipate the matter somewhat at this point.

The cataphoric action of electricity is very much more active when the metallic electrodes are formed of zinc for one terminal and platinum or steel for the opposite pole. This can be easily seen by making a comparative experiment with electrodes made from these different metals.

Gröh apparently is of the opinion that the zinc electrodes act as caustic destroyers of tissue by means of an alteration which is due to the chemical reaction of the zinc metal in presence of an acid at the positive electrode. In the experience of the author of this present treatise, it will make no difference in the destroying action upon living tissue, whether the zinc needle forms the positive or the negative terminal of the battery.[1] There is certainly no doubt that the use of zinc for its local contact with the abnormal tissue produces a stronger action upon these than if platinum or gold needles should be inserted. When the use of zinc electrodes is combined with the use of such strong currents as were employed by Gröh, the destructive action upon tissue may reasonably be supposed to be also very much increased. We very much doubt, however, whether it is correct to assume that the action is entirely due to a chemical cause. We have seen that the introduction of irritating medicinal agents into tumors may arrest for a time the increasing size of these growths, but experience has taught us that the arrested growth is only a temporary effect. Acetic acid, hydrochloric acid, caustic alkalies, gastric juice have all had their fashionable day of local treatment. It is difficult to believe that the local action of an "alterable electrode" should produce a destroying action which is explicable on chemical grounds. We must look farther for a proper explanation of the effect, because it can hardly be possible to discredit the successful results which this and a few other authors have reported so much in detail.

We may possibly obtain some inkling of the cause of the action of elec-

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[1] It should be understood that we are speaking only of those cases where both electrodes are used for electro-puncture, and not in those cases where one is used for surface application and the other for a puncture beneath the skin.

tricity in destroying the activity of living tissues by an examination into the cause which promotes their growth. The study of the enlargement of the thyroid body, and the growth of new hairs from their papillæ or from the adjacent connective tissue, offer a fair field, because the histological knowledge of their formation and development has received so serious attention by competent and faithful observers.

The next chapter may present some of the results of this study which will perhaps be useful in our present inquiry. It will treat of the various forms of goitrous tumors, their growth and natural retrocessions.

CHAPTER VIII.

THE APPLICATIONS OF ELECTROLYSIS TO BASEDOW'S, OR GRAVE'S DISEASE, COMMONLY CALLED EXOPHTHALMIC GOITRE.

Before describing the therapeutical application of electrolysis to the treatment of this disease, it would be well to pass in review the pathology of the different forms of goitre, in order to learn, if possible, what effect this kind of treatment will have in limiting and reducing the abnormal growth in this glandular enlargement. The author of this treatise will be pardoned if the description must necessarily occupy considerable space in the presentation of these details.

Exophthalmic Goitre, or Basedow's disease, is found to exist and to be recognized by the pronounced symptoms of anæmia, exophthalmos (protrusion of the eyeballs), palpitation, and very rapid action of the heart, and by an enlargement of the thyroid gland or body. This enlargement may involve either or both of its alæ, or wings (or bodies), as well as the isthmus which connects these two wings.

The pathological enlargement of the thyroid body[1] may be due to a hypertrophy of the thyroid body, to adenoma, to cystic adenoma, to carcinoma, and to sarcoma of the thyroid body. The hypertrophy of the thyroid may be formed by simple hypertrophy of the acini, or of the follicles in the gland, or by an increase in the normal contents of the glandular vesicles. These hypertrophies are distinguished from adenoma, from the fact that these latter are not seen in the embryonic tissue, and that the vesicles, which may be filled with colloid substance, are clearly defined by the vessels and connective tissue. Wölffler describes two varieties, parenchymatous and gelatinous hypertrophy, and states that these two forms may coexist.

Adenoma of the thyroid body is composed of epithelial neoplasms which originate from the embryonic glandular formations without typical vascularizations, which sometimes retain the embryonic conditions, and

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[1] Ueber die Entwicklung u. den Bau des Kopfes, A. Wölffler in die Archiv. f. klinischen Chirurgie, Band 29, p. 1 and 754, 1883.

sometimes are transformed into glandular tissue of normal appearance. Many of these tumors are congenital, while others may be developed during puberty or during pregnancy. They often attain an enormous size and are generally benignant; yet sometimes they give place to metastatic changes. It is sometimes impossible to differentiate between simple and cancerous hypertrophy. Wölffler describes several varieties of adenoma:—fœtal, interacinous, gelatinous or colloid goitre with two subdivisions;—myxomatous adenoma, and cylindro-cellular adenoma.

Cystic adenoma is divided into the inter-acinous cystic adenoma and the papillar cystic adenoma.

Carcinoma of the thyroid gland is met with under three forms: alveolar, which is the most common; epithelioma with cylinder cells; and epithelioma with pavement cells. These last, Wölffler thinks, are developed by including a portion of the external fold of the blastoderms in the gland.

Sarcomata are met with of several varieties:—sarcoma, angio-cavernous sarcoma with fusiform cells, a sarcoma with giant cells, an alveolar angio-cavernous sarcoma with trabeculæ of muscular fibres, and finally a sarcoma having round cells.

According to Orth[1] "Goitre, in the more restricted sense, comprises enlargements originating either in the glandular or interstitial tissues, or in the vessels. The first of these varieties is called parenchymatous or hyperplastic; though, in accordance with the more modern nomenclature, it should perhaps be classed among the adenomata, and consists in simple hyperplasia of the glandular alveoli. Its cut surface appears granular and of uniform brownish-red color. The most common form is called gelatinous or colloid, and is characterized by a dilatation and distention of the alveoli with a translucent yellowish or brownish substance, the collections of which project slightly above the level of the cut surface, and are larger in proportion as the process is more advanced. The entire gland may be affected, or only limited portions, which are usually surrounded by capsules of fibrous tissue. This is closely allied to the cystic form, also originating in the glandular alveoli, which are filled with a soft or even fluid substance, and are greatly dilated. These cysts may be the seat of hemorrhage, which imparts a brownish-red color to their contents:—hemorrhagic bronchocele.

The variety of bronchocele, which is characterized as fibrous or osseous,

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[1] Diagnosis of Pathological Anatomy, translated by F. C. Shattuck, G. K. Sabine, R. H. Fitz. Hurd and Houghton, Cambridge, 1878, p. 178.

originates and runs its course chiefly in the interstitial tissue, which becomes greatly increased in amount, and dense, gradually replacing the glandular elements more and more, and finally may become calcified. Any or all of the above-mentioned forms are often found in combination, and, in fact, scarcely any two bronchoceles are exactly alike.

We now come to the third variety, comprising those forms which originate in the vessels. These may be further subdivided into aneurismal and varicose bronchoceles, according as the dilatation is arterial or venous. The latter form is very apt to be combined with some one or more of the preceding forms. Amyloid bronchocele is the result of amyloid degeneration of the arteries, and may also occur in the form of encapsulated nodules."

Another writer[1] in a recent communication describes the normal anatomy of the thyroid gland. He also states that complete hypertrophy is rare; that the right lobe is oftener involved; and that the tumor may be attached to the remainder of the gland by a pedicle. Poland, Billroth and Pitha, say that this enlargement is never due to new development of thyroid tissue, but to hypertrophy of the tongue-like process, or to the remains of glandular cells. The tumor is chiefly found between the hyoid bone and the thyroid cartilage, on the side of the œsophagus. This latter is sometimes compressed by it, though not often; it may lie in front of the arch of the aorta, and has sometimes been mistaken for lymphatic enlargements (Albers). The surface may be smooth or lumpy, and the consistence of the interior structure often varies. The onset of the disease is obscure, the first symptom being an increase of the size of the gland; the progress is slow and painless, and the swelling increases by paroxysms which, in women, correspond to the menstrual periods and to that of pregnancy. Certain varieties, especially the colloid, possess an indefinite period of development. Others, as the fibroid, after reaching a certain stage, remain stationary. There is also much diversity as regards the form of goitre in the individual cases. Vascular goitre increases most rapidly (Nélaton). The cystic likewise increases rapidly, and also by paroxysmal growth; this latter is due to effusions of blood, spontaneously or not. Certain goitres remain stationary for life, others grow for a few years, and then undergo secondary degenerations. To these changes probably are to be referred the varieties described by Savoyen as hyper-

[1] Krishaber. Dict. Encycl. des Sciences Medicales, Art. Goitre, 4. s., ix., p. 489, 1883.

æmic and anæmic. All authorities recognize resolution as one of the natural modes of its termination. Fatty degeneration occurs and is followed by reabsorption. This latter mode occurred in a few cases of small dimensions, and were of apparent parenchymatous character.

A. Wölffler[1] states that congenital goitre is positively proven to occur both in the endemic and sporadic forms, both in man and animals, cattle, horse, goat, sheep, and dog. In all cases this form represents the anatomical basis of the pathology of the thyroid gland in the fœtal state. The temporary hyperæmia of the gland, which subsides a few days after birth, is to be excluded from the true goitre. The development of this form may occur very early in life, tumors of large size having been found with fœtuses in a very early state of development.[2] Some cases are forms of pure hypertrophy, others are telangiectasia (Mondini, Cammerer) or cystic. According to Friedreich, Boucher, Bednar, Bubbauer, Lœhlein, Adelmann, and Demme, this variety sometimes begins as a colloid infiltration; also as a fibroid (Demme); also as adenomatous (W. Mueller). While it is not proven that every case of goitre is embryological and that it only begins to develop between the ages of eight or fourteen to that of forty to sixty years of age, it seems probable that in many cases of adenomatous goitre the origin is embryological. Fœtal localized atrophy of the thyroid, and abnormalities of position of single or distinct parts, point to the conclusion that embryological pathology is not without significance in the development and formation of goitre. Hypertrophy of the thyroid is understood to be a multiplication of, and an increase in, the solid gland follicles or vesicles as regards their normal growth (not as regards embryonic development), or it may be consequent upon the increase of the normal contents of the vesicles. This form is commonly found to consist of hypertrophy of the parenchyma, or colloid infiltration, or both together. Wölffler has recently proved that the normal development of the gland vesicle is by destruction of the central cells of the gland mass or by endogenous nucleus-division. In hypertrophic goitre the growth is due to multiplication of the gland cells into gland masses and the change of the masses into vesicles, or by direct endogenous proliferation of the single gland cell. Its microscopical characters distinguish hypertrophic goitre from adenomatous, especially by the absence in the former of glandular

[1] Ueber die Entwickelung u. den Bau des Kropfes. Berlin, 1883.

[2] Cases Mondini, Nov. Comment. Acad. Sc. inst. Bononiensis, t. iii., 1829; Danyau, Gaz. d. Hop., p. 77, 1861; Virchow, Demme, Hecker.

structures of an embryonic character. We judge of this distinction by the conformation of the gland masses, whether atypically large and vascular, or long and much branched, or normally round gland masses. Hypertrophic goitre is not infrequently congenital; many mild cases are overlooked. Rokitansky considered this to be the only form, and thought that the other varieties were only degenerations. Neither he nor Virchow distinguished this from the adenomatous form. A pure example of gelatinous (colloid) hypertrophic goitre can hardly be found, as the specimens indicate either an adenomatous nature or an atrophic change.

Adenoma of the thyroid is an epithelial new formation developed from embryonic atypically vascular gland structure, pre-existing or as the metamorphosis of apparent normal tissue. It is often difficult to distinguish from true hypertrophic goitre, but yet distinctions do exist. This form may be congenital, or develop during pregnancy; and may grow so large as to produce danger of suffocation from compression of the air tubes. In this respect the largest cysto-adenomata are not so serious as the adenomata of puberty and pregnancy, which are succulent and rich in cells. Apparently benignant adenomata may become metastatic; many return after extirpation, but so slowly that a second operation is seldom demanded. This return confirms the fact that the smallest trace of thyroid tissue may not have been destroyed but continues to grow. In some adenomata, on the contrary, spontaneous retrogression occurs and the gland may afterwards again increase with future attacks. In a case of an oldish woman every pregnancy produced an increase in size. This was followed by decrease after delivery. On one occasion of increase, symptoms of suffocation demanded and compelled extirpation; the tumor showed the different stages of increase and decline (hemorrhages, cysts, fibroid degeneration, etc.) No positive distinction can be made between adenoma, carcinoma, and sarcoma, many transition forms occurring.

Fœtal adenoma develops with the embryonic thyroid, and later on retains its embryonic structure and undergoes all its stages of development. These tumors are the seats of capillary hemorrhages and of larger hæmatomata; also cavernous spaces and ampullary dilatation of the capillaries; the walls, however, are not lined with endothelium. Large areas of blood extravasation cause the tissues to assume a hyaline appearance, due to alterations of the effused blood, and this change produces an increased growth of the adenomatous mass.[1] This hyaline substance be-

[1] Ziegler, Path. Anatomie, Art. Metaplasiæ.

comes vascular and is the intermediate nutrition-apparatus of the adenomatous formation.

SUMMARY.—1. The fœtal adenomata develop, as a rule, at puberty from congenital deposits. 2. The size varies from that of a pin-point to that of a goose-egg. 3. Through lacunar vascularization, diffused or cir cumscribed apoplexies are common. 4. A cortical layer (capsule) is found but is not so evident as in other goitres. 5. A variety of descriptive terms can be applied to these tumors in their different stages and degenerations, *e.g.*, Adenoma fœt. vasculosum, acinosum, myxomatosum, fibrosum, angio-cavernosum, and papilliforme.

Gelatinous goitre (Adenoma gelatinosum) consists of larger or smaller new-formed, colloid-holding gland vesicles derived from embryronic elements. Unlike the fœtal adenoma this is not in the form of circumscribed nodules. The surface is smooth or rough; involving one lobe or the entire gland. This variety is usually called colloid goitre. The histological boundary of adenomatous goitre is hypertrophy; the two pass, however, into each other; in the opposite direction is medullary or alveolar carcinoma; between the two extremes lie different forms of adenomatous goitre, some of them growing to the size of a child's head. The gelatinous presents the following forms:—(1.) Interacinous, the most common form, which presents abundant proliferation of gland cells, between the gland vesicles; and as most of the class are benignant, many cases produce no inconvenience; their very slow growth depends upon the slight amount of vascularity. (2.) Cystic adenoma consists of cysts which may have the size of a lentil to that of an egg; these contain much gelatinous fluid. Unlike the last variety there is little proliferation in the septa of the follicles; the cell-walls are liable to fatty or colloid degeneration. The large cystic sacs are frequently the seat of glandular neoplasms (Rokitansky); these are exogenous or intra-acinous; they may be found both together or singly in a goitre. (3.) Adenoma which have a papillary proliferation of the limiting epithelium of the gland vesicles; the papillary excrescences are found normally in the dog and ape. This form constitutes the congenital goitre of the goat and calf. Papillary cysto-adenoma is more rare.

Adenoma myxomatosum (folliculare et tubulare). This has a structureless hyaline appearance, of basement tissue, which substance cannot be stained. It contains groups of gland cells of different sizes; it may present fibroid or calcareous degeneration in certain portions. The higher stages of development of this form of goitre may possess solid or hollow tubes, or projections. It belongs to the adenomatous group because of its well-marked embryonic tissues; it can attain considerable size and may occur in the young and old. Its glandular masses develop with the hyaline matrix and arise from the division of the nuclei of the gland cells. Its growth, as in the others, occurs at puberty, during the menstrual periods, or during pregnancy, and the rate of its growth depends upon the degree of vascularity; later when this becomes deficient the parts undergo the degenerations before mentioned. Increase of the blood supply is followed by increase of the solid gland masses and the proportionate diminution of the hyaline matrix. Finally the larger gland masses may liquify.

Adenoma cylindro-cellulare. He examined one specimen but without conclusive results. It is difficult to distinguish this form from carcinoma cylindro-cellulare, which latter, however, specially possesses papillary and dendritic vegetations, and the interstitial tissue is infiltrated with small cells. The preceding are the benignant forms of thyroid tumors; however prominent degenerations may appear it is not necessary for that reason to make them special forms of goitre. As regards vascular goitre (struma vasculosa, struma aneurysmatica, struma angio-cavernosa, struma pulsans), Lücke[1] has shown that capillaries, veins, or arteries may be permanently or only temporarily dilated, but that in all such cases there is a goitrous formation, and that the condition of the vessels does not constitute the disease. It cannot be determined whether all adenomata of the thyroid are of congenital origin; it is difficult to determine whether all embryonic structures date from their fœtal origin.

Malignant forms of goitre may be classed as follows:—

1. Malignant adenomata of the thyroid. 2. Carcinoma of the thyroid. 3. Fibroid tumors of the thyroid. A. There is no record of Fibroma in literature, but the author of the article referred to has seen one specimen. 4. A. Lipoma. B. Enchondroma; there is no recorded case; a few cases have been seen of osteo-enchondroma; true osteoma of the gland is doubtful. 5. Sarcoma. Wölffler reports cases of angio-cavernous and of giant-celled sarcoma, of alveolar angio-cavernous and of round-celled sarcoma. 6. Tuberculosis and syphilitic disease of the thyroid; a few of these cases are reported.

Hemorrhages occur in goitre in the growth, and not in the normal gland tissue; all except traumatic effusions, are due to results of the dis-

[1] Quoted by Billroth & Pitha, Handb. d. allg. u. spec. Chir., Bd. 3, abt. 1, 1875.

ease. They may be in the form of points, spots, or streaks; may be mistaken for inflammation owing to their dark-blood appearance; bleeding occurs much less rarely at one spot and which then diffuses. The areas of hemorrhage extend gradually at times; at others it occurs suddenly with symptoms of dyspnœa. In six reported cases where hemorrhages were present, no increase was noticed in the size of the tumor at periods of hemorrhage; all were women who had had the disease for years. Blood extravasations replace the medullary substance of the gland.

The rule is for the hemorrhages to be confined to the cortical layer; this is a thick capsule which sometimes itself contains medullary tissue. The resistance of this thick capsule prevents external rupture; this latter only occurs when the hemorrhage takes place in thin-walled cysts. It is often possible to shell out the gland from the capsule easily and without loss of blood; and at other times free bleeding is encountered in the case of normal parenchyma. The subsequent changes in the extravasation are the same as are found in other organs (fatty degeneration, Cohnheim's coagulation-necrosis). Hemorrhagic goitres in time become cystic. The hemorrhages produce more or less tissue-necrosis. If the extravasation be small, usually a regeneration of tissue takes place from the remains of the gland masses and the trabeculæ, the hemorrhagic spots changing to a structureless hyaline substance. In proportion to the excess of connnective tissue and small mass of parenchyma will the hemorrhage produce a cicatricial structure which in time becomes calcareous; thus the hyaline substance is the matrix for regenerative and degenerative changes. If the degeneration is extensive, the area of infarction is destroyed; the spaces or alveoli in these cases will then be full of blood corpuscles and fibrin meshes. The cortical layer may present evidences of inflammation (chronic). Finally what remains of the parenchyma is a fatty degeneration, a soft yellowish-white smeary mass. Not infrequently all of these changes are met with in the same case. Hemorrhage is caused by the exceeding thinness of the walls of the vessels, especially the veins. Fibroid degeneration, like hemorrhage, may be confined to a very small area or may be diffused; it increases with prolonged growth of the tumor, but is not rare in young and vascular adenomata. The form of degeneration is often radiate or stellar; this is due to the fact that in goitre the vitality and activity of the degenerative changes have (as it were) their nuclear centres in the gland masses. The fibroid change extends to the periphery along the interalveolar spaces. The hardest fibroid masses resemble cartilage, from which they are only to be distinguished by the microscope. Two forms exist:—(1), induration (diffused); (2), the circumscribed fibroid degeneration; the cartilage-like masses belong to the former. The second variety develops around an extravasation. Calcification is not rare; it is as frequent as the fibroid change; it exists in the form of lumps or sand. The larger pieces in the interlobular fibrous tissue form irregular masses, or stalactitic processes, or may have a gland-like aggregation; this change may also be confined to the gland cells and masses. This may be distinguished as acinous calcification, the other forms being the interacinous. Cases are recorded where each lobe was a chalk stone the size of a hen's egg or of a fist; in others the chalky deposit formed the cyst-wall. The jelly-like degeneration is probably the result of secretion; it occurs where active adenomatous proliferation has taken place. The number of the blood vessels is diminished. It seems most plausible to refer the struma gelatinosa to degenerative changes in a previously formed adenoma; an arrest of development occurring in the gland parenchyma and the limiting epithelium becomes flattened by the increase of the gelatinous substance. This explains how such goitres are borne without inconvenience. In parenchymatous goitre an atrophy and disappearance of the gland parenchyma takes place, and is accompanied by a transformation of the interacinous connective tissue into the gelatinous substance; the increase of the goitre at puberty and during pregnancy is due to increase of this substance which is at those times profusely secreted. Multilocular cystoma belong to parenchymatous atrophy, there being usually no further increase in the size of the gland. If the gelatinous (colloid) vesicles burst, the connective tissue presents a shining yellowish-brown appearance; a cystoma results, or, if diffused, a fibroid tissue. Large cysts may rupture through the skin or into the larynx or trachea (Bruchmann). The fibroid change is a reparative process.

Pathogenesis. In regard to the cause of this disease the opinion of authorities is at wide variance. The attention of the reader is especially directed to the article by Eulenberg in Ziemssen's Cyclopædia of Medicine for a synopsis of these authorities. Since his article was written further investigations and observations have been made, which may lend some assistance in establishing the theory of the formation of exophthalmic goitre. In the treatment by electrolysis it would be necessary, if we are to apply this in a rational manner, to know something of the causes which promote the growth of the tumor as well as the way in which the natural resources of the body affect its absorption. It is by no means certain that the tumor itself is the seat of the disease, nor can it be said with equal truth that the symptoms of the disease as shown by anæmia, irregular pulsations of the heart, or the protrusions of the eyes, will cause the appearance of the growth of the enlarged thyroid gland. There is a strong probability from the investigations of the most careful observers, that the cause of this disease will be found either in the central nervous system, the sympathetic ganglia, or in the nervous periphery which takes its origin from either or both of these.

The pathogenesis is important in the indications for electrolysis.

Filehne[1] is of the opinion that exophthalmic goitre is preceded by a paralysis of the thyroid vessels as well as those of the orbit, and that this is due to a functional or organic (pathotogic) paralysis of the fibres of the vagus nerve which innervate the heart; the latter cause would thus account for the irregular pulsations of the heart. According to this writer, the symptoms may be developed in rabbits after traumatic destruction of the anterior fourth portion of the corpora restiforma. For this purpose he used a knife formed of the galvano-cautery. Some of the chief symptoms, but not all, of exophthalmic goitre will be developed by this operation. Previous section of the sympathetic would not prevent the development of the exophthalmos in these animals; and the pupil was not influenced. When a slight increase of the thyroid gland was developed after this experiment, it was caused by an increased determination of blood to this organ.

Filehne concludes from his experiments:—1. That the disease can be produced by the paralysis of certain nerve-areas which pass through the medulla oblongata, and whose paths lie in the restiform bodies. 2. The exophthalmos and enlarged thyroid are both due to a dilatation of the blood vessels. 3. The rapid and irregular action of the heart by the disturbance of the inhibitory (suspension of the tonus) action of the vagus nerve. 4. From these three he makes the deduction, that the cause of the disease in man will be found in the study of pathological changes in the medulla and the vagus.

Symptomatology. Eulenburg and Van Dusch have observed that, after the disappearance of the exophthalmos, the symptoms of cardiac disturbance may remain. This discrepancy might be ascribed to the supposi-

[1] Zur Pathogenese d. Basedow'schen Krankheit., Sitzungsber. d. phys. M. Soc. u. Erlangen, 1878-9.

tion that the extreme anæmia, as well as the relaxation of the vascular and heart tonus may combine in preventing the proper filling of the blood vessels; consequently these symptoms will persist.

Lescaux[1] in a recent thesis quotes Jaccoud for his authority in assuming that palpitations are essential to constitute this disease. He states that in the opinion of G. Sée the palpitations always are present at some period; while Burls found these absent in four out of fifty cases; while Beni-Barde found these absent in two out of twenty cases.

With regard to the sequence of the symptoms in this disease:—on the authority of Stokes and of Jaccoud, the writer of this thesis claims that the palpitations occur first and the goitrous tumor subsequently; the ocular phenomena are referred to generally as occurring after the other two symptoms. Jaccoud positively infers that, from their subsequent appearance, these ocular symptoms are produced by a disturbance of the circulatory phenomena. On the other hand, the authority of Trousseau is adduced for the opinion that the palpitations are the first symptom which attract the attention of the patient. Bruck is credited with the opinion that the ocular symptoms occur first, and that many patients seek advice from the oculist first; while See states definitely that the ocular are the only symptoms at the beginning of the disease. Lescaux reports one case in which the ocular preceded the cardiac symptoms by an interval of five months; while in another case the goitre preceded the cardiac symptoms by an interval of ten months; he quotes the authority of Story for a case in which goitre and the exophthalmos occurred five years before any cardiac palpitation. He describes the character of these palpitations as follows:—Increase in intensity, often paroxysmal, with the progress of the disease; these paroxysms may occur during the night and awaken the patient; a very peculiar feature is their continuance during the interval between the paroxysms; and the frequency of these palpitations is greater than in cases which are due to other causes.

A comparison of the character of these palpitations shows that they closely resemble those which accompany an attack of cardiac thrombosis, or those which follow the section of the par vagum. When the patient has not previously been subjected to muscular exertion, or in the intervals of repose, the rate of the pulse may be as rapid as 100-120 beats per minute, even 140-150, and during a paroxysm its rate may be 200 or more; Beni-Barde reports the sphygmographic tracings in a case to have almost a

[1] Des pertubations cardiaques dans le goitre exophthalmiques, Paris, 1885.

continuous line; the force of the pulse is oftentimes greatly increased, but sometimes it is quite feeble. The subjective sensations may be so excessive that there is some basis for accepting Rendu's theory of an hyperæsthesia of the walls of the thorax. Some writers have questioned whether there could be a hypertrophied heart; this would explain the increased area of dullness over the region of the heart, as well as the increase in the arterial impulse. Lescaux would attribute the latter as due to the increased force of the cardiac pulsation, and the former as due to the exhaustion of the heart by the rapid action in palpitations. He states that he has made careful and daily observations, and has found that the area of dullness was smaller during the time when the arterial pulsations were the most energetic; consequently, he would infer that increased area of dullness noted at other times would be caused by the relaxation of the myocardium from fatigue. This same writer reports that there were bruits to be heard in one-half of his cases, and that these resembled those of valvular disease. These were nearly always systolic, soft or harsh, and were heard both at the base and apex, the point of preference for the basic murmur being at the second intercostal space (over pulmonary artery). These bruits resembled those which are usually associated with anæmia, but were louder. The murmur heard at the apex would, in his opinion, denote a relative insufficiency, which he attributed to cardiac dilatation. On the other hand, Stokes, Trousseau and Teissier attribute no particular significance to the systolic bruits, though there may be a diffused and non-localizable murmur. Durozier attributes this murmur to paralysis of the vaso-constrictor nerves, and states that it is produced in the coronary artery. Sée explains it as an incomplete action of the papillary muscles. Again we have a conflict of opinion in regard to the causation of the irregularity in the cardiac pulsations. Constantine Paul states that regularity in the heart's beat is the special function of the myocardium, which is not under the control of the nervous system, and consequently, the irregularity is always due to an affection of the myocardium. Sée thinks that the irregularity is caused frequently by valvular disease; Letulle (in a thesis) attributes the irregularity associated with this disease to some impairment of the vagus nerve and the ganglion of Ludwig. Asystolia (or that condition of incomplete contraction in which the ventricles do not free themselves of their received blood) may in fact occur independent of previous valvular disease; for in a patient of Trousseau's this occurred to a partial extent after a paroxysm which was accompanied with œdema of the legs and with ascites; the latter soon disappeared. Asystolia may be partial or complete in this disease. The post-mortem examinations show nearly all the well-known forms of cardiac disease.

Cardiac diseases apparently confer no immunity from exophthalmic goitre. Jaccoud at one time used to differentiate between his cases of goitre, those having cardiac complications and those without them; but latterly he has admitted a functional disturbance in those cases of apparent valvular disease which is associated with exophthalmos and goitre. Sée considers that there is always a basis for cardiac disease (whether organic or from a neurosis) in exophthalmic goitre; Stokes thinks this improbable on account of the frequency of cardiac diseases and the comparative rarity of exophthalmic goitre, and would prefer to consider that the cardiac complications in goitre are due to the prolonged functional disturbance. Rendu admits that organic cardiac disease frequently is associated with exophthalmic goitre, while Trousseau admits that this occurs only "in some rare instances" of very long standing, in which opinion both Lavareau and Teissier agree. Sée reports one case in which there was no increase in the blood pressure; in this instance, at least, the abnormal work of the heart was to the normal work as the ratio of the rate of the pulse in the two cases (120 to 200: 60 to 80). Enlargement of the capacity of the arterial system is frequently met with, and in these cases the enlargement of the arterioles is so great that a venous pulse will be heard independently of the tricuspid regurgitation.

Dilatation is more frequent than hypertrophy; this is supposed to be due to the fact that nutrition cannot keep pace with dis-assimilation on account of the rapid action of the heart, and consequently, its long continuance and exhaustion will cause myocardial dilatation. Occasionally its nutrition may keep in pace, and this theory would explain the comparatively few cases of increased area of cardiac dullness; probably, frequent respite from the hurried action of the heart-beats will explain why dilatation has not occurred in every case. If the theory of trophic centres in the heart is upheld, their impairment or immunity would affect this discussion. Beau cites a case of a man who met with a severe fright, which was immediately followed by palpitations and dyspnœa. Two months later he observed cyanosis of the lips, distension of the jugular veins, small and irregular pulse; the cardiac beats became irregular in rhythm and intensity; his dyspnœa increased on the slightest exertion and death occurred in three weeks. The autopsy showed a dilated heart, with no hypertrophy nor valvular disease. Other cases are on record where hypertrophy existed in some cases of disease of the upper portion of the spinal cord. Raynaud reports a case in which asystolia occurred in bulbar paralysis, and in which the autopsy showed an enormous dilatation of the heart, while the lungs and cardiac valves were perfectly normal.[1]

That the sympathetic plays an important rôle in the production of the phenomena of this disease is evident from a consideration of the principal symptoms; the cardiac disturbances, and the goitre and exophthalmos. The forcible heart-beats (Herzklopfen) indicate an irritation, while the goitre and exophthalmos apparently indicate those of an opposite nature (depression). To avoid this contradiction Benedikt supposes the goitre and exophthalmos to be due to excitation of vaso-dilator fibres, whose existence has been shown by Bernard, Ludwig, and Schiff. Eulenburg assumes a trophic centre alteration causing glandular hyperplasia and increase of the retro-bulbar connective tissue. A corroborative symptom is the immobility, or restrictive mobility, of the eyelids; this, in their opinion, is caused by the disturbed innervation of the smooth muscular fibres, which were discovered in the eyelids by H. Mueller; this has been shown to exist in some of the lighter cases of this disease, and was first described by Græfe; these fibres are innervated by the sympathetic. Another argument in support of this theory is shown from the satisfactory results in the cure of this disease by galvanization of the sympathetic in the cervical region.

In a thesis by P. Gros[2] a table is given of the comparative frequency of this disease in the two sexes.

FREQUENCY IN THE TWO SEXES.

	Male.	Female.
Cheadle	1	8
Taylor	—	25
Praël	1	9
Vithuisen	8	42
Græfe	1	7
Emmert	10	80
Hammond	—	11
Romberg and Henoch	3	24
Total	24	206

[1] M. Meyer. Ueber Galvanisation des Sympathicus bei der Basedow'schen Krankheit. Verhdlg. d. Berlin Med. Gesellsch., (1871-3) 1874, iv., pt. 1, 116.

[2] Etude sur le goitre exophthalmique, Paris.

In the same thesis of Letulle it is shown that the most frequent occurrence of this disease originates in the years between twenty and fifty; most of the exceptions to this rule originate after fifty years of age. It always attacks those who have neurotic temperaments. The principle predisposing causes are heredity; and this disease is apt to alternate with other nervous diseases. Rheumatism is a frequent antecedent. There seems to be a connection between goitre and chorea; the author quotes cases of exophthalmic goitre which have supervened upon the cure of chorea, and *vice versâ*. He also cites cases of various nervous affections which have alternated with this disease, both in the individual and in the family. He cites cases which show that the onset of the disease sometimes occurs suddenly. He describes the symptomatology very much as does Lescaux: the cardiac murmurs do not usually indicate organic disease of the heart. The appearance and progress of gòitre is very variable, sometimes proceeding rapidly and at other times slowly; the tumor may be confined to one side, which is usually the right. In its first stages the expanding movements of the tumor and its bruit are due to hyperæmia; subsequently these symptoms may be followed by "disorders of nutrition and indelible lesions."

NATURAL RETROCESSION. In an article written thirty years ago Bach[1] describes the following course of the natural retrocession of the goitrous tumor. After parenchymatous goitre has reached its maximum, three changes may take place in the enlarged thyroid gland:—(1.) Fatty degeneration. (2.) Osseous transformation. (3.) Calcareous degeneration.

In cystic goitre the wall of the cyst frequently undergoes cartilaginous or osseous degeneration.

According to a more recent writer the disappearance of the tumor will often occur without medical aid.[2]

In cases of struma hypertrophica the growth disappears spontaneously or under the influence of absorbent agents, such as iodine and potass. iodide. Spontaneous disappearance is established and is due to resorption into its constituent parts; hence this author claims that the morbid growth must be in solution, or be soluble and that it is not formed of organized tissue elements. Since neither suppuration nor calcification occur, nor

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[1] De l'anatomie pathologique des differentes espéces de goitre. Mem. de l'Acad. de Med. de Paris, 1855, pp. 338-466.

[2] K. Stoerck. Beitrag zur Heilung des Parenchym und Cystenkropfes. Erlangen, 1874.

any other degeneration, it must be supposed that some other unknown agency produces the change which is followed by absorption. Hundreds of cases demonstrate that this spontaneous resolution is harmless; it is therefore to be supposed that this resolution consists of a reabsorption of the colloid infiltration-substance. It is remarkable that this was doubted until recently. Röser and Virchow believe that the absorption is injurious to the organism of the body. Lebert also seems to think so. Thus, it will be seen that there is a natural tendency for the enlarged thyroid to disappear under the normal processes which reside in the living tissues.

SURGICAL ablation of the goitrous tumor by the knife has frequently been accomplished without causing the death of the patient. The operation is, however, a very bloody one, and is not unattended with risks to the life of the patient during its performance. Many of the reported cases[1] show the fatality of this operation. Julliard gives thirty-five cases, two of which died during the operation, two others from embolus and pneumonia, while the fifth died without ascertainable cause. The remaining twenty-six operations were followed with healing by first intention. Liebrecht reports three hundred and sixty-one cases which he gathered between the years 1850 to 1882, of which sixty-eight died, in two the result was not stated, in two the operation was not completed. This author finds that during the last few years the mortality has only been eight per cent.; out of 164 cases which he collected between 1877 and 1881 there were 140 cures and 24 deaths.

Rapin[2] bases his remarks upon the recent works by Reverdin, Kocher, and Julliard, and arrives at the following conclusions:—that there exists a cretinism which follows the ablation of the tumors, and which is characterized by a dullness of the intelligence and by an arrest of the animal development. This happens after the excision of the whole thyroid gland, especially when this operation has been performed during the period of adolescence, that is to say between five and twenty years of age. There is also observed, after these operations, muscular feebleness, bloating of the countenance, a chilliness and also a certain stupidity in the intellectual faculties, though to a slight extent. The integrity of the functions of the thyroid gland appears to have an important influence upon the normal development of the animal body, as well as upon that of the intellectual

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[1] Revue de chir., 11 aout, 1883. Bull. de l'Acad. de Med. de Belgique, nos. 3 et 4, 1883.

[2] Revue med. de la Suisse romande, iii. p. 413, juillet, 1883.

faculties during youth, and of the maintenance of these in adult life. Why may we not assume that the retardation in the development of the animal tissues may be explained by the interference with nutrition coincident with the anæmia? The proximate cause may still be explained by the alteration of the cell functions in the trophic centres, be these where they may.

EXOPHTHALMOS. Juler states[1] in regard to its cause that the eyes themselves are not enlarged, but are simply pushed forwards by the vascular distension of the fatty tissue at the back of the orbit. There is a venous stasis of this tissue, which causes it to become turgid like erectile tissue, a simile used by Graves himself. Though true hypertrophy of the retro-bulbar tissue is sometimes found, the eyeballs usually recede after death. He also refers to the loss of the association of movement between the upper lid and that of the globe, explaining this deficiency of co-ordination in Graves' disease as due to an interference with the action of the fibres of Mueller, which has been mentioned before in this chapter as being the opinion of many. Juler refers to a case reported by Cheadle in St. George's Hospital Reports, in which were found *post mortem* considerable dilatation of the capillaries of the medulla oblongata and upper portion of the spinal cord, but without atrophy or cellular lesions, thus showing simply *increased vascularization*. No lesions were found elsewhere, neither in the viscera nor in the cervical sympathetic. "The singular nervous sensibility, which is so early and constant a symptom, and which in some cases has even gone on to mania after the cure of both the exophthalmos and the goitre, would seem to point to the brain itself as the initial seat of the disease."

Stokes considered the whole disease as caused by anæmia; however, cases have occurred without any anæmia (Frissier), and many cases of anæmia have occurred without the goitre and without the exophthalmos.

The pathogenesis of Graves' disease has been described in the foregoing pages so especially in detail for a definite purpose. It has not been the writer's object to give a synopsis of the pathology simply as a matter of diagnosis of goitre, but in order to illustrate in the treatment of this disease the principles of the action of electrolysis in effecting a degenerative change of living tissue. The attention of the reader is particularly called to the subject of electrical osmosis and to experiments which have been

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[1] Handbook of Ophthalmic Science and Practice.

mentioned in a previous chapter (Chap. II.), in regard to the effect which electrolysis possesses of producing a decomposition in the chemical organic combinations. His attention is also called to a consideration of the modern teachings of the way in which the formation and multiplication of cells is accomplished in plant life (see Chap. V.). Professor Goodale has shown, as before referred to, that in the opinion of modern botanists the growth of vegetable cells takes place by segmentation, of proliferation, and by a thickening on the inside of the cell walls and, perhaps, by the deposition of new material on the inside of these walls, which have been previously stretched by the result of receiving more food supply from outside influences. The same principles govern, in a measure, the growth of cells in the animal life, and we have seen that certain pathologists explain the increase in the structure of the thyroid gland by a thickening of the connective tissue (in which the inter-acinous septum occupies more space than in the normal condition), and, perhaps, also, by the swelling of the acini themselves, and perhaps also, by the storing up in them of a degenerated colloid material. It will, moreover, be noticed that in both of these suppositions a large number of observers join in the assertion that the blood vessels which supply the thyroid with its nutrition are enlarged; that in consequence, this gland (or organ) receives a much larger amount of material from which it may build faster than it grows naturally; or else, we may suppose that the tissues are so crowded with blood that the materials of destruction accumulate more rapidly than they can be removed. Whichever of these hypotheses may be established, the fact remains that we may have a very large variety of forms of tissue which are recognized as goitre.

We have also seen that many observers unite in the statement that certain cases of goitre have spontaneously been reduced without treatment by a natural process of resorption, and some of these observers have supposed that the resorption has resulted from a diminution in the supply of blood to this thyroid body.

It is not necessary at this stage of the discussion to speak of the cause which it is believed the nervous centres, or their periphery, play in the regulation of the supply of blood to this gland. We are, at present, concerned with the subject of the alteration of tissue growth in its relation to pathological formations, as also to the physical effects of the so-called vital processes.

What are these so-called vital processes? Formerly it was supposed that the substances peculiar to the plant and animal kingdom possessed a different composition from that of the mineral kingdom. This supposition was based on the theory that organic bodies could not be formed by synthesis out of the elements. Since the time when that opinion prevailed, Wohler artificially prepared urea by synthesis (1828), and later still other organic bodies have been artificially prepared in the same manner, which are even of a much more complicated structure than the composition of urea. It was also, and until quite recently, considered that the chemical elements in the living body were subject to other laws than those of inanimate nature, and that structures of the living body were formed by the operation of "vital" forces, which behaved differently in living nature than in inorganic chemical compounds. Since the time when that opinion prevailed, successful experiments have demonstrated that even the lower orders of vegetable structures may be artificially prepared by use of chemical agencies, and the boundary line between organic and inorganic chemistry no longer exists; moreover, it is also difficult at the present time to state where the boundary line exists between structureless organic bodies and bodies of formed structure. It is well known that an organic substance, acyteline, can be formed in the presence of hydrogen between the pure carbon electrodes of the arc, which is produced by the passage of electricity, and that from this body a form of fat may be obtained from which alcohol may be made.

We have the authority of Professor M. Foster for the presumption that in all forms of living protoplasm, the proteid base is found upon analysis to have some carbo-hydrate and some kind of fat associated with it. We may, also upon his authority, state that protoplasm gives rise by metabolism to carbo-hydrates, fats and proteids, and the two former are probably formed out of the proteid food by the agency of some living tissue; while the result of the destructive changes is particularly represented, among other organic crystalline bodies, by urea. Mention has already been made in the previous pages that Drechsel has made by means of electrolysis this latter substance, and that it is highly probable that this same agency is at work in the living body in the formation of urea.

The chemical formations of the living tissues, of organic bodies having a peculiar structure in the form of functionally active cells, is now admitted to be influenced by the chemistry of the carbon compounds. Whatever may be the conception between organic and organized bodies, we know that different carbon compounds possess the power of assuming in the living organism an organized structure in the form of cells. We do not know what causes are at work which produce these results.

Some of the proteids are soluble in water and some are not; those which are soluble, the peptones excepted, are changed by heat.

Proteids are divided into various forms of albumin, among which may be mentioned the acid-albumin and the alkali-albumin, which are probably nothing more than solutions of the albumin in an acid or an alkali, but there is reason to suppose that in addition to their solution there is formed a combination with either reagent. Acid albumin is a serum-albumin which was soluble in water, or in a neutral fluid containing only a small amount of neutral salts, and which has afterwards become converted by a very weak acid into a substance insoluble in the neutral fluid.

There are substances contained in the proteids which differ from the albumins in not being soluble in water alone, but which require for their solution the presence of a small but appreciable amount of a neutral saline material like that of common salt. These are also soluble in dilute acids and alkalis, and in that case are changed into acid or alkali-albumin, unless these reagents are exceedingly dilute.

Paraglobulin, when in solution in dilute common salt, may be precipitated from this solution by the addition of a very extended dilution of acetic acid, but if the acid is strong, this precipitate will be converted into acid-albumin. Paraglobulin is insoluble in pure water which is free from oxygen, but if this gas be present, its solution readily takes place, and it may then be converted into an alkali-albumin from its solution by the presence of an alkali in the strength of over one per cent.

The proteids form the principal solid portions of the glandular tissues, and their chemical combination is composed (Hoppe-Seylès):

O.	H.	N.	C.	S.
from 20.9	6.9	15.2	51.5	0.3
to 23.5	to 7.3	to 17.0	to 54.5	to 2.0

It will thus be noticed that the proteids differ from urea [$(NH_2)_2CO$] containing very much more oxygen, carbon and nitrogen, as well as a small amount of sulphur. The urea is the simpler nitrogenous compound, and is, moreover, the result of the waste products of the tissues. Foster states that Pflueger "has called attention to the great energy of the cyanogen compounds, and has suggested that the functional metabolism of protoplasm by which energy is set free, may be compared to the conversion of the energetic unstable cyanogen compounds into the less energetic and more stable amides. In other words, ammonium cyanate is a type of the living, and urea of dead nitrogen, and the conversion of the former into the latter is an image of the essential change which takes place when a living proteid dies." We have no means of knowing exactly what occurs in a particular form of tissue when it loses its functional activity, nor do we knew what may arrest its power of making, out of protoplasm, other forms similar to that which itself possesses; we do know that the building of higher forms of organic compounds requires the presence of some latent energy, and that the decomposition of the higher organic bodies is attended with the evolution of energy. The hydration resulting from the formation of water by the combination of oxygen and hydrogen consumes energy. The functional activity of a cell requires the supply and expenditure of energy, and those which are most actively engaged in the performance of their functions require a more liberal supply of nutritive material by which they may accomplish their object. This nutritive material is, in general terms, blood, and that kind which is found in the arterial system. It has been found that, if the blood vessels which supply the enlarged thyroid body with this blood, be ligatured, while the recurrent veins be left patent, that in many instances the enlargement will become reduced.

Electrolysis Applied to Treatment of Goitre.

The inconveniences attending this mode of treatment do not recommend it to the surgeon, but their results from the capital operation may be used by us for a comparison with the treatment by electrolysis. This comparison will incline us to assume that a proper explanation of the benefits to be derived from the use of this form of electricity ought to lie in the effects of control of the nutrition of the tissues. It will be shown in some of the cases reported, especially those of Chvostek, that the surface application of the galvanic, or constant, current has been followed by a retrocession of the goitrous tumor, as well as by an improvement in the general symptoms; this has been so marked that many observers have advanced the theory that Grave's disease is either a lesion of the medulla oblongata, of the restiform bodies, or of an alteration in either the sympathetic nerve centres or in the vagus nerve. It would be difficult to explain the improvement which follows this mode of treatment in those cases where only the enlarged thyroid exists, in the absence of the other general symptoms which are more particularly associated with the nervous system. It is equally difficult to explain these latter symptoms as being caused by the local enlargement of the goitre. We have another means of learning something of the relation which exists between these two divisions, viz., that the use of certain medicinal agents, digitalis, veratrum viride, will produce no amelioration in the cardiac symptoms; and others, iron compounds, cod-liver oil, iodide of potassium, will not promote the same hema-poietic and reconstituent properties of the organism which usually accompany this disease which they will accomplish in other cases of anæmia; moreover, medicinal agents do not produce that improvement in the irritable nervous system, as they will do in those cases in which these same symptoms exist without the symptoms of this particular disease.

The inconsistencies which mark the causation of goitre and goitrous affections are too palpable to be overlooked, and show that the actual condition of our knowledge is far from being based on solid information. It is not so remarkable in consideration of the fact, that as yet physiologists have not solved the functions of the thyroid body; in fact, they have not even agreed as to whether this body is a gland or something else. It may be absurd to call it an organ which in some way or other presides over the function of nutrition, or a trophic centre. It is certainly true that the loss of this body is followed by disturbances in the nutritive function, and is often associated with derangement of the intellectual faculties. It has been noticed by careful observers that hypertrophy of this organ is accompanied by the same disturbances of nutrition and the production of intellectual deficiency. On the other hand, a case occurred in the author's experience, where the hypertrophy was on the left side, and yet the patient lived beyond the age of seventy years and suffered little discomfort from any other symptom than that of the increased size of the tumor.

The evidence seems to point to one fact which may be useful in settling an apparent obscurity:—the best treatment to relieve the general symptoms appears to be that which is directed to a reduction, not the entire ablation, of the enlarged goitre. It would seem as if it made little difference in what way this result is reached, whether by the natural means of retrocession, by electrolysis, by electrical catalysis (so called) by the use of external irritation from some stimulating medicinal agent, or by the incomplete ablation of the surgeon's knife. In India a well-known method of treatment, which is reputed as often successful, is pursued by the smearing of the cutaneous surface of the goitre with a strong iodine ointment; and the patient then obliged to lie on the back in the full sunshine, or in winter before a hot fire.

Other methods of treatment by the modern surgeons seem to be directed to the injection of stimulating medicinal agents, which are supposed to induce changes in the tissue growth within the capsule of the goitre. Some prefer the use of iodine hypodermically introduced (Mackenzie), and another (Agnew) has lately used carbolic acid similarly introduced.

The general constitutional treatment by the internal administration of iodide of potassium would appear to act, in the few cases in which it has been supposed to have had a curative effect, by an interstitial change of tissues and in the general condition of nutrition of the whole body.

T. Kocher[1] mentions the impropriety of the use of injections into some of the forms of tumor of the thyroid body, and illustrates the evil effects of this treatment. He shows that this injection of irritating substances into these tumors may be followed by the appearance of subsequent acute and chronic inflammatory, as well as suppurative, processes. He quotes the authority of Luecke for the advantage to be derived from these injections in cases of struma hyperplastica, in which connective tissue and follicular growth occur to the same extent. The treatment by injection is also recommended by Kocher in cases of struma fibrosa or calcarea (goitre); as also treatment by surgical extirpation. The two forms of struma fibrosa and calcarea, which exist either, as (1) diffuse hypertrophy or (2) tuberous hypertrophy, present great clinical but no anatomical differences, according to this author. The diffuse calls for the internal and local use of iodine, while the tuberous calls for the local use of iodine by injection. He is also of the opinion that the latter rarely reaches the size of a cherry without undergoing a softening, which is probably caused by disturbances in the vascular supply. The earliest changes are those which are the result of punctate or infiltrated hemorrhages or the encapsulation in cysts. He agrees with Virchow, however, that hemorrhages do cause cysts; these latter and their capsules are due to a cellular degeneration, or disintegration. An acute inflammation of the thyroid occurs only as the result of a predisposition, from which originates an anatomical change in the tissues. The most usual change of this kind is a hyperplasia with

[1] Zur Pathologie u. Therapie des Kropfs. Deutsch. Ztschr. f. Chirurg. u. Therap., 1873-4, p. 417.

thrombi; hemorrhages represent subsequent degenerations, such as those of a colloid or fatty character; the most common predisposing cause of these changes is that of tissue-necrosis. A rapid development of this predisposition is caused by traumatic irritation or in consequence of that produced by the injection of irritating substances in goitre.

Many observers believe this disease to be an affection of the sympathetic nervous system. Chvostek is inclined to the opinion that the seat of the lesion is in the medulla oblongata, and that it is either a functional neurosis or at most a lesion accompanied with only very slight anatomical alterations. The continued current has played a very important part in the treatment of goitre. Remak applied the constant current to the cervical sympathetic ganglia, and especially to that of the superior cervical. Friedrich thinks that galvanism of the cervical sympathetic and to the upper portion of the spinal cord is well worthy of more serious consideration. Von Dusch[1] reports a cure which followed the use of a constant current from a battery composed of ten to twenty Meidinger cells. In this case one electrode was applied to the inner border of the sterno-mastoid muscle and the other to the nape of the neck; this treatment was followed in a very short time by a reduction in the rate of the pulse, which fell in eight days from 130 to 70-64. Simultaneously with this improvement in the arterial circulation there was a decrease in the exophthalmos, and the patient enjoyed a quiet sleep. This improvement continued at the end of four months.

Luecke[2] mentions the obsolete method of the ligature of the afferent arteries of the goitre, especially that of the superior thyroid artery, which is condemned by Koenig. The method of the operation does not concern us in our present discussion, except on the principle which was involved: viz., that of interrupting the means of nutrition of the enlarged growth. The dangers of the operation for cutting off the blood supply by means of ligature of the arteries has too often resulted in serious, and not unfrequently, fatal hemorrhages, which have also sometimes been followed by other secondary and serious effects. Therefore this difficult operation has been supplanted at the hands of the later surgeons by the injection of tincture of iodine and of other irritating medicinal substances, or by the capital operation of extirpation; both of these methods have been pre-

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[1] Lehr. d. Herzkrankheiten, Leipzig, 1868.

[2] In Handbuch der allgemeinen u. speciellen Chirurgie, redigirt von Pitha u. Billroth. Stuttgart, 1880, Abschnitt iv., No. 4., p. 75.

viously discussed. The principle of the method of ligaturing the arterial supply seems to be based upon the interruption of the vascular supply to the hypertrophied tissue formation; its success would doubtless depend upon the degree to which this effect could be carried, without causing sufficient inflammatory action to counterbalance the benefit to be obtained from the slight disturbance originally incited. There can be no doubt that the action of electrolysis may accomplish the same object as in the treatment by these other means, whether it is supposed to be the result of the simple method of restraining the amount of blood supply, or whether it is supposed that some more subtle effect is produced in the prevention of the formation of cell growth, or whether it be supposed that the process of re-absorption of the already formed cell is encouraged. It will naturally be supposed by some of our readers that many of the attempts for the cure of an enlarged thyroid have been undertaken with a view to secure the absorption of the fluid material in the goitre; for upon this ground electrolysis has been attempted for the absorption of the fluid in hydrocele, as well as in varicocele; a careful examination of these latter reported cases would show that, though the absorption of the transuded fluid occurred at first, the transudation again took place subsequently, and that the first promise of the permanent cure was not always sustained. A comparison of those cases which are reported of successful treatment of goitre by electrolysis, whether by surface contact of moistened electrodes with the skin or by the method of electro-puncture, will show that the temporary cure within the growth has not been followed by a return of the goitre. This evidence would seem to prove, that the cure of the enlarged growth by electrolysis is brought about, not only by a reduction in the blood supply to the tissue, but also by some effect produced in these tissues themselves.

The chemical composition of the thyroid seems to be but little known to the best investigators in physiological chemistry. This may not be of much consequence in the light of our present enquiry; yet, because the treatment by electrolysis is naturally supposed by many physicians to be explained upon the ground of a pure chemical nature, it may be advisable to reproduce one of the later chemical investigations into the composition of the tissue of this "ductless gland":—

Bubnow of St. Petersburg,[1] after giving the views of various authors

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[1] Zeitschrift für phys. Chemie, Band viii., p. 1, 1881.

upon the composition of the thyroid gland, in which he shows the great divergence of these opinions, gives the results of his own researches. He subjected the substance of the gland to various chemical processes by which he found it was composed of xanthine, hypoxanthine, paralactic acid and other substances which he called by the name of thyreoprotine. To obtain this latter from the thyroid of a man, and from animals, the gland should be cut up into little pieces, and then washed with water until they are decolorized; then these pieces were treated by him with several washings of water containing 10 per cent. of sea salt; then a precipitate was formed by acetic acid, which represented the first thyreoprotine. The gland was then washed immediately with a cold solution of potassa, (1 per cent.) for an hour. The filtered solution was then precipitated by acetic acid, and this voluminous precipitate was his second thyreoprotine. Finally the solution was again washed with a solution of potassa, and the addition of acetic acid gave another voluminous precipitate. Thyreoprotine, which he thus obtained, when boiled with dilute sulphuric acid, did not furnish a substance capable of reducing the salts of copper.

The three precipitates thus obtained were washed with water and successively purified by alcohol, 80°, by ether, absolute alcohol, and dried in a vacuum. Their elementary composition is given by him as follows:—

	First Thyreoprotine.		Second Thyreoprotine.		Third Thyreoprotine.	
	Man.	Beef.	Man.	Beef.	Man.	Beef.
C.	49.53	49.36	50.27	50.20	49.15	49.27
H.	6.30	6.45	6.47	6.31	6.45	6.29
N.	15.90	16.04	15.80	16.90	16.68	16.68
S.	1.38	1.38	1.35	1.34	1.39	1.40
O.	26.89	26.77	26.11	26·02	26.33	26.36

Whether this chemical substance is a different form from that which is recognized in other tissues of the internal organs may not be easy to say; still, the elementary composition varies from that of the proteids as given by Hoppe-Seyler. It contains a little less carbon, very little less hydrogen, about the same amount of nitrogen, more oxygen and more sulphur. It is hardly probable that the action of electrolysis, whether accomplished by electro-puncture or by the method of surface application, may be explained as concerned with the organic chemical changes of the tissues in the thyroid body. It would be mere presumption to state exactly in what these changes consist; for we have no means of ascertaining what the natural chemical changes of any living tissue consist. We do know, however, that the use of electrolysis will accomplish the slow absorption of proliferous cell growth when it acts upon those portions of the human body which are visible to the eye--in warts and moles upon the skin—and that this may occur without the process of any inflammatory action. The induction of changes of tissues which are subcutaneous is certainly accomplished by the surface application of the ordinary moistened electrodes; this is shown in the cases of Chvostek, which are soon to be detailed. The experience furnished from most of the cases in which he caused the absorption of the goitrous affection, as well as in the cases of others who have successively accomplished the same effect, would show that it seems to make little difference in the result, whether the application is made at one particular point in the neck or head or at another, provided that one of the electrodes is placed over the skin upon the tumor; it has been also shown in a previous chapter that the electrical current will produce a transmission of its manifestations through a portion of the human body, whether the connection with the battery poles is made by surface contact or by subcutaneous needles; the only difference would seem to be, that the action in the former case is very much more slowly accomplished than in the method of electro-puncture. It has probably been noticed by the attentive reader in the detailed account given on a previous page, that the behavior of the proteid bodies, especially the paraglobulins, will vary in the presence of a very weak acid or alkali. It is fair to presume from this laboratory experience, that the use of very strong electrolytical currents (by which it has also been learned in the laboratory that the strength of acid or alkali collecting around the interpolar region is proportionally greater) may produce a different action than that of very weak currents. This may account for some of the conflicting reports presented by various writers.

It is stated by Erb,[1] that the cataphoric (electrical osmosis) action of electricity in its application to the removals of growths like those of goitre, has been overlooked by many writers; and we should not forget that, in the case of these enlargements of tissue growth which are attended with the presence of a very large proportion of saline and neutral solutions, and which are also accompanied with increased amount of blood, this action of the transference of these watery solutions may be followed by a very great increase of activity in the

[1] Handbook of Electro-Therapeutics.

promotion of metabolism, especially in those tissues included in the external circuit. It should be remembered that this transportation of liquid goes from the positive electrode to the negative, and that the empirical use of electricity tends to prove that the negative electrode should be applied to that portion of the tissues nearest to the growth whose absorption it is our object to accomplish; it is highly probable that this particular function of the current is adapted to the use of the surface application. Yet, in the latter method, there is not the same opportunity for the escape of the gaseous or watery products which result from the chemical decompositions, but in electro-puncture we can see the escape around the needle punctures of water and of gases.

It has been thought advisable to precede the detailed reports of cases of the treatment of goitre by electrolysis with this somewhat lengthy discussion of causes and effects both in the disease, as well as with the assumed explanation of the modus operandi of the natural and artificial curative agencies. It is hoped that their applications to the study of the clinical experience will show that this discussion has not been irrelative.

This cataphoric action of electricity deserves more than a passing word in relation to the subject of the treatment of simple goitre. This disease has been purposely selected as a typical application for the treatment by the so-called electrolysis, for we can readily understand that the basis of the effect must have a uniform action, which may be applied as a special therapeutical agency.

A simple vascular goitre results from a multiplication of the cell growth, and the latest and best authorities appear to be agreed upon the character of the growth. This growth is formed by segmentation of the nuclei. In another portion of this treatise the method of the segmentation of embryonic cells has been portrayed as that which is due to the endogenous segmentation of the nucleoli. Simultaneously with this segmentation, fibrillæ are thrust out in regularly defined figures, and this harmony of action is probably essential to the proliferation of new cells.

The increase of the enlarged thyroid body must be dependent for its growth upon the multiplication of these embryonic cells, because it is clearly shown in the preceding pages that a simple growth, like that observed in Basedow's disease, is in no way a neoformation. We must exclude from the curable tumor of exophthalmic goitre all those other forms of tumors of the thyroid region, whose pathological structure belong to the class of tumors the cell formation of which is not of the embryonic type.

It will be evident that any process of treatment which will prevent the multiplication of cells by their natural method of segmentation will, also, stop the increase of the enlargement of the thyroid tumor. The reverse must also be true. If electrolytical treatment can arrest sarcomatous or other malignant forms of tumors by application to them, it would be unreasonable to assume that its curative agency can be explained upon the simple process of a physical basis, which is antagonistic to that of the physiological process. It may be fairly assumed that a cancerous growth is one of a degenerative charater. The simple goitre is not a degenerative growth.

Now, it may be asked, in what way does electrolysis arrest the growth of this goitre by interfering with its cell proliferation? The answer to such a question lies in the reference to the chemical changes produced by this form of electrical force, but more especially to the physical effect of electrical osmosis. In our opinion the latter is the more important of the two effects. Let any one of our readers try this simple experiment, and he will be surprised at the magnitude of the result:—

Place a porous cup of pure water in a glass vessel, and observe that the level of the water in each vessel is as nearly as possible at the same height; then place two irido-platinum needles, which are connected with the negative pole of a battery, and two others, connected with the positive pole, in the outer vessel; let on the battery current from ten cells. In the course of one or two hours, according to the constancy and strength of the current, the water of the inner cell will rise to more than an inch higher level than that within the outer vessel (provided the diameter of the porous cup does not exceed an inch in measurement) and the level of the water in the latter will be correspondingly lowered from its original height.

The chemical action upon pure water from the action of electricity is very slight, if any. Yet, it will be observed that the ebullition in both vessels immediately around the metallic electrodes will be very active from the motion of the fluid and gaseous particles in the water.

No one, who has performed this simple experiment, can fail to realize that its application to the porous tissues within the body must be followed by correspondingly great disturbances in the movements of the fluids of the human tissues. It is very natural to conclude that the disturbances within these tissues must play havoc with the normal physiological changes which are essential to the proliferation of the cells.

CHAPTER IX.

TREATMENT OF EXOPHTHALMIC GOITRE BY THE METHOD OF ELECTROLYSIS, AND THE REPORTS OF CASES.

We will commence this chapter with the published reports of cases which have been treated by electrolysis.

Case I. (Eulenberg). This was of a woman; this patient was treated by the surface application of the electrodes by the method recommended by Chvostek, and with weak currents; the pulse rate was thus reduced from that of 108-130 down to 84-70; the force of the arterial impulse was much decreased in the carotid and radial arteries, and there was also a decided improvement in the subjective symptoms; since this case he has reported six others which were treated by the same method of galvanization of both sympathetics in the neck, either simultaneously or alternately; the application of the negative electrode was over the superior cervical ganglion, and was followed by an abatement in the force of the arterial beat, and an improvement in the symptoms connected with the nervous system. Eulenberg did not find that the employment of electro-puncture was followed with certain results.

Case VIII. (Chvostek). An unmarried woman, of nineteen years of age; menstruation ceased three or four years previously from "taking cold." The patient was quite anæmic, and had forcible cardiac pulsation with rapid but feeble pulse; the symptoms of chlorosis were very pronounced. The goitre and exophthalmos were of one year's standing; the protrusion of the right eyeball was so great that approximation of the lids failed by an extent of from one to two lines; the movements of this eyeball were particularly restricted. The lobe of the thyroid on the right side was equal to the size of a pear, that on the left side to the size of a plum. Chvostek applied by means of surface electrodes the use of weak currents for the duration of two or three minutes over the position of the cervical sympathetic ganglion on both sides; one electrode was either on the tumor, eyelids or submaxillary region; improvement in the general symptoms and the retrocession of the tumor began after the first few sittings. After the twentieth sitting the eyes could be entirely closed, and the goitrous tumor was much diminished; but the greatest improvement seemed to be in the general condition and in the color of the face. After fifty-two sittings the eyes had returned within their orbits, the tumor was greatly diminished in size; the menstruations, which had been absent four years nearly, returned for a period of six days, and were subsequently regular in their recurrence. No other treatment was pursued. The patient went home and died six or eight months later from over-exertion, which was probably induced by dancing all night.

Case IX. A married woman of thirty-eight years of age, who had seven children; four years after her last delivery she was the victim of extreme nervous irritability and anæmia; for the relief of these symptoms she resorted to some French baths, and considerably improved, although she did not completely recover. The Franco-Prussian war obliged her to return home, and during this time her previous symptoms recurred. An examination at this time showed the development of goitrous tumor and exophthalmos; the menses had also become scanty. The enlarged thyroid extended from the lower jaw to the clavicle and in shape resembled a pear elongated; the middle lobe was as large as a plum; she complained of distressing cardiac palpitations, 120-130 per minute. After twenty-four sittings the goitre was reduced to about one-third of its original size, the exophthalmos was also very much diminished and allowed the eyes to close with facility; the general condition was very much improved, the cardiac pulsations causing less distress. After seventy-two sittings there was a complete cure, no distressing palpitations, disappearance of nervous irritability and of the pre-existing exophthalmos; but the goitrous enlargement still remained.

Case X. A feeble, slightly built female servant, aged thirty, who commenced her menstruation at the age of fifteen, then became chlorotic and two years later had gastric fever; subsequently she was troubled with violent cardiac pulsations. An examination showed an enormous goitre on the right side, which measured eighteen centimeters in its transverse diameter, and exophthalmos; there was also a strong pulsation in the arteries and veins. The surface electrodes were placed one upon the eyes and the other on the tumor; the goitre and the exophthalmos underwent after a course of thirty-six sittings a diminution in size, but the cardiac symptoms persisted; the menstrual flow still remained scanty. The goitre and exophthalmos subsequently, after sixty sittings, disappeared; but the anæmia, violent cardiac pulsation and a pre-existing sleeplessness still remained.

CASE XI. An unmarried woman of the age of forty-six; this patient had been a sufferer for many years before with diseases of the abdominal viscera. A month after the use of the baths of Kreusnach, in 1870, she was attacked with pain in the head and about the cardiac region, which was also associated with a troublesome itching of the eyes and excessive lachrymal flow; these ocular symptoms were more marked with the right eye and were followed by a protrusion of the globe, which was continually increasing. These and other symptoms of a burning pain in the eyes and head were somewhat relieved by the use of bromide of potassium, except at the menstrual periods, at which time they became intense and were accompanied by a stiffness in the neck. Examination revealed a very marked exophthalmos of the right eye, the lids not approximating by the width of two or three lines, and those of the left eye by that of one or one and a half lines; the vision was frequently that of two superposed images, owing to a restricted movement of the downward mobility of the globe; there was no evidence of a goitrous tumor. A perceptible diminution of the exophthalmos occurred in fourteen days after the use of galvanism like that practised in the preceding cases, and the premenstrual pain was also diminished; some days before the period of menstruation the protrusion of the globe from its orbit was more pronounced, as well as the cardiac distress and the stiffness in the neck. There continued to be after eighty-four sittings a diminution of the peculiar ocular look, but there was no decrease in the pulse rate nor in the cardiac palpitations.[1]

These and other cases, in all amounting to the number of thirty, reported by Chvostek in detail as being subjected to the treatment of galvanism (surface contact of moistened electrodes in the cervical and the region of the malar protuberances) appear to have given credit to the opinion that this method, if continued for a sufficient length of time, will effect a cure of this disease which is now under our consideration. Chvostek's method was based on the supposition that exophthalmic goitre has its seat of lesion in the medulla oblongata or in the cervical and vagus nervous tissue, and that the ocular symptoms were caused by a

[1] These last four cases are reported by Chvostek in an article published in Die Therapie der Basedow'schen Krankheit. Zt'schr. f. Ther. mit Einbzhung der Elektro. u. Hydro-therapie, 1, '81-85.

disturbance of Mueller's fibres in the eyelid. Consequently he passed transverse and oblique currents for short periods of time, frequently repeated on succeeding days, through the head for the purpose of affecting the medulla oblongata, the cervical sympathetic and the vagus nerve; for this object he used very weak currents. He also passed the same kind of currents through the temples, from temple to orbits, and from the nape of the neck to the closed eyelids, for the relief of the exophthalmos; he does not venture to say, however, how much benefit has been derived from this mode of treatment.[1]

M. Meyer[2] has obtained remarkable results in the rapid diminution of exophthalmos and goitre by placing one electrode on the closed eyelids and the other over the submaxillary region; decreased frequency of pulse also has followed this treatment in his experience, as well as an improvement in the regularity of the cardiac pulsation. Others have passed the current over the cutaneous covering of the superior cervical ganglion and to the closed eyelids. Many of these cases, which were at first reported as improved at the date of the report, have since demonstrated a permanent cure.

Case XII.[3] A maiden lady of the age of thirty-two years, a native of Devonshire, presented herself for treatment of cystic goitre which had existed for about ten years. He inserted three needles into the cyst and passed a current through them from fifteen galvanic cells for ten minutes. This operation was repeated nine days later, and again fifteen days later. At the third sitting the size of the tumor was so much reduced that it was scarcely perceptible. On the twenty-sixth day after

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[1] Chvostek's method; an ascending current to the cervical sympathetic, each side, stabile, not longer than one minute, the negative pole being on the superior cervical ganglion; also an ascending current to the cord, the positive pole on the 5th dorsal vertebra, and the negative high up on the vertebral column; also through the occiput, one pole being placed on each mastoid process; also through temples, stabile, not longer than one minute and feeble currents; just sufficient to produce a sensation of burning; strong currents have not seldom been followed by patient's getting worse. At the height of the disease he has frequently seen a hyperæsthesia of the head (manifested by burning sensation with only one or two Siemen-Halske elements) which disappears as improvement takes place. He employs transverse galvanization of the temples for sleeplessness, physical irritability or great exophthalmus; also applies the stabile to the tumor with very weak cursents reversing every minute, daily sittings.

[2] Ueber die Galvanisirung des sympathicus in Basedow'schen Krankheit. Berl. Klin. Wœhenschr., 1872, No. 39.

[3] H. Campbell, Electro-Surgery, etc. W. Alexander, London, 1872.

the first sitting there was no remaining vestige other than a slight thickening of the integuments over the original seat of the disease, and which marked the former position of the sac; at this time no trace of the tumor could be discovered. A year later the tumor had not returned.

CASE XIII. (Idem.) A native of North Germany, but resident in London for many years. She was fifty-two years of age. This patient had a "bronchocele" which, by its pressure, gave rise to some very unpleasant symptoms. Six needles were inserted into the mass and were connected with a galvanic battery of fifteen couples, which were gradually increased to thirty, and the current was passed through them for twenty minutes. This same procedure was repeated weekly for two months, at the end of which period it had almost entirely disappeared, leaving the overlying skin wrinkled and shrivelled. Immediately after the commencement of the electro-punctures it grew softer and decreased in size week by week.

CASE XIV.[1] A man aged sixty-four, with a tumor of the neck of thirty years standing. This tumor was the size of a walnut one year before, but then began to enlarge, grow painful and at the time of examination it extended from behind and below the clavicle to the superior border of the thyroid cartilage. It was supposed to be a fibrous tumor of the right lobe of the thyroid body; its greatest diameter measured eight centimetres. Two platinum needles were used for electro-puncture with a current from five Bunsen cells with a surface area equal to nine square centimetres for each couple; one needle was connected with the opposite poles of the battery. The first sitting lasted for thirty minutes. The second sitting, ten days later, lasted for twenty minutes. The third sitting, eight days later, lasted fifteen minutes. The diminution in the size of the tumor commenced with the third sitting; the freedom of the movements of the neck and arm returned. The patient went off to his work as a mason with the tumor reduced to one quarter of its original size.

CASE XV.[2] A man of the age of sixty years with a moderate goitre was treated by the method of electro-puncture; a battery of twenty-five Frommhold's cells (lead and platinum) was used for fifteen minutes; subsequently, it was increased to thirty-two cells and this current was employed for two minutes; this treatment was followed by pain,

[1] Rouge, Bull. de la Suisse Rom., Lausanne, 1869, iii. 128. [2] Gröh, op. cit.

but the tumor began to flatten at either electrode, and it grew smaller at the end of a few days.

To these cases which are above reported may be added three which are mentioned in Beard and Rockwell's book on Medical and Surgical Electricity, as well as those which are referred to in the table in chapter seventh of this present treatise, making a total of about sixty cases cured by electricity.

In addition to the cases which have been published by others the author of this treatise has met with six cases in his private practice; two of these were supposed to be of the fibrous character and four of the vascular form. One of these was that of an elderly woman who had a fibrous tumor for several years; it was unilateral (left) and, as it was before the author had seriously turned his attention to any special treatment of this kind of disease, it never received any particular care; the case was under his observation for a number of years until the year before the patient died, and at this time he was absent from the country and consequently there was no post-mortem examination. The patient was a married woman and had rather a feeble amount of intellectual capacity, but otherwise than this she did not suffer any particular inconvenience from the large size of the tumor. Neither this case nor that of the other case of fibroid enlargement of the thyroid had any symptom of circulatory disturbance except that of æenemia and, possibly, a slight nervous irritability, one mark of which was a sleeplessness and neuralgia of the face and head. Of the other cases which were supposed to belong to the vascular type, stroma hyperplasia of some authors, two occurred so early in his professional career that they received only the then classical treatment of iodide of potassium and electrical treatment by the faradaic, or intermitting rapid changes of the poles from an induction-coil; neither of these two cases were in the least benefitted by either treatment, so far as could be determined.

The other four cases have been treated with great care and in the light of careful observation. Two of these received long-continued medication from iodide of potassium, but without any special benefit, and each of these was a case of fibrous hypertrophy and of vascular enlargement respectively. The first three cases being of no particular value in the matter of electrolytical application are not presented here.

Case I. A young girl of twenty years of age. In this case exophthalmos was the first symptom which attracted attention, and about a year afterwards the swelling of the thyroid gland with the attending symptoms of frequent and irregular action of the heart was noticed and led the patient to seek advice. With these symptoms there was a good deal of hysterical tendency as well as neuralgia, sleeplessness, lachrymation and a very pronounced anæmia. This latter symptom did not yield to ferruginous tonics or to iodide of potassium. This patient was so anxious for the relief of her symptoms that it was thought desirable to try the action of electrolysis. For this purpose the current from a dynamo-machine, which was arranged for low tension, was passed through a good sized gilded brass needle, which was insulated nearly to the tip with hard rubber and which was inserted into the tumor to the depth of a quarter to half an inch, and the positive electrode was either held in the hand or placed upon the skin in the cervical region; the weak current was continued twice a week during fifteen or twenty minutes for sixteen sittings. The improvement was not as great as could be wished, and, therefore, this mode of treatment was discontinued; however, after its discontinuance the patient was under observation, and at the end of three or four months, the eyes were very much less prominent, her color was improved and the tumor was reduced to half of its original size. It should be remarked that the strength of the current used in this case was very feeble in its chemical action, and yet, when connected with the needle, it caused considerable amount of pain. After each sitting the galvanic, and sometimes the faradaic current, was applied by means of moistened electrodes in contact with the skin over the region of the superior cervical ganglion and near the angle of the jaw.

Case II. This was a case of supposed vascular enlargment of the thyroid body, and was very carefully examined by Dr. J. C. Warren in the fall of 1884, as also during the progress of the treatment. This was, like the previous case, that of a young woman of about twenty years of age. The exophthalmos and the violent action in the arterial circulation were not, however, noticed until the appearance of the thyroid enlargement. The patient was anæmic, had inappetence, was emaciated, had fainting turns, was sleepless, and emotional (crying) on the least excitment; the catamenia were too frequent, but scanty. At the first visit a measurement around the neck at the upper margin of the goitre was equal to thirty-six centimeters. She was ordered to take daily doses of iodide of potassium to the amount of ten to twenty grains well diluted in water, and she went from Boston to her home in Nova Scotia for a three months visit. This patient had been a resident of Cambridge for several months before this consultation, and it was hoped that a change of air would benefit her general condition. On her return to Boston she reported that she had faithfully taken the iodide in the largest doses until the local effects of coryza had compelled her to reduce the daily dose to fifteen grains. The examination of the neck showed no improvement in the shape or size of the goitre, which measured thirty-six centimeters in circumference at the upper margin of the thyroid enlargement, thirty-nine at the middle, and forty at the lower margin. She then wore a collar of the size of sixteen. There was by means of palpation no evidence of any cysts, but it seemed that there was a general parenchymatous growth, which was firm and unyielding and incompressible. The two lobes were enlarged, the right rather more than the left, and the isthmus was quite distinctly marked. After a pretty thorough digital examination the skin would become reddened and the tumor would swell for several hours.

Dr. Warren had advised against an operation for extirpation of the gland. The treatment pursued was that by electro-puncture, and the battery selected was that of Gaiffe's modified small Leclanché of twenty-four cells, which has been described in Chapter III, in which the internal resistance measured about seven ohms, and the electromotive force of each cell was about 1.35 volts. These cells were arranged in twelve groups of two, so that each pair would give with no appreciable resistance in the external circuit about one-third of an ampère, and with the twelve double pairs, counting the particular resistance of this patient, a current strength equal to about fifteen milliampères. (It will be remembered that the milliampère unit is measured by the minute of time the current is passing.)

The needles used were made of gold wire .022, .015, .011, of an inch respectively. These electro-negative needles were inserted into the tumor to the depth of half an inch, and the circuit was closed by a carbon cylinder electrode (positive), which was moistened and held in the hand. The current strength was gradually increased until the whole power of the battery was in action, and was applied for twenty minutes duration. The pain of the electro-puncture was sharp but not unbearable, and soon gave way to a sense of numbness. The electro-punctures were repeated on the fifth, eighth, eleventh, fifteenth, nineteenth, twenty-second, thirty-sixth, thirty-ninth, forty-first, forty-fifth, fifty-first, fifty-fifth, fifth-ninth days and for the same duration of time and with the current strength.

During the continuance of this treatment the tumor gradually grew smaller and the protrusion of the globes disappeared, the circulatory disturbances were improved, but the anæmia and the nervous irritability still persisted. At the close of the fourteenth sitting the patient went back to her home in an improved condition, and under the use of iron tonics gained in health and strength and in color and weight. Six months after this time she reported herself as being perfectly well, that the tumor and other symptoms had entirely disappeared. She had been so much reduced in strength and was so anæmic before the treatment that after walking a very short distance she would become so short-breathed that she was obliged to rest; this symptom had also disappeared. The annexed illus-

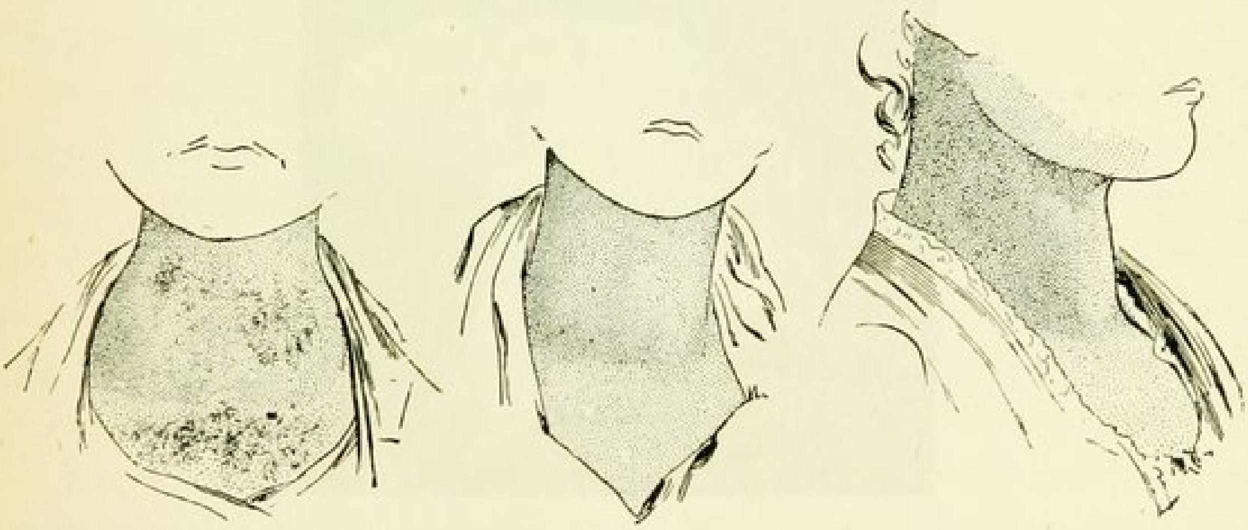

Fig. 29.

trations, which are photo-lithographed from her photograph, present a good idea of her appearance before, and after, the treatment by electrolysis. She was so much impresssed with the results of her cure that she sent me the next case from her town, which is under treatment at the present time of writing.

Case III. This patient was born and resides in a town in Nova Scotia, and is twenty-nine years of age, unmarried. Twelve years ago, Jan., 1874, she had a choking sensation and a sense of fullness in the throat, which the "doctors told her at that time was imaginary." About two years ago (1884) when living in Boston she noticed a small swelling in the centre of her throat; since then it has grown to the present size (see Figure); at that same time she noticed a projection of the eyeballs, difficulty in swallowing, nervous irritability, dyspnæa irregular and too frequent catemenia, which were never less often than once in four weeks and during the last two years as often as once in every two weeks, tumultuous action of the heart and especially after the slightest exertion; in short, the history of the symptoms familiarly known to us under the name of exophthalmic goitre. An aunt, still living, has had a similar swelling in her throat for thirty years, which is much smaller than that of this patient, but with none of the other attending symptoms. She knows of no other member of her family who has had a similar tumor.

This patient presented the appearance of a tall and rather thin woman with a long neck. The goitre is very marked and was about the size and shape of a large Florida orange. It was quite symmetrical and evidently involved the isthmus and portions of the two lobes of the thyroid body.

FIG. 30.—This photo-lithograph was reproduced from a photograph taken at this first visit (Jan. 28).

There was no sense of fluctuation or appearance of cysts, and the swelling was firm and unyielding to compression; the tumor was freely movable on manipulation. The size of the two alæ measured respectively four centimetres in transverse diameters, and five centimetres in the vertical axis, making the combined goitre, including the isthmus, about twelve centimetres in its transverse measurement and five in the vertical line. It was somewhat difficult to take accurate measurements on account of the blending of the margins of the tissue of the tumor with the adjacent softer tissues, thus making the boundary ill defined to tactile sensation. The circumference around the whole neck measured thirty-five centimetres.

First sitting (Jan. 28, 1886); the electro-negative needle was inserted only just through the skin and connected with a weak current, about one milliampère,[1] because the patient was tired with a long railway journey and was somewhat apprehensive of the "electric shock."

Second sitting, four days later. The largest sized electro-needle was inserted into the right half of the goitre to the depth of half an inch, and was connected as negative with a current of about three milliampères' strength, the circuit being closed with a carbon cylinder moistened elec trode (positive) held in the hand; the circuit was kept closed for ten minutes, and then another electro-negative needle (also gold) was inserted for ten minutes longer, the current thus passing through one needle for twenty and through both for ten minutes; the total amount of current used at this sitting would be therefore equal to sixty milliampères, which would have the electro-chemical power of decomposing the equivalent of about 620 c.m.m. of the combined gases which combine to form water. This half of the goitre became softer and reduced in volume; the circumference of the whole neck measured thirty-four centimetres.

Third sitting (two days later). The same method of treatment as in the previous sittings, but three needles were inserted and a weaker current (only one milliampère) was used for the same length of time. Consequently, the whole amount of current at this sitting would be equal to twenty milliampères. The puncture at this sitting was made into the left lobe of the thyroid. The battery in use was the cylinder cell which is described at length in the third chapter.

Fourth sitting (two days later). The skin of the neck is somewhat shrivelled from the shrinking of the thyroid enlargement; the exophthalmos is also less pronounced; the patient is less nervous and sleeps more and can lie lower in bed without the previous sensation of suffocation; the tumor is much softer to palpation and there is no appearance of cutaneous inflammation around the needle punctures. Three gold needles were inserted as before, to the depth of half an inch below the skin, on the lower margin of the tumor; a gradually increasing strength of current was passed through these as negative, the circuit being closed as in the previous sittings by a moistened electrode. The strongest current used was equal to fourteen milliampères, and the whole sitting lasted twenty minutes; the total amount of current used for this application was equal to 280 milliampères. The resistance of this patient's body amounted to 2000 ohms, and after the sitting the current from the same number of cells passing through this same resistance was tested by a water voltameter

[1] The current should always be measured with the total resistance in circuit.

for twenty minutes' time; this was for the purpose of comparing the measurement with that of the galvanometer used during the time of the operation; this test showed that any error of current strength, if any, was very trivial. After the conclusion of the electrolysis the tumor measured eleven centimetres in the transverse diameter and in the vertical line, on right lobe four and three-quarters centimetres, and on left lobe four and a half centimetres.

Fifth sitting (six days later). The three smallest needles of those which are described on a previous page (page 232) were thrust into the left lobe of the thyroid to the depth of a quarter, three-quarters, and seven-eighths of an inch, respectively; a current of a strength equal to forty milliampères was passed through these, the positive being a moistened surface electrode. The tumor at this time had become so soft that the needles could be inserted with the greatest facility. The duration of this sitting was twenty minutes.

Sixth sitting (two days later). The tumor before this sitting measured in transverse diameter ten centimetres and in the vertical line three and three-quarters centimetres. A photograph taken of the profile of the tumor at this time was compared with one which had been taken on the first visit; the comparison showed a diminution in the depth of the enlargement of at least two millimetres and the size of the width and height of the tumor had been very much decreased. The strength of current used at this sitting was equal to two milliampères and was applied during fifteen minutes through the electro-negative needles, which were inserted to the depth of half an inch; afterwards compared with the water voltameter with a resistance in the external circuit equal to that of this patient the total current would be equal to thirty-three milliampères.

Seventh sitting (four days later). The tumor had now become still more softened and was easily compressed by palpation. There was so little depth to the enlargement that the fine needles were inserted at about a quarter of an inch below the surface of the skin and parallel to it; the entrance was made on the right margin of the tumor and at the outer border of the sterno-mastoid muscle, and just above the clavicle, and were pushed nearly to the median line into the isthmus. A current strength of two milliampères only was used, and the application was continued for fifteen minutes. During the continuance of the passage of the current, the tumor would almost entirely disappear, and at the close of the sitting what remained of it was very soft and almost diffluent.

Eighth sitting (two days later). The tumor is still very soft and compressible and is smaller and thinner; the exophthalmos has been reduced to a very remarkable degree, and the circulatory and emotional symptoms are scarcely noticeable to the patient; the dyspnœa is so much less that the patient had almost forgotten that she had complained of it. The same treatment by the electro-punctures was repeated, but with very much stronger strength of current equal to seven milliampères; the total amount used at this sitting would be equal to 200 milliampères.

Ninth sitting (six days later). The same strength and amount of current was employed as at the last sitting, and the boiling and escape of the gases resulting from the intense chemical and physical action was very strong. A photograph, which was taken at this visit and compared with that taken before the sixth sitting, showed a still further decrease both in the size of the tumor and in exophthalmos. The tumultuous and irregular action of the cardiac pulsation was very much diminished.

Tenth, eleventh and twelfth sittings (at intervals of five or six days). The current strength used at these sittings was much increased by the use of hot salt water on the moistened positive electrodes; the consequence was an increase in the amount of pain caused by the action; this was followed by signs of local inflammation and by a slight œdematous infiltration of the skin accompanied with tenderness; these would subside in four or five days. The eschars produced by the punctures were much larger than when the weaker current had been used. The scars of the first punctures had all entirely healed, leaving only red marks which were on a level with the skin, and not pitted. The sittings were then intermitted for two weeks.

Thirteenth sitting (fourteen days later). No treatment since the previous report. Photographs were taken, and, on comparison with that taken on the ninth sitting, showed very little, if any, diminution in the size and extent of the tumor. This was supposed to have been caused by the use of currents of too great intensity, which may have irritated and stimulated the growth by the result of inflammatory action. It is well known that the use of chemical caustics on warts, or of any similar method of irritation on growths of this character, which do not completely destroy the adventitious growth, are apt to be followed by an increase in size. Therefore it was thought advisable to apply the constant current only by means of surface electrodes, which were moistened in hot salt water; one of large surface was placed in contact with the skin in the form of a covered metallic tinplate, which was connected with the carbon element of the battery (negative) and was applied to the surface over the right lobe, and the positive electrode was held in the patient's hand. A current strength of five milliampères was passed through this circuit for fifteen minutes. The effect of this current reduced the tumor during its use, but in a few moments after the conclusion of the sitting it resumed the shape and size which it showed before.

The next three sittings were occupied with the same system of electro-puncture as had been previously described.

Nineteenth sitting. The tumor was very much reduced in size, and a photograph was taken before the operation. The exophthalmos was also much diminished, but the rapid action of the heart was not changed. At this sitting, which lasted half an hour, three electro-positive zinc needles and two electro-negative irido-platinum needles were inserted into the lower margin of the tumor, the former to the depth of quarter of an inch, and the latter to the depth of an inch, parallel to the surface of the skin and about half an inch below. There was some slight swelling around the zinc electro punctures, but none around those of the platinum, the whole skin between the needle punctures was quite red during the continuance of electrolysis; but the redness around one of these disappeared five minutes after the conclusion of the sitting.

Twentieth sitting (seven days later). The tumor is reduced to a flat shape, is very much softer, its circumference is smaller, and its consistence is so much softer that it can almost be compressed out of sight; the exophthalmos is very less noticeable to her friends as well as to herself; the patient sleeps all night without waking, and the palpitation and irregular action of the heart is slight, but the palpitations occur as often as once a day (never, as formerly, during the night,) but last only for a few moments; these palpitations, which before treatment used to occur several times a day while the patient was sitting and occupied with sewing, now only come after exercise; the patient's appetite has improved greatly, and the anæmia is also much less; the "bruît de diable" is very marked when a stethoscope is placed on the tumor; when this was listened to at the first visit it was scarcely audible, and it would seem now that the circulation through the vessels of the goitre is of a different character than before the treatment.

At this treatment four electro-punctures were made, two with zinc (positive electrode) needles, and two (negative electrode) with irido-platinum needles. All of these needles were protected from the skin by means of hard rubber canulas, which fitted loosely around these needles. A current strength of four milliampères was employed for twenty minutes.

Twenty-first sitting, (on the following day). There is hardly any mark of inflammation visible from the punctures of the previous day, and the tumor is even softer than on that day. Chvostek's method of surface contact was employed with a current strength of thirty milliampères during twenty-five minutes, and the direction of the current was changed every five minutes. The skin upon which the electrodes were placed in contact was pretty thoroughly reddened after the close of this sitting.

Twenty-second sitting (four days later). The transverse axis at the widest part of the tumor measures nine and a half centimetres, and the vertical axis of the larger wing (on the left side) is only three and a half centimetres; the skin over the thyroid body, which at the first visit was tense, is now very loose and can be picked up in the fingers; the outer margin of the right lobe, which extended beyond the outer margin of the sternoid muscle is now fairly within the inner border of this muscle. Surface electrodes were applied with a current strength of twelve milliampères, a large moistened covered block-tin plate, as negative, covering the whole thyroid region, and the positive being a covered carbon electrode (its segment surface measuring four centimetres) overlying the position of the left superior cervical ganglion; another circuit of ten milliampères was formed by two electrodes having the same surface size as the smaller of the two preceding, the negative of which was in contact with the right malar process and the positive on the opposite malar process; the application of this surface contact of the four electrodes was continued for sixteen minutes. A separate battery was used for each pair of electrodes, and all the points of contact were kept moist with salt and water. The patient reports that she had been entirely free from palpitations since the last visit except that there has been a slightly increased frequency of the pulse beats after rapid walking.

Twenty-third sitting (three days later). A current from a Volta-Pavia battery, arranged for surface, of four cells, which furnished a strength of one milliampère only, was applied by means of two electro-positive needles inserted at the left outer margin of the thyroid enlargement and two electro-negative needles inserted at the right outer margin; each needle was made of iridio-platinum alloy, was inserted about quarter of an inch deep into the subcutaneous tissue through the sac, and then thrust to the length of three quarters of an inch parallel to the surface of the skin; each puncture of the skin was first made by means of a small exploring trochar which was then withdrawn; a small ivory canula was afterwards inserted into the same opening; the needles were then introduced within the canula, so that the skin should be protected during the sitting from the contact of the metal; the action of the electrolysis was continued for twenty minutes, during which time the direction of the current was changed twice. No pain accompanied the passage of the current except when its direction was abruptly changed. A slight rose-colored efflorescence of the skin spread for about one and a half inches from each puncture, which disappeared within a few moments after the sitting was concluded. There was no particular change in the appearance or size of the tumor to be noticed since the last report. The skin over the thyroid region was very loose, so that it was difficult to insert the needles, unless the skin was made tense.

Twenty-fourth, twenty-fifth and twenty-sixth sittings (at intervals of two or three days). During these sittings Chvostek's method was repeated, but so little change in the size of the tumor ensued that, at the patient's own request, the method of electro-puncture was resumed at intervals of three and four days. The decrease in the goitre and in the exophthalmos continued after the resumption of the punctures. Sometimes four needles and sometimes only two or three needles were employed as the electrodes, and the current was sent through these needles, which were used both as positive and negative, the circuit being completed by the electro-punctures and not through surface contact. The metallic contact with the skin was shielded by the insulating canulas previously described. When the insulation was complete, no subsequent inflammation occurred in the skin. The catamenia reappeared on the expiration of the third month of treatment and lasted but one day.

After five more sittings of twenty minutes duration, the tumor had almost entirely disappeared, and the palpitations and exophthalmos were cured. At the last few sittings it was noticed that immediately after the current began to pass through the circuit, the tumor would entirely shrink away, leaving the skin shrivelled. During the subsequent day the skin around the punctures would become slightly œdematous, and at the next visit the size of the tumor had noticeably decreased. The patient was then discharged with the expectation that the subsidence of the enlargement would continue as in the preceding case. The final disappearance of the goitre should not be expected to occur in adults for three or four months after the discontinuance of the electrolysis. It is not necessary to continue the treatment until the last vestige of the tumor has gone, because when once arrested its decrease will go on spontaneously. The treatment was concluded at the time of going to press. The accompanying woodcut taken from a photograph represents (Fig. 31) the appearance of the tumor at the close of treatment by electrolysis.

FIG. 31. -After treatment by electrolysis.

It will be noticed that the position of the head in this photograph was more erect than in the first (Fig. 30, page 234), and that the chin is depressed; consequently the skin over the tumor is not tense. The engraver has not presented the details shown in the photograph, so that the marginal outlines of the lateral portions of the tumor do not appear in this last figure (Fig. 31). The difference in appearance between these two photographs is very marked, showing that the goitre had been very materially reduced in size.

A case of a supposed goitre, and which afterwards turned out to be a sarcomatous tumor was not even arrested in its growth. Electrolysis is not applicable to malignant growths, except when used as thermo-cautery for a separation of diseased from the adjacent healthy tissues very much in the same way as can be done by the knife.

CHAPTER X.

HYPERTRICHOSIS, AND ITS TREATMENT BY ELECTROLYSIS.

Hypertrichosis, or the excess of a growth of hair, may occur upon the skin of the face and produce a very serious disfigurement. Hairy moles may also grow upon the face and produce a repulsive appearance. We owe to Dr. Hardaway, of St. Louis, the introduction of the successful and permanent cure of this obnoxious growth. The natural causes which operate in the gradual decay and loss of the hair have been described in the fifth chapter. In order to understand the way by which electrolysis may destroy the life of the hair it will be necessary to present the histology of the hair and its follicle.

According to Satterthwaite[1] the hair proper is a cylindrical structure which is seated upon the papilla of the hair within its follicle. Its base is embedded in the subcutaneous connective tissue or in the corium. That portion of the hair which is within the follicle is called the root of the hair, and the remaining portion is its shaft. The true hair-follicle includes all that of the hair-sac below the place where the sebaceous duct enters the hair-follicle. It is of very variable size, and consists of the blind extremity and a funnel-shaped orifice (a). A constriction of the follicle occurs just below this orifice and this is the neck of the hair follicle (b); into this neck the duct from the sebaceous gland enters. Below this neck the hair-follicle increases in size, and its largest diameter is at the lowest end, and at this point it rests upon the papilla. The follicle and the hair-root are below the neck.

The follicle consists of the external, middle and internal sheaths, but it is hardly important for our purposes to describe these in detail.

The hair-papilla is formed from the stroma of these sheaths, especially that of the middle sheath. Numerous round cells may be seen in the connective tissue fibres of this papilla, which latter is separated from the hair-root by the internal follicle sheath. Within the papilla one or more

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[1] Manual of Histology, Thomas E. Satterthwaite, New York. William Wood & Company, 1881.

arteries, veins and non-medullated nerve fibres are found. The general appearance of the papilla is delineated in the figure.

The root of the hair is for our purposes of study the most important portion of these tissues, since a hair ceases to be reproduced when no new

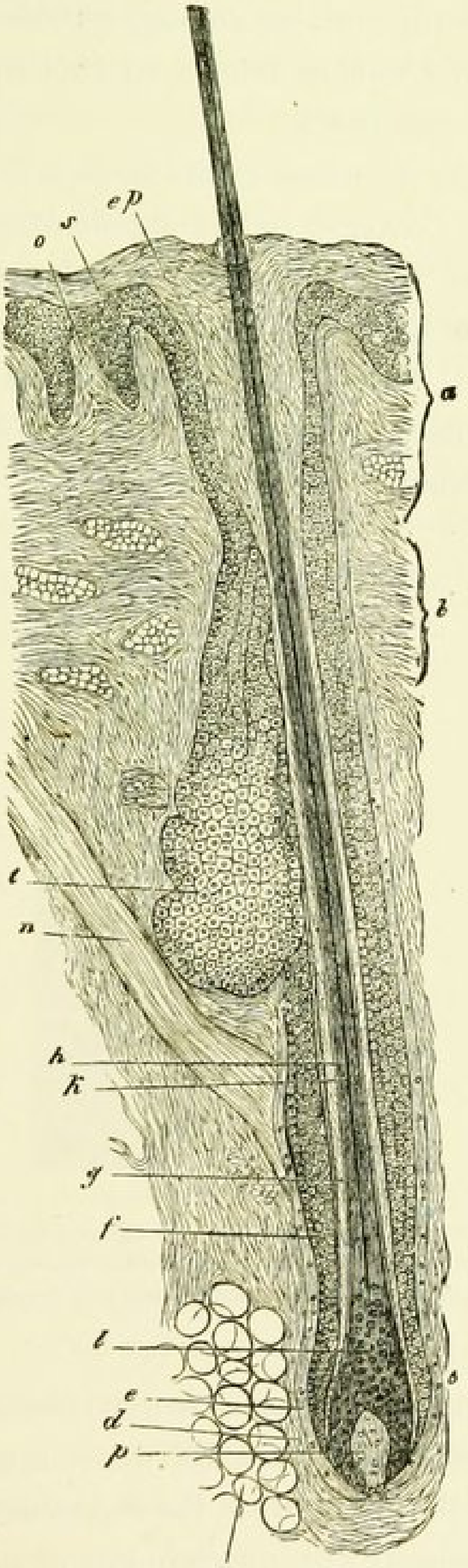


FIG. 32.—Hair from beard: *a*, canal of exit; *b*, neck of hair follicle; *c*, lower part of follicle; *d*, external sheath of hair follicle; *e*, internal sheath of hair follicle; *f*, external root sheath of hair; *g*, internal root-sheath of hair; *h*, cortical substance; *k*, medulla of hair; *l*, root of hair; *m*, fat cells; *n*, arector pili; *o*, papillæ of skin; *p*, papilla of hair; *s*, rete mucosum; *t*, sebaceous gland; *ep*, stratum corneum, which is continued into the follicle.

cells are formed in it. These cells bear a close resemblance to those of the rete mucosum; those which are seated directly upon the basement membrane of the papilla are cylindrical and those which are more superficial are polyhedral in shape. In the upper part of the hair-root the external portion of the bulb contains oblong, spindle-shaped cells, and these are, finally, lengthened out in fibres; in this condition they form the fibrous portion of the hair shaft.

The shaft of the hair is formed of the medullary substance and a fibrous portion, which latter is covered by the cuticle of the hair. This medulla consists of polyhedral cells which contain fat and pigment granules. Toward the free end of the hair this medulla becomes smaller, and terminates near the point. The fibrous portion is the principal part of its shaft, and consists of flattened fusiform cells, which latter contain numerous spindle-shaped granules.

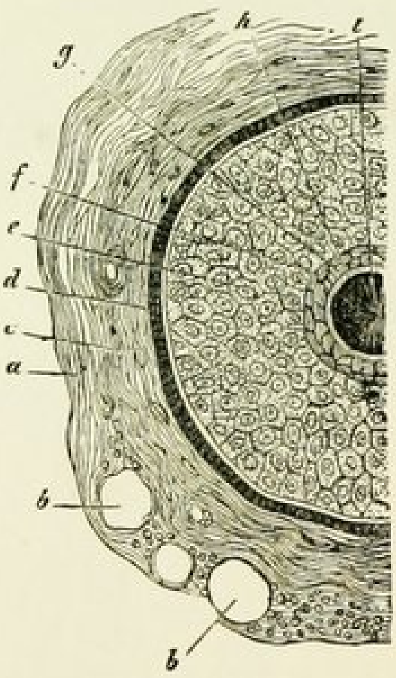


FIG. 33.—Transverse section of the hair beneath the neck of the hair follicle. *a*, external sheath of the hair follicle; *b*, transversely cut blood vessels; *c*, inner sheath of the hair follicle; *d*, basement membrane of hair follicle; *e*, external root sheath; *f*, cells of Henle's layer; *g*, of Huxley's layer; *h*, cuticle; *l*, hair shaft.

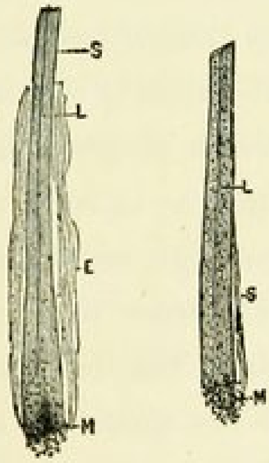
From the foregoing description it will be noticed that the appearance of a transverse section of the hair will depend upon the portion of the hair which may furnish this section, the reproduction of the accompanying figure from Biesiadecki will illustrate one of these sections.

A hair increases in length by the formation of new elements in its root, which elongate and push the shaft of the hair and its cuticle before these elements.

When a hair which is at first fine, gives place to a thick growth, the external root-sheath penetrates downwards, and thus forms the papilla; then this papilla becomes atrophied, the hair falls out, and its place is occupied by the new and thicker growth. If a hair has reached its natural growth, it will fall out and will be replaced by a new hair which grows from the old papilla. The last cells which are formed and converted into the hair proper, will appear as a conical or knobbed extremity at the lower end of the hair-shaft.

The hair follicles and the hairs do not stand at right angles to the surface of the skin; their direction of growth is oblique from this surface. After they have been frequently evulsed the direction of their growth may be quite tortuous, and sometimes the hair-root may lie at right angles to the shaft of the hair.

When a hair has been forcibly evulsed, without previous electrolysis, it will appear like the accompanying illustration (Fig. 34, B), a reproduction of a micro-photograph, which was taken by the author. This hair was



A. B.

FIG. 34.—A, Hair removed after incomplete electrolysis. *e*, cortical substance of the shaft; *l*, medulla of shaft; *m*, corium. B, Hair pulled from man's beard: *l*, medulla; *s*, cortical substance of the shaft; *m*, corium.

pulled out of the beard of a man. In the same plate is shown (Fig. 34, A) a hair which was removed by the forceps after incomplete electrolysis; this is also from the beard, and viewed side by side with the other, shows that all of the hair shaft, external and internal root sheaths, have been removed, but without the hair-root or the sheaths of the follicle, or the papilla.

From what has been previously mentioned in the fifth chapter and what has been described in the present chapter, in regard to the natural life and the natural decay of the hair, it will be noticed that an operation for the destruction of a hair must destroy the hair-root, the papilla, the sheaths of the follicle and the adjacent tissue within the corium. Any operation which will accomplish the destruction of all of these structures will destroy the life of the hair and prevent its reproduction. Formerly, the introduction of an instrument and of some chemical substance, which could set up an inflammatory or suppurative action, would destroy all of these tissues; but great pain attends this mode of procedure, and an ugly pitted scar would mark the spot, which will remain through life. The local effect of an electro-puncture, as has been previously remarked in a preceding chapter, will produce in the skin a conical mark of destructive action, with the base of the cone at the external surface and its apex a little deeper, in the subcutaneous tissue at the point of the needle.

We have seen in a preceding chapter that the segmentation of the cells, upon which depends their proliferation, is accomplished by the segmentation of the nucleolus, and that this is preceded or accompanied by a prolongation of certain fibrillæ in karyokinetic figures. We may assume that an interruption of these processes of nutrition will more or less, according to the extent of this interruption, interfere with the cell proliferation. It is also observed by histologists that a lowered state of vitality is usually accompanied with an increased quantity of water in the tissues, hydræmia, in which condition the processes of general nutrition are seriously retarded. We have also seen that the introduction of an electrode within a fluid conductor, which offers a high resistance to the transmission of an electrical current, will collect a mass of the fluid around the negative electrode. Empirical experience teaches that the negative electrode is the most efficient destroyer of the nutrition and growth of the hair. It is undoubtedly true that the introduction of the positive electro-needle will also destroy the tissues, but not without a caustic action, and the character of this destructive local effect is that of a dry eschar. It would seem from these considerations that the destroying action of the negative electro-puncture into the pilous follicle should be attributed, as much to the cataphoric, as to the electrolytical action of electricity. The evidence of this is shown, moreover, in the large amount of water which collects around the puncture; the amount of this water which is there collected cannot be entirely accounted for on the supposition that it is the result of the combination of the oxygen with the hydrogen, which gases are supposed to be the products of decomposition. It is undoubtedly true that these gases come from changes into the chemical elements of the composite organic structures of the living tissues, and it has been shown from the experiments of Burgoin in the second chapter that the phenomena of electrolysis are as simple in the organic as in the inorganic structures. We cannot but admit that the disruption of the hydrogen elements from carbo-hydrate combinations, of which the living tissues are largely composed on the authority of the best physiological chemists, would be a serious blow to their integrity; yet, the conditions which would attend such a fundamental change as to account for simple chemical decompositions of these structures, are not those which we see in the simple destruction of life of the hair. In this case the destruction goes on most frequently without any, or hardly any, inflammatory process or suppuration; indeed, we might with good reason say that if the electrical operation has been properly done, very little inflammatory, and no suppuratory effect should follow. Now, it is well known that the diseases which accompany, or are the cause of, deficient general nutrition of the tissues, are most commonly attended with inflammatory processes of these tissues; this is especially the case with those diseases in which disturbances within the interstitial tissues are most noticeable. What more common instance than that of diabetes in elderly people, or in the gouty and rheumatic constitutional taint, is seen than to have local inflammations of the tissues, such as inflamed joints, furuncuous or carbuncular affections, and the like?

It has been stated that, if the operation of electrolysis, so-called, is properly performed, there should not follow any serious inflammatory local process. The proper conduct of this operation should depend, in our opinion, upon this very theory of electrical osmosis, which has received the name of the cataphoric action of electricity by medical electricians. The tissues of the human body are especially adapted for the display of this peculiar physical process. As has been over and over again mentioned in these pages, our bodies offer a very high resistance to the transmission of electrical force through its tissues. This resisting conductor of electricity is largely composed of fluids, and these fluids are of the very kind which possess the property of potentials of variable degree; in fact, many physiologists appear to hold to the opinion that these tissues have in themselves or their chemical constitution, the characteristics of local electrical batteries. If we bear in mind that the process of nutrition is a matter which requires a constant dissipation of the natural forces in order to continue the reproduction of cell proliferation, it will not be difficult to understand that any disturbance of the liquids, or its motions between the interstitial tissues, will seriously interfere with the functional activity of the embryonic cells. We should not for a moment lose sight of the fact of chemical changes in these tissues, but they are of far less importance than the physiological functions of the cell life.

The cataphoric action being of the first importance, when we desire to employ electricity for the destruction of a tissue whose nutrition depends upon the rapid performance of cell segmentation, the character of the current demands our most serious consideration.

It will have been noticed that an electrical current may have what is called either a low tension or a high tension. In order to produce a current of strong chemical action through a conductor which offers a high resistance to passage of electricity, we should, theoretically, use a current of high tension; in other words, we should drive the force at high pressure through the resisting medium. The effect of this would be to intensify the action in order to overcome the resistance, and the strength of the current would be principally exerted upon that part of the conducting medium which would offer an obstruction to the transmission. We have already seen that the fine wire, which offers a higher resistance than a wire of larger diameter of the same composition, will often become heated by a current of high tension. The result of passing a current of this character through the dry skin will show the local irritating effect upon this resisting medium. On the other hand, if we attempt to pass a current of large volume through the resisting tissues its action will be displayed more slowly, and the chemical action in the same period of time will be much less. The cataphoric action, however, will be greater with a current passing through a resisting fluid conductor. This fact has been shown in a previous chapter.

It will thus be noticed that the current should be one of low tension and of as much quantity as can be conveniently obtained. The battery should, therefore, be arranged with its elements of large surface exposed to a large body of exciting fluid, and this fluid should be so selected as not to obstruct the electro-chemical action within the galvanic cells. The battery should, also, be one whose internal resistance should be at the smallest minimum practicable; in other words, the best battery for epilation should be one that has a high electromotive force. It may seem as if this conclusion was paradoxical, because it is directly opposed in theory to Ohm's law, that the electromotive force will be decreased by the inequality between the two resistances in the circuit. There is no doubt that the initial electromotive force of the battery will be reduced by the additional resistance of the external circuit; but the conducting medium in this case is a medium of constantly varying resistances, and it is this very resistance which we are utilizing for our purposes; we should, therefore, have a battery which should give out an excess of a low tension of current. We do not want a stream of high pressure, but we want a large volume.

The effects of the two characters of the electrical current is seen in practice: the high tension current will redden the skin during the process of epilation, and in order to prevent a confluent inflammatory effect upon the skin, we should be obliged to select the hairs for epilation which are far apart; on the other hand, if we use a current of large quantity[1] the reddening local action is very much less, and the amount of water which will collect around the electro-negative needle puncture will be more voluminous. The time which will be required to destroy the hair may be probably a trifle longer, but this difference is inappreciable and may, even, be imaginary, because it is not easy to state exactly how long a time is required for a destruction of a particular hair; from thirty to forty hairs can be destroyed within an hour by either current. With either kind of current the same primary effect is produced on the cutaneous tissue:—a central depressed point surrounded by a circular œdematous swelling whose diameter is about half a centimetre; if a current of high tension has been employed, forty eight hours later a soft eschar will have formed of the same size as the original "bee sting," which will dry up and form a small scab; if left to come off by a natural process, and if it is not picked off by the finger nail, this will be replaced by a red spot, which is smaller than the original mark, and which usually disappears by the tenth day. If, on the other hand, a current of low tension has been employed, usually on the second day only a small dry scab will form, which is about one-third of the size of that which followed the use of the other kind of current, and when this scab falls off naturally, only a slight mark is left, which will have the same color as the surrounding skin; in the latter case, the scab most generally falls off within six days. If a current of high tension is used, that is, where one or more cells are connected together in series or groups of two in series, the current strength should not exceed five or six milliamperes, because a stronger current than this

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[1] Though the word "quantity" is a misnoma, we are obliged to use it because it probably will be better understood in this case than another *term* which may be more exact.

will cause too much local inflammatory action; if a current of low tension is used three milliamperes will be sufficiently strong, and hardly any pain will follow the latter kind; the former current causes so much pain that usually patients will prefer to have cocaine pricked into the skin punctures for the numbing sensation it will usually occasion.

Many operators use for the puncture into the hair follicle a watchmaker's (steel) broche, from which the temper has been drawn to prevent oxidation and consequent insulation of the steel. Gold or the alloy of irido-platinum furnishes a very much better material for this needle, because these needles are much better conductors of the current, and the collection of water around these latter electrodes is more voluminous. The needle should have as fine a point as possible, and can be readily sharpened on very fine emery paper or on a piece of Arkansas stone. In order to clean them after use with a patient, the gold or irido-platinum needles may be heated in an alcohol flame.

It should be remembered that the hair root and its follicle do not lie at right angle to the surface of the skin, but that these are at an oblique angle; consequently the electro-puncture should follow the opening at the root of the hair through the duct of the skin and the needle may often be bent to suit the inclination of this opening; it should not be thrust in deeper than the bottom of the follicle, which can usually be felt after a little practice. Where a hair has been frequently removed by the forceps, its root is often at right angles to the apparent growth of the shaft, and in these cases, it is better to bend the point of the needle to suit the unnatural position of the hair; again, in these cases, the bottom of the follicle will be found at a deeper point than in those which have not been forcibly evulsed.

The positive electrode should be applied by being firmly held in the hand of the patient. The best form of this electrode is that which is furnished by a cylinder of gas-carbon, through the centre of which a brass tube is fitted, and into which latter the metallic point of the rheophore may be tightly adjusted. This cylinder should be thoroughly soaked in hot water and surrounded with a wad of absorbent cotton, in order to make a more perfect conductor for the current; the skin should be as thoroughly soaked as possible, but not dripping wet. The cylinder of carbon may have a diameter of about three-quarters of an inch and a length of four inches. Salt dissolved in the water makes the skin a better conductor, but it has the disadvantage of corroding the brass connections.

The accompanying illustration will show the relative parts of the structure of the skin and the openings of the various ducts. It will be observed that there is a depression in the skin, which surrounds the hair shaft. The electro-puncture should follow the direction of this shaft and penetrate as far as the hair-root, and a little below this point; this distance will be found to have a depth of one-tenth to one-fifth of an inch. Some physicians recommend that the current should not be connected in

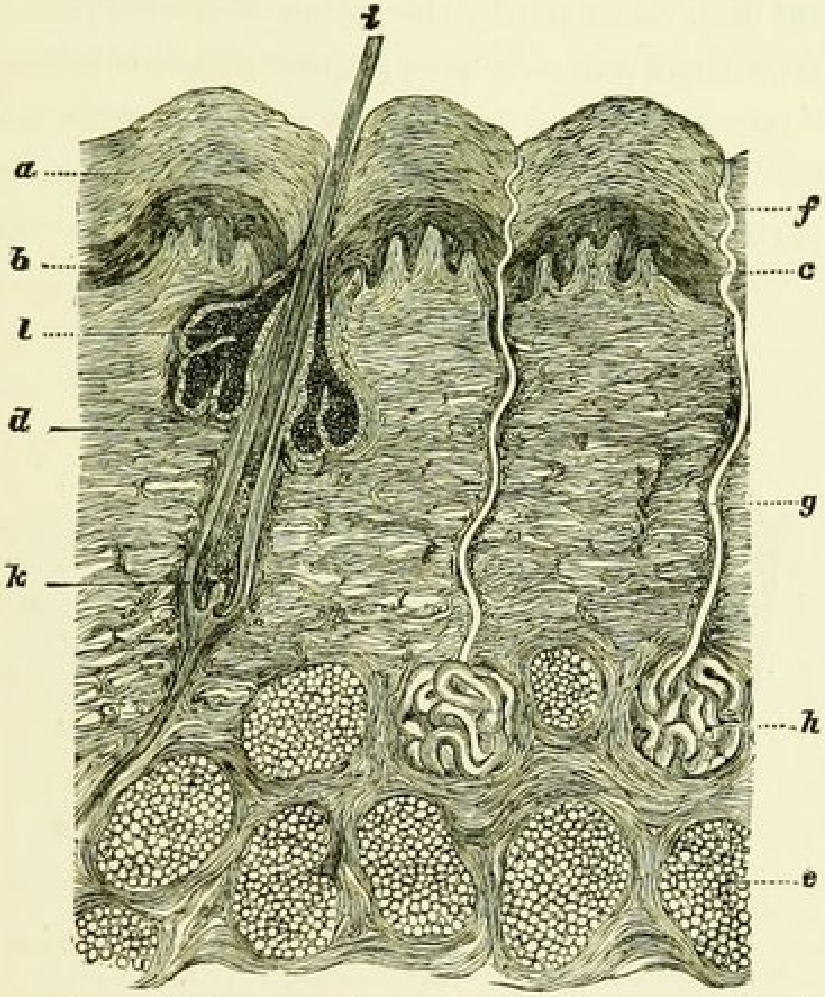

FIG. 35.—Section of normal skin. *a*, stratum corneum of the epidermis; *b*, stratum mucosum; *c*, corium, with papillæ; *k*, papilla with vascular loop; *l*, sebaceous gland; *h*, sweat gland; *e*, subcutaneous connective tissue; *t*, shaft of hair protruding from the skin.

the circuit until after the puncture has been made; in practice, however, it will be found more convenient to keep the electrical circuit closed except when the needle is withdrawn, and to close the circuit only by means of the puncture; the pain which attends the passage of a current of low tension is not commensurate with the momentary prick of the needle, and the time lost in removing the positive electrode, as well as the cooling of the surface of the skin and electrode, makes this practice inconvenient and useless.

When the electro-puncture has been made, and the circuit closed between the two electrodes, bubbles of gas and drops of water will collect around the needle electrode if this is the negative terminal, but not if it is the positive, and in a period of time varying from half a minute to a minute the hair will be loosened from its lair, and can be easily withdrawn.

The hair which has been removed will have the appearance which is presented in the accompanying illustrations (Fig. 36), which are reproductions by photo-lithography of micro-photographs taken by the author of hairs which had been destroyed by the action of electrolysis. These hairs immediately after their removal, were stained with a solution in glycerine and aniline "fast blue," and afterwards in a glycerine solution of an aniline orange, "coralline"; by this method of staining the outline of the various parts are sensitive to the ordinary bromo-iodide plate for photography.

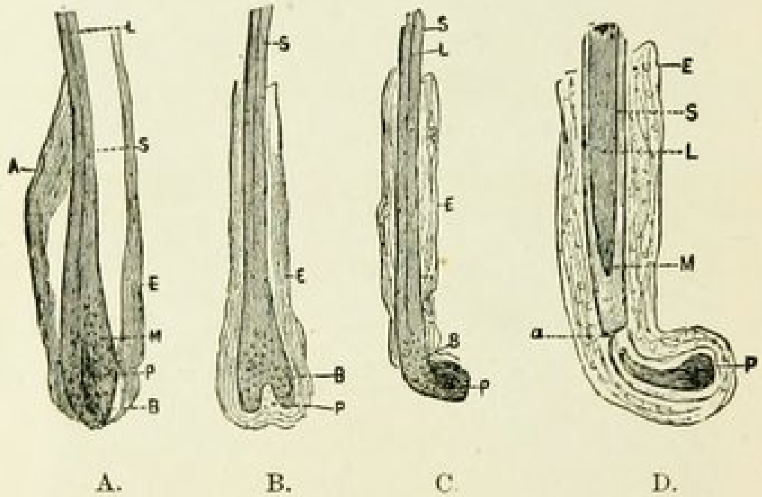

FIG. 36.—A, Hair removed by electrolysis. *S*, shaft of hair; *L*, medulla; *E*, external root-sheath of hair; *P*, hair papilla; *M*, root of hair; *B*, subcutaneous connective tissue.

B, Another hair, in which is shown at *P* the opening into which the papilla was supposed to have fitted: below this point is represented the subcutaneous tissue; *B*, hair root.

C, A third hair with the bulb and root bent almost at right angles to the shaft; *P*, papilla of hair.

D, A hair, similar in appearance to the former, magnified with a No. 7 Hartnack objective. *a*, point of intersection shaft with the hair root; *M*, fibrous portion of the shaft; *P*, papilla.

These micro-photographs were obtained by the use of a Hartnack objective, No. 4, with the exception of D, which was photographed with his No. 7; therefore, as no eye piece was used the magnifying power was not strong enough to show the cell structure, except in that of D. The papilla was well recognized with the eye piece, but too little light would pass through the latter to allow a distinct image to be taken photographically with this combined with the objective. A large number of hairs, which were removed by the use of electrolysis, were repeatedly examined by the aid of a microscope. The result of these examinations would prove that any hair will return after the incomplete use of the electrolysis, unless the microscope will show that the adjacent tissue which surrounds the papilla of the hair, in which the papilla is often recognized, comes out with the hair and its clubbed end. None of the hairs which are figured in the illustration have since (a period of six months) returned.

Extreme care in following the directions which have been above detailed will result in destroying permanently ninety-five per cent. of all the hairs operated upon. It is claimed by many of the most prominent operators for epilation by this method, that the usual result of their experience will show a permanent destruction of eighty-five to ninety per cent. of all the hairs electrolyzed.

The accompanying illustrations of a case of hypertrichosis will serve to exhibit certain points of interest in the treatment of this disfigurement by means of electrolysis. These are all photo-lithographs, which were taken by the author as original photographs from the face of a female patient. The first illustration (Fig. 37), represents the appearance of the woman's face after about three hundred hairs had been removed.

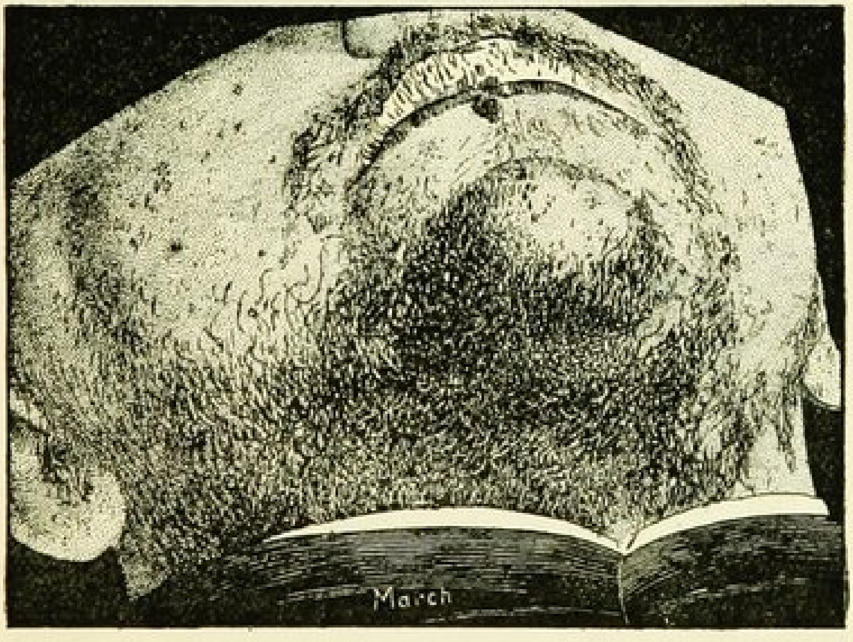

FIG. 37.

Treatment was intermitted between the first of June and the first of October. At the former date 2500 hairs had been removed. On the fourth of October the second photograph was taken, of which a representation is presented in the photo-lithograph of Fig. 38. This photograph was taken immediately after the sitting on that day, and some of the marks of the electro-punctures can be seen in the figure. The hair low down on the throat has been cut shorter than at the time of the previous photograph.

The next illustration (Fig. 39) was taken seven days later, and in this interval four long sittings had been given, during all of which about two hundred hairs more had been removed. This photograph was taken immediately after the fourth sitting and the marks of the punctures are plainly visible upon the right side of the chin.

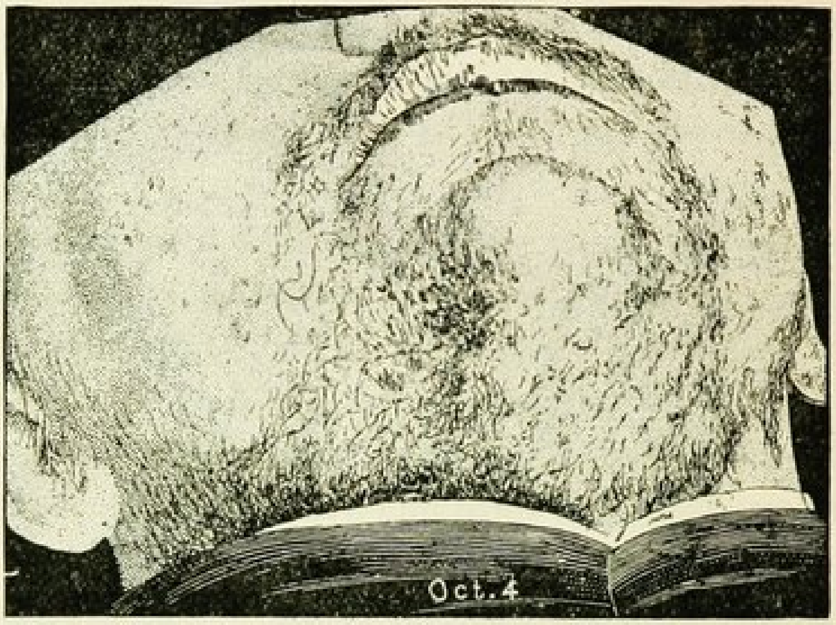

FIG. 38.

The last of this series of illustrations was photographed in the early part of January, and in this may be seen several scars of the punctures at

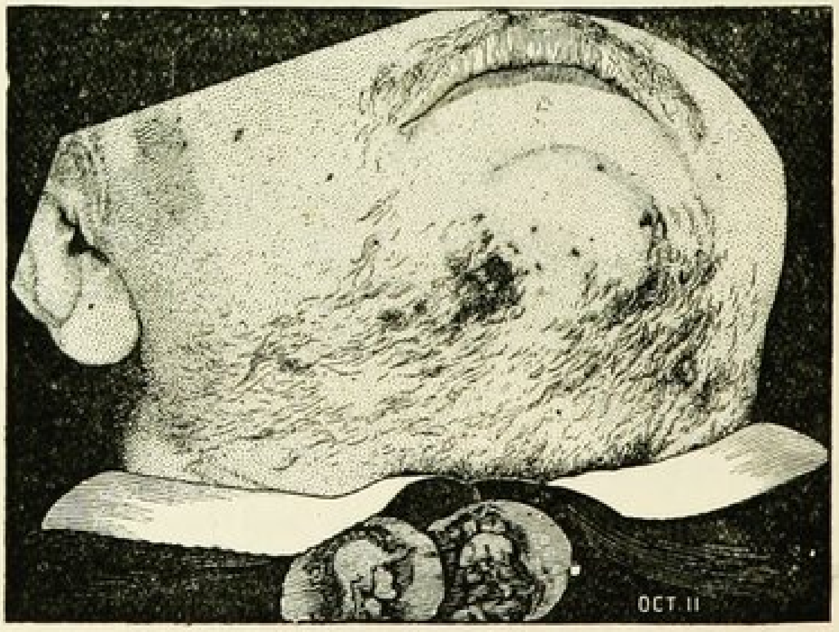

FIG. 39.

a sitting three days previous. It will be noticed in this figure (Fig. 40) that the hair under the chin has been allowed to grow long, and that there are but few marks of the punctures to be seen. These details, of course, are not so noticeable in a print as they appear in the original negatives of the photograph. It will, also, be noticed that the hairs on the upper lip are few and far between. A calculation was kept of the number of hairs removed up to this time, and the number was nearly 4000; this occupied

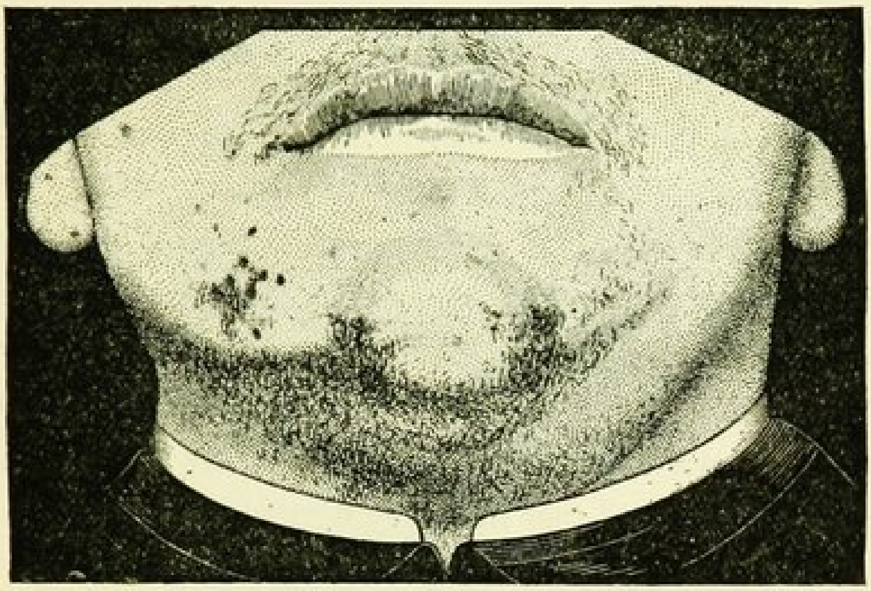

Fig. 40.

about 110 hours, and the work is still in process. It will thus be observed that a vast amount of patience is required for this method of treatment, both on the part of operator and patient.

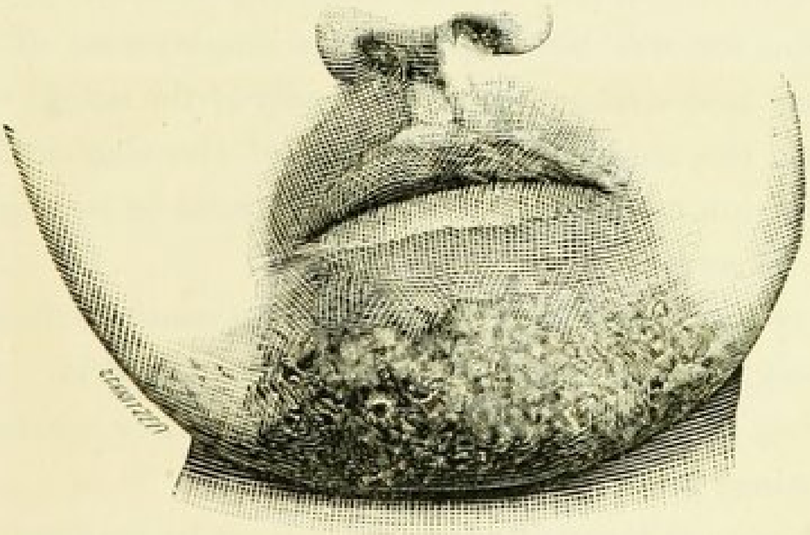

Fig. 41.

A patient who was in great haste to have all of her facial hairs removed, and who devoted six hours a week for five weeks to the operation had some very ugly scars; she was, also, ambitious to have a current of strong intensity. The result of this work is shown in the portrait which is represented in the above figure (Fig. 41). It should be stated that her skin does not appear as badly marred and pitted as this illustration would seem to show. This engraving should act as a warning to such severe and hurried operations. This case of hypertrichosis was especially aggravated, for the hairs were deeply rooted, some to a depth of over one-third of an inch, and were as stiff as is often seen in a man's beard. This woman was of a blonde complexion, while the preceding case was in a dark brunette. It is usually supposed that the pitted marks in a blonde are not so likely to follow the electro-puncture as in a brunette.

A delicate skin should always be favored by the use of a milder strength of current, and this will require a relatively longer sitting than when a stronger current is employed. This consideration is important in forecasting the time requisite for the removal of a definite number of hairs; more allowance should be made for those patients who have tender skins.

No application of a soothing character is needed after treatment by electrolysis, unless the strength of the current has been great, or unless the weather is severely cold and high drying winds are prevalent; in these cases it will be advantageous to apply a little vaseline or the petrolatum of the U. S. P. immediately after the conclusion of the sitting, and before the patient exposes her face to the outer air.

It should be mentioned that the skin is drier during the dry and cold weather of winter, and in consequence of this condition, the conductivity of the skin is much less than in the warm and moist air of the summer; on this account one will be tempted to the employment of stronger currents than may be desirable, because intensity of the action will be largely expended upon the most resisting portion of the electrical circuit, viz., the skin. The intense action on the skin is liable to be followed by local inflammatory effects.

It is always much wiser not to repeat the operation oftener than once or twice a week, and especially in cases of delicate skin. It is far wiser to give a sitting of two hours' length in these latter conditions than to repeat the sittings too closely together.

The operation of electrolysis should always be performed with a galvanometer in the main circuit, by whose deviations the strength of the employed current can be under the observation of the operator. A galvanometer should be used which will measure proportional strengths of the current. This question of the measurement of currents is of sufficient importance to be discussed in a separate chapter.

Hair moles may very readily be removed by this method of treatment, and, when properly performed scarcely any disfiguring mark is left. The annexed illustration from a photograph shows the extent of the resulting space occupied by a slightly whiter portion of the skin, from which a hair mole of over twice this surface was removed at a single sitting of an hour and a half. (Fig. 42).

Fig. 42.—The round spot is simply to show where the mole existed, because in the photographic print it was even more indistinct than in nature. A very close inspection of the face would be required to find the scar made by the operation on the skin.

CHAPTER XI.

THE METHODS OF MEASUREMENT OF A CURRENT OF ELECTRICITY.

THE principle by which the strength of a given current is measured should naturally be based on the amount of work accomplished by the display of its force. Formerly this unit of measurement was absolute without the relation of the time in which this definite amount of work was done.

The International Electrical Congress, held at Paris in September, 1881, agreed upon certain units which are now pretty universally adopted. In order to understand the significance of these units, we should be first familiar with certain primary ideas:

(1). *Potential*, or the condition of electricity contained in a body;

(2). *Electromotive force*, or the power which a galvanic cell exerts of transferring electrical force from one point to another in a conducting body;

(3). *Electrical conductivity*, or the property possessed by a conducting medium of allowing the transmission of the electrical force, in contradistinction to its resistance;

(4). *Resistance*, or the relative degree of obstruction which a conducting medium opposes to the transmission of the electrical force;

(5). *Intensity*, or the resulting strength of a current in the combined circuit of a battery and its conducting intermediums; this is directly proportional to the electromotive force and inversely to the resistance of the conducting mediums;

(6). *Quantity*, or the resulting strength of the current during the period in which it is acting;

(7). *Capacity*, or the charge of one kind of electricity which accumulates upon an electricized body as the result of a difference in potential between the electricizing and electricized bodies, or the quantity of electricity required to raise the potential from zero to unity.

This Congress adopted the following resolutions:—

(1). In electrical measurements, the three fundamental units shall be centimetre, gramme and second; these are usually expressed in electrical works, as (C.G.S.)

(2). The absolute units, the ohm and the volt, will preserve their actual value.

(3). The unit of resistance, the ohm, will be represented by a column of mercury of one square millimetre section, at 0° centigrade.

(4). Establishes a commisssion to determine the length of this preceding column.

(5). The current produced by a volt and passing through the resistance of one ohm shall be called an ampère.

(6). The quantity of an ampère current which is produced per second of time shall constitute a coulomb.

(7). A farad shall be the capacity which answers to the condition that a coulomb in a farad will give the resistance of one volt.

It should be noticed that the difference in potential and the electromotive force are not synonymous terms, and that the ordinary misconception of the term "*Quantity current*" cannot be applied to the character of a current in relation to its chemical action or its low tension. The quantity of a current is the amount of electricity which is produced from a battery in a given period of time. This will depend upon the size of the battery elements, of their area of surface; if, however, the resistance of the external conductor is greater than that within the galvanic cells, it is clearly evident that the amount of the resulting current in a given period of time (its quantity) will be decreased in proportion to the amount of resistance which is offered by the conducting medium. This matter has been sufficiently explained in a preceding chapter.

The quantity of a current may be measured in various ways; the method of these should be dependent upon instrumental measurements, which are based upon the unit of measurement and are a matter of uniform agreement; that is, an initial electromotive force which may originate in a galvanic cell may pass through indefinite number of units of resistance in the external circuit; these latter may be calculated by a comparison of the same original current strength which may be made to pass a known number of units of resistance. The amount of work accomplished by the current in a unit of time may be measured by the amount of chemical decomposition of a known chemical compound, through which the same strength of current may be made to act always through the same units of resistance. It is known that a coulomb will decompose from a one per cent. solution of sulphuric acid in distilled water a mixed volume of hydrogen and oxygen, which is equal to .176 cubic centimetre.

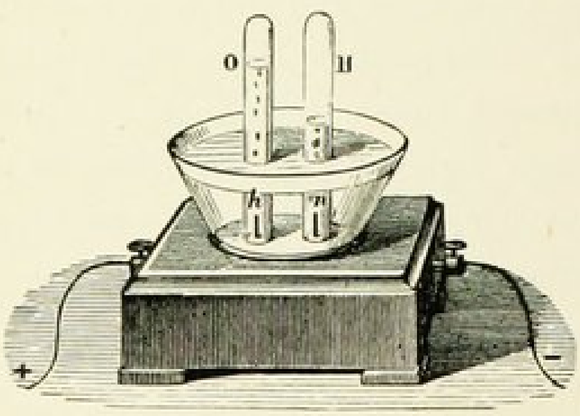

Fig. 43.

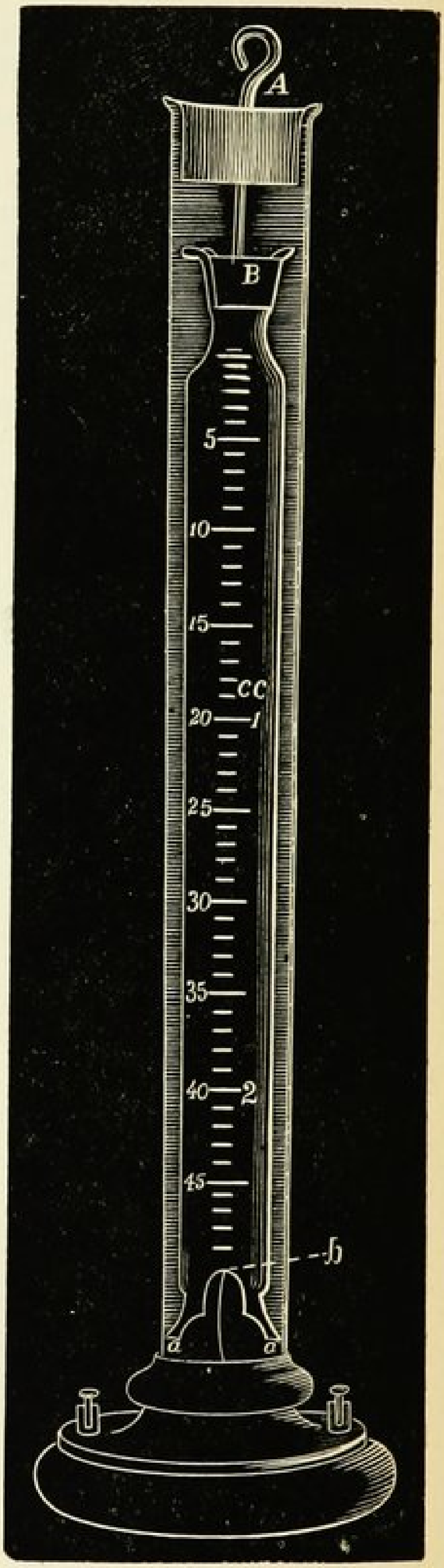

Fig. 44.

Upon this known fact Volta devised his voltameter, which is illustrated in accompanying figure (Fig. 43); the voltameter which is here shown collects the gases separately, the oxygen at the positive terminal (O), and the hydrogen at the negative (H) terminal. It should always be remembered that this total amount of mixed gases as calculated for the coulomb is evolved in a second of time. A more convenient form of voltameter for use in measuring the strength of a current for medical uses has been devised by Gaiffe. This form of instrument, of course, is not accurate in theoretical application for several reasons:—the oxygen gas will have intermixed with it a certain portion of nascent oxygen, ozone, which is the form of this gas when first liberated, and this will recombine with some of the hydrogen to reform water, thus reducing in a slight degree the primary products of decomposition; it is sufficiently accurate, however, for practical purposes. The instrument, which is shown in Figure 44, is composed of an inner tube into the bottom of which the two platinum electrodes are sealed in a glass stem, b; this inner tube is enclosed by an outer glass tube, and which is filled with a one per cent. acid solution of distilled water. In order to fill the inner from the outer tube, a cork may be withdrawn by means of a wire, A, which passes out of the outer cork. The current is then transmitted through the two electrodes into the bottom of the inner tube, and the evolved gases will then bubble up through the inner solution and be collected at the top of this tube. The fluid will then be forced out at the bottom of the inner tube by means of two outlets and will be received back into the outer tube. The time during which the gases are being evolved is then noted, and so, also, the amount of the mixed gases collected in one, two, or three or ten minutes. The amount of the mixed gases can then be calculated by means of the graduated scale, in cubic centimetres on the right hand side, or in fifths of cubic millimetres on the left side. Since one milliampere will liberate 10.3 cubic millimetres of the mixed gases in a minute of time, we may approximately determine the strength of any current by dividing the total number of cubic centimetres of gas set free, in, say, ten minutes by ten; if the time of the liberation of the gases was one minute, the amount of cubic millimetres set free should be divided by one. It should be remarked here that probably in most of the voltameters in use, the transference of fluid en masse by cataphoric action has not been taken into account in the chemical decomposition of the liquid.

A few illustrations will exemplify this method of calculation:—suppose we have employed a strength of current which, working through all the resistance in the circuit, would liberate during twenty minutes a volume of mixed gases equal to the amount of twelve subdivisions of the left hand scale, or sixty cubic millimetres, the calculation would then be 60 : 20=3 milliampères.

A more convenient method of measuring the strength of the employed current may be obtained by the use of a galvanometer, which may be placed in the same circuit with the patient's body; the advantage of this method consists of a constant comparison of the strength of current while in operation.

The principle of all galvanometers is the same, and is based on the fact that a magnetized piece of steel, when freely suspended or hung on a pivot, will have one of its free points directed to the north pole and the other towards the south pole. It will be evident that this needle should be equally balanced in order to be freely movable, and that it may hang on a pivot, be suspended from a silk fibre, or be hung on a knife edge which is supported on a bearing of a smooth bar or hardened piece of steel.

If an electrical current be made to traverse a piece of a conducting wire, which passes above the magnetized needle, in a direction from south to north, the north point of this magnet will be deflected towards the west.

If the current traverse this wire, passing in a plane below that of the needle and in the same direction as in the preceding case, the north point of the magnet will be deflected towards the east.

If, instead of passing in the above-named direction, the current traverses in an opposite direction, the magnet will also reverse its direction.

Ampère's rule of this deflection was:—if we suppose a man to be swimming in the electrical circuit, so that the current shall enter by his head and leave by his feet, when he faces towards the needle its north point will turn to his right hand; under the same circumstances, when the current enters by his feet, the north point will be deflected to his left.

In order to increase the momentum of the galvanometric needle, a coil of wire is protected by an insulation of silk thread wound around the wire to prevent its contact with the surface of the metal in its various parts; this coil then is itself wound in such wise that each one of its turns shall lie in a plane as nearly as possible perpendicular to the axis of the undeflected needle. The transmission of an electrical force, traversing this coiled and insulated wire, will induce in the magnetic field of the magnetized needle lines of force, the direction of whose action will depend upon that of the transmitted current. Now, it should be remembered that the earth is itself a magnet and exerts its magnetizing effect upon the needle, so that this latter will point in the same direction as the magnetic influence of the earth. The magnetic influence of the earth results in lines of force which are very nearly north and south, of course varying with the position on the globe in which the magnet may be situated. The south pole of the magnet is what we call the negative pole. The neighborhood of a magnet is called a magnetic field, because any other magnet brought into that region experiences a peculiar force.

In a certain class of galvanometers, in which the magnetic needle is suspended in a horizontal plane, the resulting lines of force from the magnetism of the earth will act upon the magnet equally, and no increase in the momentum will increase its sensibility; but the smaller the wire and the shorter its coiled length, within a certain relation, in proportion to the light weight of the suspended needle, the less will be its inertia; consequently, the quicker will the needle find its maximum deviation, and the more rapidly it will come to rest, than if it were a heavy magnet wound with larger wire; its inertia being, also, more easily overcome, it will indicate lighter and more transient currents. This class of galvanometers will evidently not be so useful in medical applications on account of the great resistance which the current meets in the human body.

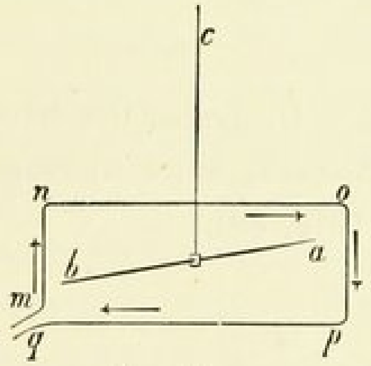

FIG. 45.

The direction of the lines of force is represented in the foregoing illustration (Fig. 45); *a b* represents the magnet suspended from a thread *c*; the current enters at *m* and passes in the direction *n o* and returns by the path *p q*; the arrows show the resulting line of force by the parallelogram *n o p q*.

A still more sensitive galvanometer, known as astatic, may be formed by suspending from one system two magnetized needles, arranged in such a manner that the north pole of one overlies the south pole of another. This is represented in Figure 46; in this illustration *a b* represents one needle and *a′ b′* represents the other, with its poles in a reversed position.

If, instead of placing the wire through which the current traverses a straight line in a direction either above, *or* below, the needle, it should be carried both above *and* below this needle so that the current shall be

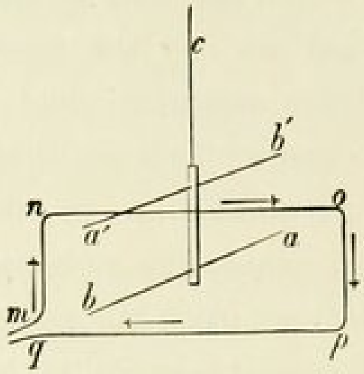

Fig. 46.

made to pass around the needle in a vertical line, the direction of the force will traverse the wire in opposite directions (Fig. 47). The deflecting

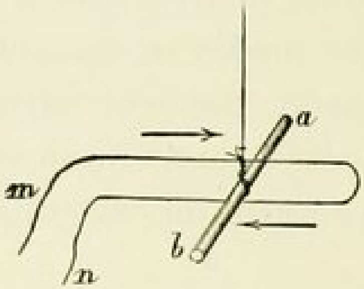

Fig. 47.

action will then be doubled. If, again, the wire be made to take one or more turns this action will be still more increased, and in proportion to the number of these turns (Fig. 48).

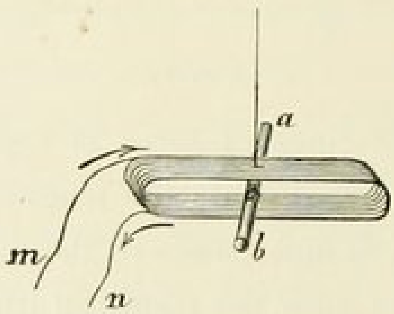

Fig. 48.

If, again, the upper needle of an astatic pair be placed above the coil, and the other lower one be placed within the coil, its deflection will be increased more than that of a single needle, on account of the needle being retained in its position by a smaller power, and because the force of the current is exerted upon two needles instead of upon only one.

The angle of deviation of these forms of galvanometer is not, however, proportional to the strength of the electrical current which traverses the coils surrounding the needles. This fact can be easily understood by remembering that the lines of force exerted by the earth's magnetism, which tend to bring the magnetized needles back to their proper position, are proportional to the sines of the angles of deviation, and not to these angles themselves; therefore, the farther outside of the coils these needles are moved the difference between the arc of their motion and its sine becomes greater. The sine and tangent-galvanometer were devised to overcome these errors, but their use in medical electricity are not of sufficient importance to require a detailed description of the principles upon which these instruments are based.

The use of some form of galvanometer, or galvanoscope, which will measure proportional strengths of current has been urged so strongly by medical electricians, and so ably presented by De Watteville in the work to which we have so often referred, that no apology is offered for reproducing the excellent description of an instrument from his book:

"The milliampère is the most practical unit of measurement, for its multiples correspond to the strength of the currents used in medical applications. With the resistance of the human body included between electrodes of medium size and applied to the spots commonly selected, a current of one milliampère (about two to four Daniel's cells) is about the weakest ever used therapeutically or diagnostically. Likewise its multiples 5, 10, 20 express currents yielded by 10 to 30 or 80 cells under similar conditions. It is apparent that in the milliampère we have a convenient unit by which to express the electrical doses, as it were, administered to patients; or, the current strengths necessary to obtain muscular contractions in electro-diagnosis. And this in terms enabling us to not only compare the results obtained by ourselves on the same galvanometer, with one another, but also with those obtained by other observers on galvanometers of any construction, but graduated in absolute units. An idea of the peculiarities of the absolute galvanometer,[1] contrasted with the galvanoscope,[2] will be obtained by a glance at the diagram. It

[1] We object to the use of this term, absolute galvanometer, because the measurements obtained by the use of galvanometers of any description are simply comparative and not absolute.

[2] The galvanoscope is strictly speaking a galvanometer which does not, necessarily, show variations in the strength of the current, but simply its direction.

(Fig. 49) represents the dial of an instrument divided in its upper half into degrees, in its lower half into milliampères. The principle that the angle of deflection does not increase proportionally to the current strength, is illustrated by the fact that, whilst for instance a current of 30 milliampères deflects the needle to about 45°, a current of 150 milliampères is required to deflect it to 70°.

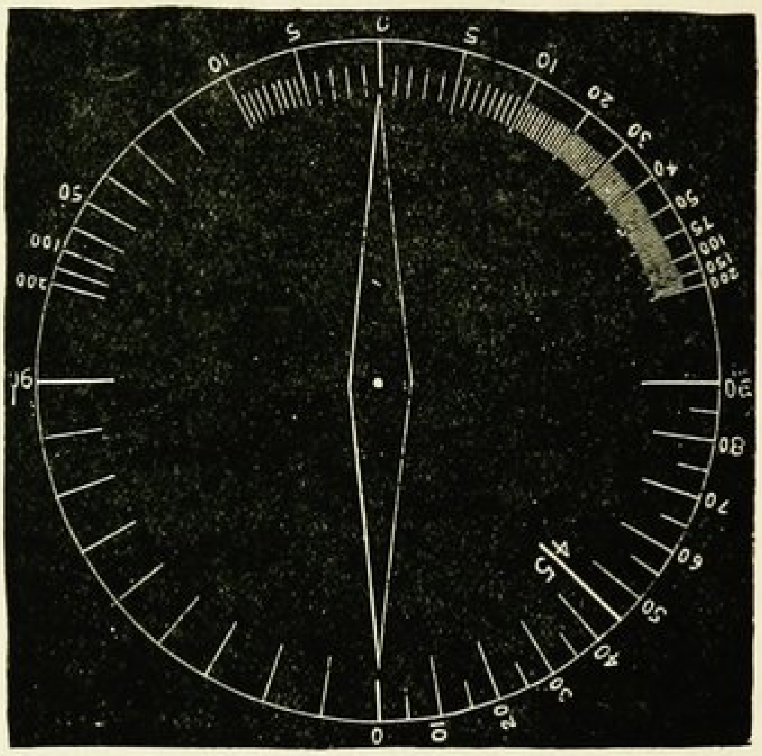

Fig. 49.

The simplest method of graduating a dial of a galvanoscope into subdivisions of an ampère, is to place the instrument in the same circuit as a tangent galvanometer of which the reduction factor is known (or of a galvanoscope already so graduated) along with a constant cell and a box of resistance coils. By means of the latter the current is modified so as to produce a deviation of 1, 2, 3, etc., to 20 or more milliampères as measured on the standard galvanometer. The corresponding deviations of the galvanoscope are indicated on the dial, and their value in milliampères written down.

In the absence of a standard galvanometer, a large standard cell is taken of known electromotive force. The most convenient for this purpose is the Daniel, in which the sulphate of copper is replaced by nitrate of copper. The electromotive force of such a cell is as near as possible *one* volt.[1] Placing the cell in a circuit with our galvanoscope the resist-

[1] The cell with dilute sulphuric acid (1: 4) has an electromotive force of 1.79 volts; with dilute sulphuric acid (1: 12) .978 volt; with dilute sodium chloride,

ance of which must be known (call it 50 ohms) and a rheostat. The cell being large its internal resistance may be neglected.

We then introduce 950, 450, 200, and 50 ohms in the circuit. The current in each case will be (Ohm's law):

$$\frac{1}{950+50}=.001,\quad \frac{1}{450+50}=.002,\quad \frac{1}{200+50}=.004,\quad \frac{1}{50+50}=.010.$$

In other words, 1, 2, 4, 10, milliampères. The cell acting through the galvanometer will give $\frac{1}{50}$=.020 milliampères. The intermediate subdivisions are obtained in the same manner.

The operation should be repeated with the current flowing in the opposite direction through the galvanoscope, but, owing to irregularities of construction, such instruments give different deviations on either side of the zero with the same current.

The reduction factor of every galvanometer (horizontal) contains a variable element, viz., the magnetic force at the particular point of the earth's surface, which enters into account in the graduation of galvanoscopes. Hence this graduation is absolute only for such places where the magnetic force is the same as that of the locality where the graduation has been performed. For medical purposes, however, this source of error would be felt only if a graduated galvanometer were to be used in a place far distant from that where it had been graduated.

The intensity of the terrestrial magnetism varies also at the same place, from year to year, but in an amount altogether negligible when approximate measurements only are required. This amount is about .004 yearly.

To give an idea of the variations of the earth's magnetism, I subjoin the following table of the approximate magnetic intensities in various European cities.

In the year	1870	1875	1880
In Paris	1.94	1.96	1.98
" London	1.78	1.80	1.82
" Leipzig	1.86	1.88	1.90
" Darmstadt	1.91	1.93	1.95
" Edinburgh	1.62	1.64	1.66

(1: 4) of 1.06 volts. Either of the latter might be taken, allowance being made for the slight difference between its electromotive force and the volt, (adding 5 ohms to every 100 in the first instance; subtracting 2 ohms in the second.)

In the year	1870	1875	1880
In Zurich	2.00	2.02	2.04
" Dublin	1.67	1.69	1.79
" Turin	2.07	2.09	2.11
" Vienna	2.05	2.07	2.09
" Koenigsberg	1.79	1.80	1.83

The angle produced by a given current on a given galvanometer being inversely proportional to the directive influence of the magnetic force acting on the needle, it is obvious that the indication of a galvanometer graduated in London, for instance, would be excessive when used in Turin or Vienna, (in the proportion of 182 to 211 and 209 respectively), deficient when used in Edinburg or Dublin, (in the proportion of 182 to 166 and 171 respectively). It will be noticed that the magnetic intensity goes on increasing as one goes eastwards and southwards from London."

This "absolute" galvanometer referred to by De Watteville is devised by Gaiffe of Paris.

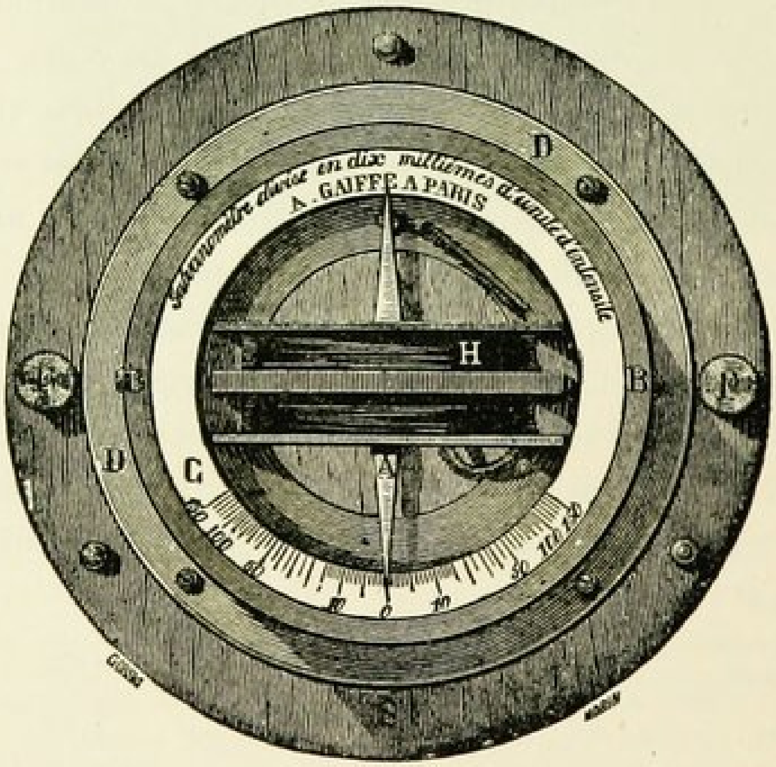

FIG. 50.—*B*, box containing the apparatus; *D,D*, metallic circle which connects the galvanometer with the battery, and which can be circled on its axis so that the needle will be outside of the coil and point at the $O°$ when at rest; *H*, multiplied coil which is placed underneath in the smaller size of the instrument which is attached to the portable battery.

Instead of placing the magnetic needle on a horizontal plane, it is often placed in a vertical line, and the coils correspondingly in the same axis; but, in this form of arrangement the needle should always be magnetized with the same intensity, and which it is obviously impossible to do, as magnets lose their maximum intensity from constant use or from their proximity to other magnetic influences. These vertical needles are not liable to the variations which are due to their geographical positions.

In another class of galvanometers, the directive influence is not due to magnetism, but to weight. The magnet may be pivoted like the balancing beam of a balance. This short and heavy magnet rests on pivoted knife edges and a weight is hung under its centre of gravity, so that a vertical pointing needle, made of light aluminum, may be deflected from a central 0 on a scale from left to right, or to the opposite according to the directing influence from the current. The magnet beam is surrounded by a multiplied coil above its steel bearings, and another coil of the same length below these bearings; its movements are so restrained that the oscillations never permit the beam to pass outside of these coils. This instrument was devised by Lorenzoni and (Fig. 51) is constructed upon the principle

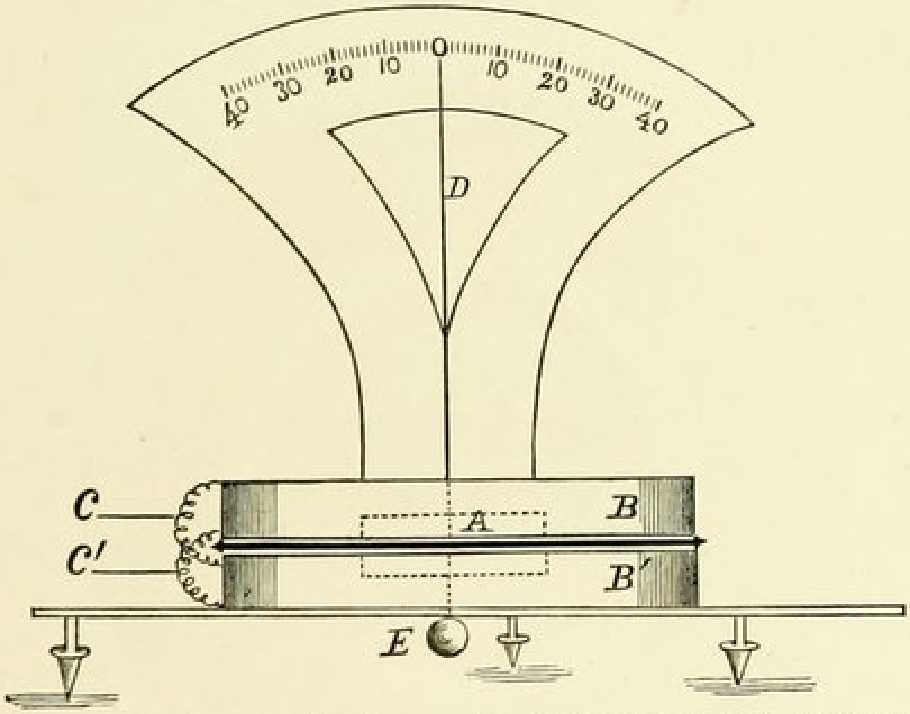

Fig. 51.—Galvanometer for proportional currents. *A*, heavy magnet pivoted on knife edges like the beam of a balance; *E*, weighted ball hung to the magnet to carry the weight below its pivots; *B*, *B′*, two coils wound around the magnetic field of the pivoted magnet; *C*, *C′*, wires connecting the two coils, to allow the upper one to be removed and to disclose the magnet; *D*, needle fixed to the magnetic beam to allow proper reading of the oscillation.

that any increase in the magnetic movement of the magnet increases its sensibility, assuming the counterbalance or directing weight to remain constant. As the vertical component of the earth's magnetism exerts a certain directive force upon the magnet, this should be magnetized to saturation, but its effect is usually not in comparison to the weight of the magnet. These instruments are not intended for the indication of very small currents, but are very convenient in measurements of proportional strengths of currents when the interpolar region, like that of the human body, offers high resistance. That one which has been used by the author for the last two years gives a deviation of five degrees to each milliampere strength, while the graduations of Gaiffe's instrument will give only one degree. The subdivisions of the scale are also uniform and so far apart that these can be easily read at a distance.

Whatever form of galvanometer may be selected for use, the convenience of introducing a resistance box in the circuit will add material assistance to the graduation of the strength of the current.

CHAPTER XII.

APPARATUS AND INSTRUMENTS USED IN TREATMENT FOR ELECTROLYSIS OF THE LIVING TISSUES.

THE various forms of battery have already been described. It will add much to the convenience of the operator if some form of switch-board be adopted by which the strength of the electrical current can be increased, or diminished, at will; it is naturally inconvenient to change connections by the simple process of attachment of wires to the poles of a series of galvanic cells.

Various mechanical contrivances have been devised by which a larger or a smaller number of these cells can be introduced into the circuit without removal of the electrodes from the patient.

THE SLEDGE COLLECTOR.—One of these devices, the sledge collector, is familiarly known in its attachment to the Stoehrer's zinc-carbon battery. In this arrangement a sledge runs in a groove, carrying with it a spring on its under surface, which makes contact with metallic pieces arranged in two rows. Wires from the cells are attached to these metallic buttons. On its upper surface two screw-cups are connected with the springs, into which the rheophores, or flexible conducting wires, may be inserted. The cells can thus be taken in twos.

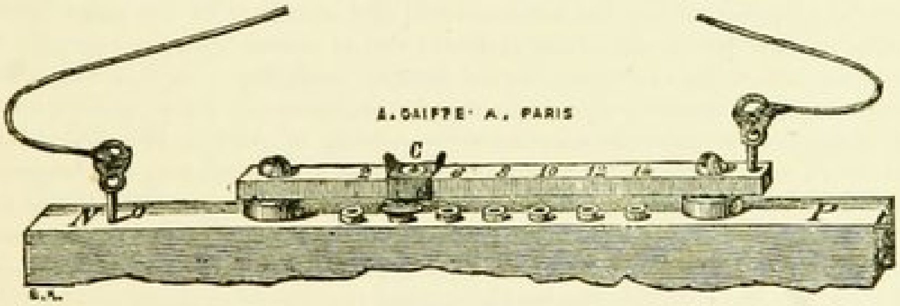

FIG. 52.

A simple sledge collector (Fig. 52) consists of a stiff metallic bar and is arranged to allow a slide, *C*, to make connection with brass studs, which latter are numbered for convenience. A binding post for one of the rheophores is connected at the negative, o, with the first zinc. A second binding post is connected by means of the bar and slide with any one of the studs; these latter are severally connected with the copper or carbon element with the cells, which compose the battery. Thus, the slide being in connection with a selected number on the bar will indicate how many cells are in use.

The Dial Collector is an apparatus devised by Gaiffe for selecting any particular pair of cells of a battery. The advantage of this arrangement is obvious, because if the same pair of cells are always selected for use when only a very small current is required, this pair would be worn out long before the remainder of the cells. The contact springs are so constructed that they make contacts without causing a break in the circuit; before leaving their first metallic button the spring touches the next

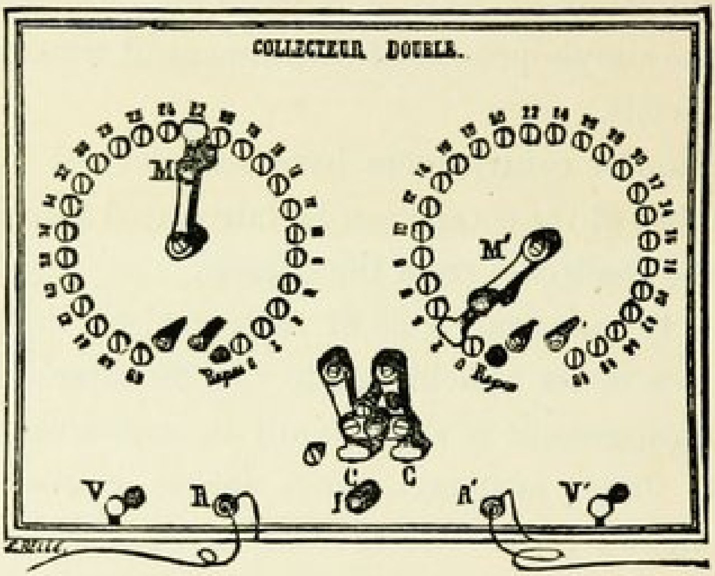

Fig. 53.—The double collector is formed by two dials. The studs on each dial are numbered alike, and these numbers correspond with the pairs of cells, as shown in the figure. The zinc of the first pair is connected with the stud numbered 0. The carbon of the last group, marked 48 on the dial, is connected with that stud on the left-hand dial, and also, with number 48 on the right-hand dial. This last connection forms the positive terminal of the battery for either dial. The first connection, attached to 0 of the left-hand dial and also to 0 of the right-hand dial, forms with either dial the positive terminal. Both of these twofold connections are made by a transverse wire which runs across from the same number of stud to each dial. In this manner the various couples, or groups used as couples, are connected throughout the whole system, each numbered stud of one dial being short connected on to the same number of stud in the other dial. M M' are circular handles which may be swung on to any desired stud and thus form a connection with any number of the cells. M of the left hand dial is connected with the pole cup R for the insertion of a rheophore. M' of the right hand dial is connected with R' of the same side for the insertion of the other rheophore. Provided the current reverser C C' is placed in the position which is shown in the figure, that dial on which the switch indicates the smaller numbered stud will render the pole cup of the same side the negative terminal; but, if the current reverser be turned to the left, the polarity of the rheophores will be correspondingly reversed. Again, the number of cells included between the studs on which the switches are in contact will indicate the number of cells in use; for instance as shown in the figure, the switch of the right hand dial indicates the connection of the second pair, and that on the left indicates twelfth pair; therefore ten pairs are in use.

button, and so the strength of the current may be gradually increased without interruption of the connection with any pair. This system is quite simply arranged and may be easily understood by the illustrations (Figs. 54 and 55).

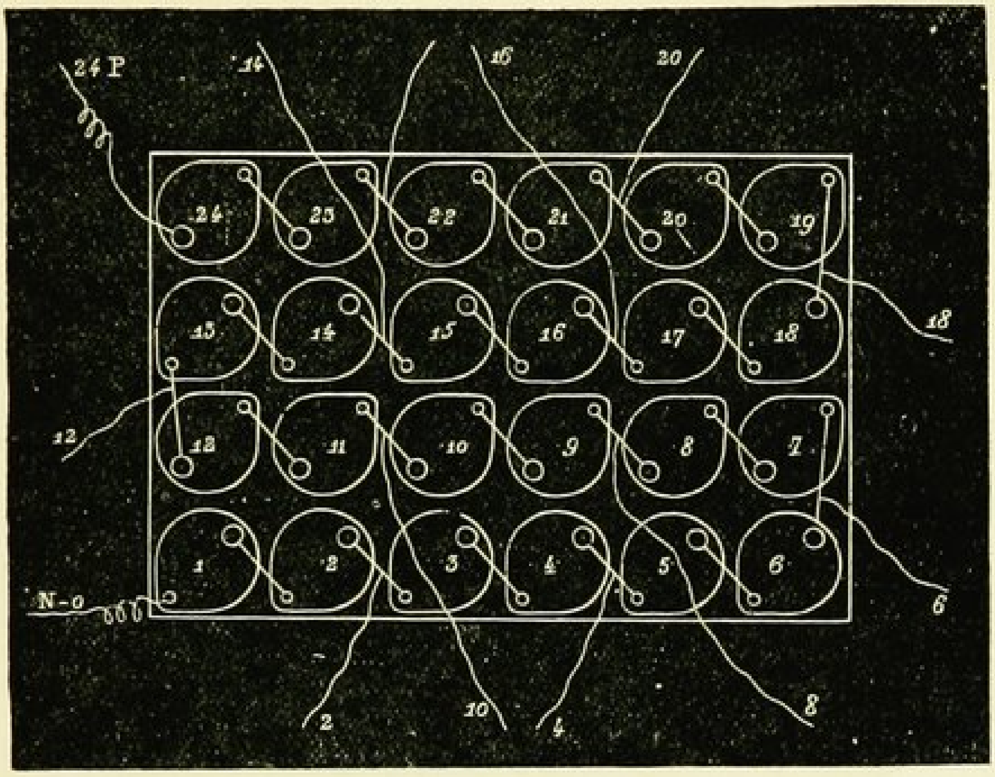

FIG. 54.—This diagram shows the disposition of twenty-four cells arranged in groups of two and their arrangement in series. The N-o forms the negative terminal of the battery, and is attached to the first zinc. The wire 24 P forms the positive terminal of the battery, and is attached to the last carbon element.

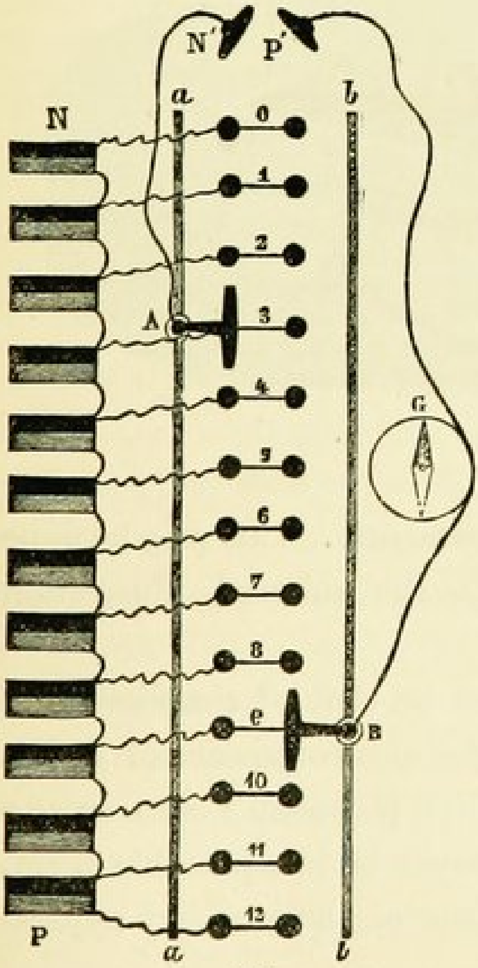

FIG. 55.—Twelve cells are supposed to be connected in simple series to twelve metallic buttons, and are also short connected by transverse wire 0, 1, 2, to 11, 12. The zinc of the first couple is attached to the last carbon in the battery. Two metallic slides A, B, by sliding along the rods *a a*, *b b*, will make contact with the buttons which are numbered in succession. The electrodes A and B form the negative terminals N and P respectively. This diagram clearly shows that the number of cells in the selected circuit will always be those which are included between the two slides, or from 3 to 9, making a battery of six cells. As the cells are connected, as it were, in a circle, the polarity of the terminals will depend on the relative position of the slides; if the relative position of these latter is transposed from that shown in the diagram, the polarity of the terminals N' and P" would be likewise reversed. Thus the electrode which is connected with the smaller number on a button would form the negative pole. If this same scheme were compared with the arrangement as described in regard to the double collector its meaning would be made clear.

It is always convenient to reduce the number of metallic studs, so that groups rather than single cells shall be connected, and then used as pairs; for in this way a smaller box may be used, and the extra size of the surface of the elements may be increased by the arrangement in groups of two or more cells.

In a preceding diagram (Fig. 54) the arrangement of groups of two cells, which are afterwards arranged in series, shows the manner in which Gaiffe disposes his batteries for medical use.

Gaiffe's battery with the dial collector and graduated, or "absolute," galvanometer is represented in the figure (Fig. 56).

It is often convenient, especially for electrolysis, to have some system by which the operator may quickly arrange his battery for coupling the cells

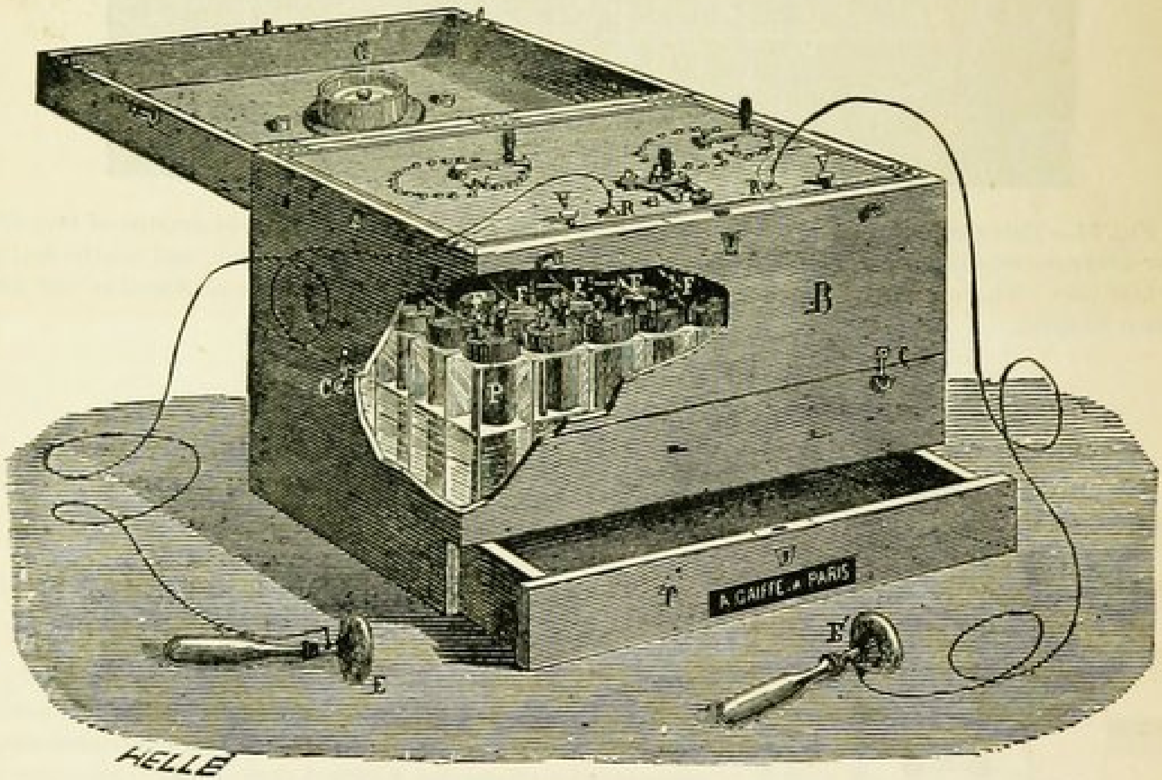

Fig. 56.

either for series or groups or for mixed arrangements. This may be done readily by a switch board like that shown in the annexed illustration (Fig. 57).

The first desideratum of apparatus should be that of simplicity and easy application. As most of the operations for electrolysis are of such a nature that they will naturally be performed in a physician's office or at a hospital, it is not essential that the battery should be in a portable form. Portable batteries are expensive, and when some of the auxiliary apparatus which has been described in the preceding pages are combined in a portable form, they increase the expense very materially.

A battery of twelve cells should not cost a great many dollars, and the switch board previously mentioned can be easily made for five dollars.

A voltameter for measuring the current strength is a cheap matter, and a galvanometer with a roughly made resistance box or a water rheostat can be obtained for a few dollars more.

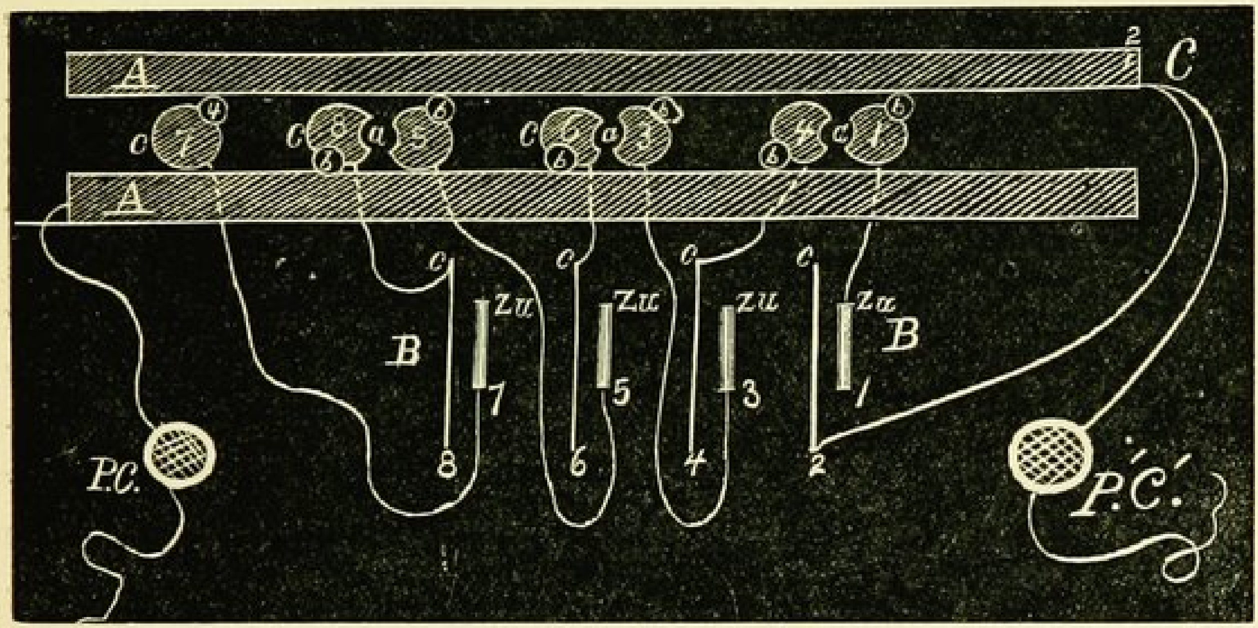

FIG. 57.—This diagram is intended to represent a combination switch board. *A A* are two strips of brass, each of which is connected with a pole cup, *P C*, to which the rheophores may be attached. *B B* is the battery; the zinc of the first cell *Zu* 1, is connected with the brass knob, 1; the copper element, *c* 2, is connected with the brass strip, *A*; the copper element of the last cell, *c* 8, is connected with the brass knob *c* 8, and the zinc of the same couple, *Zu* 7, is connected with the last knob *c* 7; the intermediate battery elements are connected as marked in the diagram. It will be evident that brass plugs introduced in the various holes between the metallic strips and the numbered knobs will make a connection in any desired combination; for instance, plugs inserted in *a a a* and 4 will connect the four cells in simple series; and plugs inserted in *b b*, *b b*, *b b*, and 4, will connect the cells for surface, that is, all the zincs will be connected directly together for the negative electrode, and all the coppers will be connected together for the positive electrode.

It is often convenient to apply two or more needles for electro-puncture which are connected with the same pole of the battery. Hard rubber cylinders may be fitted with brass inner tubes into which the ends of the rheophores may be inserted, and there held by means of set-screws; at the other open end of these cylinders a copper wire may be also held by set-screws; these copper uninsulated wires from two or more of these cylinders may be carefully twisted together to form a single rheophore to be connected with the battery pole cups. It will add to the convenience of their manipulation, if the wires should be first coiled by winding around a pencil, and then withdrawing the pencil. In this way a flexible rheophore is converted out of a comparatively inflexible wire.

The needles used in electro-puncture can be made from a wire of the irido-platinum alloy by filing the point of a coarse wire into a bayonet tip, or like a glover's needle. This needle can then be fastened by a set-screw into a piece of thin brass tube, which is covered with a hard rubber hollow cylinder; the rheophore can be fastened by the same method in the other end.

Needles for hypertrichosis should be as fine as possible, and these may be filed on a piece of emery paper from the finest purchasable irido-platinum wire, and afterwards can be sharpened on a piece of Arkansas stone.

The positive electrode may be easily manufactured from a piece of gas-carbon, and fitted with a small piece of metallic tube for the reception of the rheophore; a wad of wet absorbent cotton should be interposed between the carbon and the skin, preferably moistened with hot water.

In operating for hypertrichosis it is desirable to have a magnifying glass fitted to the operating chair. This will make the hairs and the opening into the skin along the hair shaft more readily seen. The magnifying glass can be fitted into a ball and socket joint, which latter may be attached to a rod which is itself movable in a collar; in this way the glass may be moved up and down in a vertical plane and, also, may be adjusted nearer to, or farther from, the patient's face.

CHAPTER XIII.

GENERAL SUMMARY. A DISCUSSION OF SOME OF THE CAUSES OF THE RESOLUTIVE ACTION FROM GALVANISM OF THE TISSUES BY SURFACE APPLICATION OF THE ELECTRODES, OR FROM THEIR ELECTRO-PUNCTURE.

THE effects of what is called electrolysis upon the absorption of certain hypertrophied growths of the structures of the animal organism have been presented in the preceding chapters. It should have been observed that the theory of true electrolysis—viz., electro-chemical changes of the constituents of the organic structures—is not appropriately applied to explain the resolution of certain hypertrophied structures of living tissues.

It cannot be denied that the animal organism should be considered as a solution of certain chemical compounds. It is not improbable that the transmission of an electrical current through these dissolved substances may be attended with the same phenomena which are observed in the chemical laboratory. The tissues of the animal organism are constantly undergoing chemical transformations, the extent of which is not known to science.

The therapeutical applications of electrolysis, or, as we should rather prefer to consider it, electricity locally applied to the tissues, cannot be intelligently understood without having first a clearer knowledge of the natural processes in operation in these structures, than is usually presented in the treatment of diseases by the ordinary medicinal agents. It should not be supposed that we intend to cover the whole ground of this discussion, but it should be remembered that in the application of this agent, called electricity, we are principally concerned with the growth of normal tissues. The treatment of pathological formations in them is a more complicated affair. It is undoubtedly true that the use of medicinal agents for the relief of diseased tissue, and its restoration to a normal condition, has occupied the attention of careful students from time immemorial. Even at this later date observers of disease have accused the practitioner of medicine of attributing the results of his *cure* to art, when in reality the restoration of the unhealthy tissue should be explained upon the grounds of the natural resources, the *vis medicatrix naturæ*, which are inherent in the organism.

In our opinion the subject before us should be discussed upon those natural facts which are revealed to us in histological formations, and should not be viewed in the same light as that of medicinal agents which are used to combat pathological formations. We should seek, if possible, to grasp the simple truths of natural formation before we attempt to understand the more complex phenomena of anomalous changes. The former are sufficiently intricate and of doubtful character to occupy the whole of our attention. It would indeed be bold to forecast a permanent settlement of these doubts from the small amount of evidence now in the hands of our physiologists. Yet we may be pardoned for our presumption in the attempt to occupy the ground which is recognized at present as a state of probable truth, provided that we confine ourselves to these as problematical hypotheses, rather than to accepted facts.

We will first consider the application of electricity, simply upon some of the chemical problems at work in the tissues. The knowledge of these chemical processes is necessarily limited to a very small circle of information. Most of the study of these chemical phenomena has been directed to the analysis of dead organic matter, from the very fact of the difficulty of observing these effects in constantly changing living matter.

The vague use of the term ELECTROLYSIS has been by common consent transferred from its known effects upon chemical compounds in solution within the chemical laboratory to the structures of living tissue. This incorrect use of the term has grown out of the empirical application of electricity to the tissues of the human body. The inconsistencies of the results of its empirical use have puzzled the operator, and he has sought from the mass of chemical research to obtain what would reconcile these conflicting effects.

We frequently hear the explanation of the action of "electrolysis" to a destruction of the normal hair growth as being ascribed to the decomposition of the structure into its elementary chemical gases. This explanation is based upon the teachings of chemists, whose experiments have been performed upon tissues which have ceased to be functionally active. It cannot be denied that the application of the electro-puncture to the hair follicles is attended with the evolution of bubbles of gas, and that these accumulate around the needle electrodes; yet no published report has been produced to show the exact proportions of these decompositions into elementary gases, or their relation to the organic chemical compounds which belong to the organized structures. In the absence of such information it is impossible to draw correct conclusions of the *modus operandi* of the electrolytical action upon direct chemical changes in the living tissues.

It should constantly be borne in mind that in the consideration of this question we are merely discussing the action of electricity as modifying the results of hypertrophy of normal tissues; it cannot be denied that many of these hypertrophies are easily reduced by a very feeble current of electricity, when the electrodes are brought in direct contact with these growths.

It would seem as if many writers who treat of the application of electricity to the arrest of growths had attached far too great importance to the chemical decompositions of organic compounds. We find the same peculiarity in treating of the physiological relations of the histological formations of tissues. Among one class of writers it may be observed that the chemical formations are considered of higher importance than the biological formations. On the other hand, it will be observed that the functions of the cells are more highly exaggerated than the behavior of organic chemical structures in the nutrition, repair and dis-assimilation of the elementary formation of these composite tissues. It is extremely difficult in the midst of this uncertain knowledge which we possess of the causes which are at work in forming and destroying the effects of metabolisms of the human tissues, to separate the causes from effects in these processes. If this be the case in the general subject of histology and the physiology of the living tissues, it will be evident that the problem of therapeutics, which is even more complicated than the normal processes of repair and waste, is far more difficult of solution.

Electrolysis of the inorganic and organic chemical structures has occupied our attention in the second chapter, and the details of laboratory experiments have been carefully described in that portion of this treatise. The electro-chemical reactions in the galvanic cell are well known to us, and the interference which is offered by polarization of the elements and the solutions in these cells, is an important factor, which enters in the resulting current of electrical action.

The electro-chemical effects which are produced by this electrical current in the intimate structure of the tissues of the human body, comprised in the interpolar zone, are even of a more complicated character than those which are observed in the galvanic cells themselves. We have seen that the chemical effects in this interpolar zone must be equal to the chemical effects in the galvanic battery; because this is the very basis upon which scientific facts rely. We measure the strength of the current of electricity by the amount of decomposition of the chemical compounds in all the cells which form our galvanic battery:--as well by the deposition of the metallic elements of copper, and the reformations of zinc salts, as by the evolution of the gaseous elements which are set free.

When this electrical force is transmitted through a conducting medium comprised between the two terminals of the galvanic battery, and whose chemical structure is well known to the physicist, it is an easy matter to trace the transmission by the amount of destruction of the composite material of the known conductor; provided that the latter is susceptible of chemical analysis, and provided that this conducting medium is formed of inorganic chemical compounds. In this case the energy of these compound bodies, stored up in a latent form, is computable from a knowledge of the units of combining equivalence (see page 18) of the elements whose union forms the compound inorganic structures.

We may compare the effects of this combination with the regular forms of bricks which are used by the artisan to make a definite simple structure. A repetition of their orderly arrangement according to a definite plan will always reproduce a simple structure, and one whose shape is recognizable. On the other hand, if we can imagine that the materials of a formed structure (though in their elementary composition we may separate the simple bodies entering into the combination and count the number of each of these elements) are formed into a mass of uniform similar shape to that of the bricks, and yet of some compressible material like soft peat or mud, the resulting structure may not be reproduced a second time by the artisan; because the materials are constantly liable to alteration.

Though this illustration is crude and perhaps not exactly applicable to the case before us, yet its suggestive relations may not be inapplicable to a study of the effects of electricity upon organic chemical compounds whose composition has been determined by the chemical expert. He has not only found the elements which compose organic compound, but he has also determined in what way the introduction of an electrical force of measured amount will change the form of the combination of these elements; so that the same elements will produce an organic structure which has a different shape from that combination which is formed without this added force.

Now, the action of electricity, or electrolysis as it is called, upon a simple inorganic chemical compound like that of hydrochloric acid causes the separation of hydrogen at the kathode and chlorine at the anode. The chemist knows in advance of his experiment that he will obtain thirty-five times by weight as many parts of chlorine at the anodal terminal, as he will obtain in hydrogen at the kathodal terminal. He knows, moreover, that this will always happen on a repetition of the same experiment.

When the chemical compound is an organic body the chemist knows in advance of his experiment that the substance, camphoric acid for instance, will split up by the action of electrolysis into a camphor-anhydride at the positive pole, and potassium at the negative pole; but he also knows that camphor-anhydride has by this decomposition two uncombined elements of oxygen which are not satisfied; in other words he has some nascent oxygen which is seeking for a combination with some other element and may combine with both carbon and hydrogen. When the chemical operation is restricted in the laboratory to a reaction with the organizations which the chemist may bring into their neighborhood, the resulting decomposition may be definite and calculated; but where the reaction is in living tissues, the complex materials which compose the latter may change the resulting decompositions and reformations. Thus the more complicated the structure the more complicated are the resulting decompositions and reformations.

Notwithstanding all these facts, the statement is true that the same law governs both inorganic and organic chemical structures. The apparent difference between the reactions is due to the difference of the compounds themselves, and is explicable on the ground that secondary decompositions occur subsequently to those which are first observed.

The gases which collect at the two opposite electrodes in the living tissues are in a free state, and may combine to form other secondary compounds with the gases or elements which are in solution within the tissues comprised within the interpolar zone.

Again, the decompositions which occur in the organic chemical compounds are not finished at the first moment of electrolysis, but may go on after the original cause of disturbance has been removed. The exact limit of reaction has not yet been determined.

Another complication of electrolysis of organic compounds should be pointed out in contradistinction to that of the inorganic compounds:—The variable concentration of an inorganic substance in solution will not vary the result of its decomposition by electrolysis, while this is not true of the organic compounds. Concentrated acetic acid is more rebellious to electrolysis than a weak dilution of this acid.

It should be remarked that we have been discussing the behavior of organic substances apart from the living organism. It can readily be supposed that in the latter instance the complications are even more complex, because we are dealing with force employed against other forces. We can thus suppose that much of the introduced force has been expended in overcoming the forces which are constantly at work in the living tissues. We have seen (page 55) that the dissipation of energy in overcoming the potential energy at work in a given case is enormous as compared with those cases in which it meets with no opposing force. We cannot estimate the loss thus occasioned by the use of an electrical current in the living tissues, because we are unable to calculate the amount of force at work in the tissues, when no electrical disturbance is transmitted through them. When a muscle lifts a ten-pound weight it is known that this force must be expended in the tissues which accomplish this power. The amount of force required for the lifting of this weight by means of electricity is of course calculable; but it would be absurd to suppose that the transmission of an equivalent amount of electricity would be required to neutralize the power necessary to lift this weight. It would be found that the application of a rapidly interrupted current of a feeble strength would paralyze the muscular contraction so that the lifting of the weight would be impossible.

It is not necessary to assume that the effects of electrolysis must be displayed to such an extent as completely to destroy the chemical integrity of the living tissue. A feeble chemical action in these structures, when of a character to oppose the processes usually displayed in the organism, may so disarrange these normal actions as to interfere with the organic combinations which are essential to the repair of these tissues. If, then, we are to assume that the whole effects of electrolysis as presented in these foregoing pages relates only to the chemical basis of life, we cannot suppose that an amount of chemical action is required equal to that which decomposes dead structures in the laboratory.

This mode of reasoning would naturally lead to the consideration of other effects of electricity than simply those of a chemical nature. The teachings of physiology show us that living structures are endowed with functions, whose action may result in very opposite effects. Chemistry is a science which rests upon data which are sufficient to allow the chemist to formulate its teachings upon certain mathematical rules, the application of which will most generally produce similar results. Physiology, on the contrary, is not a science and probably never will rest upon mathematical formulas; its teachings are constantly attesting the error of previously established theories. Therapeutics, again, rests upon the two preceding and other classes of natural observations; consequently its foundation is never secure, and never stable, and shifts on the sands of time.

At present, the very essence of the teachings of physiology, apart from the study of chemistry, is founded upon the functions of living cells. "Our information in reference to the chemistry of the connective tissue cell is, necessarily, of the most limited character and is almost confined to a knowledge that the protoplasm is proteid in nature and that the nucleus shares the characters of nuclei elsewhere and has probably the same composition."[1]

"Speaking broadly we may, however, say that the epithelium covering the external surface of the body is composed of cells which are, even in their most active stages, the seat of but slow and unimportant chemical changes, whilst a large number of them cease to be the seat of any material exchanges whatever, or to manifest any phenomena which characterize them as living, long before they cease to form part of the living body."[2]

Speaking in a general sense in regard to the nutrition and formation of healthy tissue of the body we may classify these under two principal heads:—that of METABOLISM, which comprises the whole range of transformations under the influence of chemical processes, and by means of which the proteid substance undergoes its many changes; and that of CELL PROLIFERATION, by means of which the cells are multiplied.

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[1] Gamgee, op. cit. p. 251.

[2] Idem, p. 294.

In regard to the first of these, we must undoubtedly admit that lower forms of organic structure are raised by some process of synthesis into higher forms of organic structure.

In regard to the second, it is difficult to believe that one form of cell can be changed into a second form of cell which is endowed with a higher kind of function.

The first-named class partakes of the chemical characteristics, while the last named is purely biological. We can thus suppose that the former passes down the steps, as it were, by successive chemical stages in its destructive career, whilst the latter dies and is immediately carried off as detritus. Moreover, when the second loses its existence it ordinarily carries along with it an unborn child, the nucleus, upon whose separate existence depends the perpetuation of the tissue; the former, on the contrary, can again receive new energy in its arrested path, by which it can be built up again into a similar structure.

When the current of electricity, even though its strength is equal to eight or ten milliampères, is brought into action for a few moments within the hypertrophied connective tissue growth with papillary formations of the skin, as for instance a wart, the vitality of this tissue is arrested, and within a few days it will fall off from the neighboring living tissue as a dry eschar. The underlying tissue is healthy and no cicatrix results which is commensurate with the original extent of the hypertrophy. In this case it is extremely difficult to suppose that the whole effect of the destruction is explainable upon a simple chemical decomposition of the living structure. There must be some more remote cause than this.

Again, the electro-puncture into a hypertrophied vascular tumor, which is composed simply of an increased amount of connective tissue growth or embryonic cell formation, like that of a simple goitrous enlargement, is followed by a diminution in its size, but not immediately after the puncture. The first effect to follow the application of electricity, is an infiltration with water of the subcutaneous tissue which overlies the hypertrophied growth, so that the flesh looks swollen. Secondarily a slow retrogression of the enlargement ensues with a shrivelled condition of the cutaneous covering. Repetition of the treatment is succeeded by a continued shrinking of the growth, which may be prolonged for several days after the enlargement has begun to retrograde. This effect follows the introduction of the electro-negative needle, but not that of the electro-positive needle; but it also follows the application of the positive electrode to the surface of the skin, the negative only being inserted into the growth. A reference to the cases reported by Chvostek, where both electrodes were applied simply to the surface of the skin, and where neither pole was inserted into the growth, shows that by his method the retrogression of the tumor will also result.

We are quite aware that many writers are led to believe that the cause of the cure of goitre by Chvostek's method of application is to be attributed to the improvement through stimulation of the ganglionic nerve centres, including also that of the nerve filaments which pass through the restiform bodies or the medulla oblongata. The cases of cure which have been reported as following the electro-puncture, where the positive electrode has been held in the palm of the hand, as well as those which followed treatment by the introduction of carbolic acid into the growth, and those which followed the irritating applications of strong tincture of iodine to the surface of the skin on exposure to the hot sun or to a hot fire:—none of these cures can be explained on the supposition that the goitrous affection is caused by some peculiar enervation of ganglionic or other nerve centres; nor can it be reasonably inferred that these cures were caused by some stimulating effect upon these nerve centres.

Let us turn for a moment back again to the chemical explanation of electrolysis as applied to living tissues.

It has been shown in detail that the action of electricity produces similar changes in organic chemical compounds which have been observed in the inorganic kingdom. The human body however, is not simply an aggregation of organic chemical compounds in solution; other processes than those of chemical transformations are going on in the living tissues. These latter processes are of a biological character and are more intricate than those of chemical changes. These metabolisms, whether of the constructive or destructive character, are chiefly performed by functionally active cells. These cells are multiplied by functions inherent in themselves, and their food or nutrition may be received (we do not say positively that they are received) from the chemical substances which are dissolved in the fluids in which these tissues are bathed. It may indeed be doubtful whether the cell multiplication can be performed except in the presence of these dissolved chemical substances.

It may be reasonable to suppose that any interference with the stability of these chemical compounds, from which the cells might receive their food, may arrest the process of cell multiplication. It may even be supposed that the presence of a force in opposition to that evolved in the healthy tissues, may cause a degraded condition of this food supply, in consequence of which a degraded cell formation may ensue. These hypotheses may be reasonable, but yet they rest upon too slender a foundation at present to receive much credit.

The explanation of the reduction in the extent of hypertrophied normal tissue by means of the display of an electrical force, transmitted from without through these tissues, does not seem to rest simply upon chemical grounds. The amount of chemical action caused by the presence of electricity in the living tissue is too insignificant to have the whole weight of evidence in its favor. We have seen that these chemical changes, as shown in the third chapter, are as positive with the organic compounds in solution as with the inorganic compounds in solution; but we have also seen that the amount of these chemical changes is in proportion to the strength of the electrical action; we have also seen that to produce these chemical decompositions in solution to any great extent, the conducting medium for electrical action must offer a ready transmission of electricity and that the resistance in a conductor will reduce the strength of the electrical current in proportion to its resistance.

There is another view of the question which is of serious importance in this discussion. If the effects of so-called electrolysis are simply of a chemical nature, why does it happen that a certain class of hypertrophied tissue is amenable to the action of electricity, while another class is not only rebellious to this form of treatment, but even seems to be favored by electrical display in these degraded forms of tissue growths? We have seen that those tissues whose nutrition or growth are concerned by multiplication of the embryonic cell are ordinarily dissolved by electricity, while those growths which seem to be increased by multiplication of a degraded cell-formation, and are neoformations, are stimulated by electricity.

It must be distinctly understood that we are not speaking of the use of the heat of thermo-cautery by means of strong currents, by which the diseased growths can be marked off and separated, as by a knife, from the adjacent healthy tissue. This effect is not that of electrolysis in any sense of the word. We are discussing the property which electricity possesses of causing an arrest of growth of the cell formation, from the hypertrophy of which the normal tissue may form a benign tumor. The cases reported from clinical record bring this question most prominently before us.

It would seem, therefore, that the cause of the arrest of hypertrophied or normal growths of the animal tissues should be attributed to some other causes than those of a chemical nature, and that electrolysis is a misnoma when applied to this treatment.

If the chemical explanation of the action of electrolysis in living tissue is applicable to those cases of hypertrophy of tissue growth, it would be reasonable to suppose that all forms of tumor should be amenable to the action of electrolysis; because the same rules of chemical decomposition would apply in malignant as in benignant growths. In both of these classes the organic living structures ought to be destroyed by the chemical decomposition of the compound elementary organization. Again, if this mode of explanation is applicable we might even suppose that a degraded form of organic structure of the simple hypertrophy of normal tissue would follow treatment of a benign tumor by electrolysis; in this case the growth would be changed into a neoformation from an alteration in the elementary structure, a benign tumor might be secondarily a malignant growth. It is generally admitted that neoformations of cancerous character are simply a degraded form of tissue. If electrolysis causes a decomposition of the organic compounds in healthy tissue, we would have good reason for the supposition that its display in normal tissues would change the latter into a degraded cell formation; or if the latent energy set free by these chemical decompositions is free to act upon their living structures, it would stimulate cell proliferation.

We have also seen in the preceding chapters that electrolysis, so-called, induces coagulation of blood in the vessels, and that this effect has been applied to the cure of erectile vascular tumors, to varicose enlargement of veins and to arterial enlargements or aneurisms. In the two former instances the therapeutical applications are most generally followed by successful cures, provided that the application has been properly conducted. Many clinical observers have been led to explain the process of cure on the supposition that an acid reaction of positive electricity causes a coagulation by the presence of the acid evolved from this electrode. Reference to chapter second (p. 23) will demonstrate that the amount of acid set free at the positive electrode is very inconsiderable. Moreover, it is shown in the same chapter that the liberated acid is only immediately in the vicinity of the electrode, and cannot penetrate deeply into the blood; while, on the other hand, the coagulation extends beyond the possible point of acid penetration.

These and other considerations presented in the preceding portions of this treatise would appear to show that the action of electrolysis in living tissue does not rest upon the simple basis of decomposition of the organic chemical compounds of animal structure. How can the absorption of the fluid contents of a cyst, as in hydrocele,[1] sebaceous wens, and ovarian dropsy be explained simply upon the decomposition of these fluids? There is no doubt reason for believing that these cystic tumors have been cured, not only by the electro-puncture, but also by the surface applications of the electrodes in these abnormal growths.[2]

The cure of these effusions is not entirely to be credited to the simple action of electricity acting in living tissues any further than in supposing that a pleuritic effusion can be absorbed simply by a rubefacient. In fact, we find that, besides the electrical treatment, the combined medication of hydragogue cathartics and diuretic adjuvants are required to assist the emunctories in getting rid of these fluids from the cavities of the body.

Von Ehrenstein apparently considers that the draining effects of hydragogue medicinal agents are of importance in causing the absorption and elimination of watery tumors from the abdominal cavity. We see, therefore, that the successful operators by electrolysis are not content to admit that the employment of electricity alone can effect the cure of effusions. We find, also, that some of those operators who employ this method in the treatment of goitrous affections, prescribe the advantage of its combination with the medicinal use of iodide of potassium. The theory of the action of this last-named drug is supposed to favor the chemical decompositions within the tissues, but the grounds for this hypothesis evidently are not established, and it would be more reasonable to attribute any beneficent effects to the interstitial action of this drug.

That iodide of potassium acts as a diuretic is well shown by Dr. Ringer[3] who reports the increase of a scanty uresis from 30 to 50, to 60 and even to 120 ounces in twenty-four hours; at the same time the dropsy of the

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[1] Rodolfi, in Virchow und Hirsch, Jahresbericht, 1872; Erhardt, Ibid.; Frank, Archives of Electrology, vol. i., p. 170.

[2] Von Ehrenstein Allg. Med. Central Ltn., 1876; Semeleder, Am. Jour. Obs., July, 1882.

[3] Handbook of Therapeutics, 11th edition, Wm. Wood & Co., 1886.

patient who had Bright's disease disappeared in a fortnight, "every vestige of it." He was led to suppose that in these cases there was a syphilitic taint, but in some of them "there was no reason to conclude that the patients were syphilitic." In one of his cases he gave 200 grains daily before the dropsical effusion had been eliminated.

The coincidence in the effects of iodide of potassium treatment for the cure of bronchocele (goitre), aneurism and dropsical effusions or cystic tumors, with relief following the use of electrolysis is somewhat striking; yet it may not be so very remarkable in view of the action of both remedies being attributed to the influence of interstitial osmosis. While we may be accused of anticipating a novel explanation of the action of iodide of potassium, the same accusation in respect to the action of electricity cannot lie in the face of the opinion advanced on the authority offered by Tripier, Frommhold, Von Ehrenstein and others, which has been referred to in a preceding chapter.

The action of osmosis within the tissues of the body has not received the attention of physiological students which the matter demands. The observations and suggestions of Dr. Headland many years ago have apparently not attracted the attention of therapeutists of more modern times. He has shown how large a quantity of water is thrown into the intestinal canal after the administration of certain brisk saline cathartics, like sulphate of magnesia, and thus draining off the fluids of the body. More recently the use of Carlsbad salts, phosphate of soda, etc., are used to relieve the pressure within the tissues, caused by a passive hyperæmia or stasis. This treatment pursued now so generally in oxaluria, in uræmia, and in the gouty diathesis, has produced some very brilliant cures, or a temporary relief to symptoms of oppression and malaise so commonly met with in modern days. It is highly improbable that the great improvement in these symptoms should be attributed to the increased metamorphosis of tissue, because the quantity of urea eliminated by this form of treatment is not commensurate with the improvement and oftentimes with the loss of flesh in the cases of concomitant obesity. On the other hand, it is highly probable that the mode of action is due to the increase of the osmotic currents within the interstitial tissues. It is also probable that the elimination of poisonous materials within these tissues, such as that of lead and of syphilis, is materially influenced by the promotion of osmosis by means of the medical use of iodide of potassium. The reputation of an "alterative" possessed by this drug is certainly not ill-founded; and, with this explanation of its mode of action, is certainly rational.

It would be idle to assume that the action of electricity conveyed by the electrodes directly to the subcutaneous tissues is entirely free from the production of chemical changes. The purpose of the author would be entirely misconstrued, if such deduction be gathered from these remarks. It is, however, wrong to attribute the whole action of electrolysis upon living tissues to the chemical decompositions of their organic compounds.

We cannot explain the destruction of the fœtus in extra-uterine fœtation on the supposition that electrolyisis induces a chemical decomposition of the organic structures which compose this living tissue.

We cannot explain the destruction of the hair root, its papilla and sac, on a chemical decomposition of the structures composing these tissues. For in both of these instances a total quantity of electricity equal to 100 or 300 milliampères' strength is too inappreciable to account for the permanent death of the tissues.

So far as the physical properties of electricity which are displayed in living tissue are concerned, we must be content for the present in assuming that the destructive action by this agent is in the main limited by the power of electrical osmosis, or the cataphoric action of electricity. By means of this physical property, which is recognized in fluid substances confined in porous septums, and which may be endowed with great powers of resisting the transmission of electrical force, we may explain many of the interferences with the nutrition as well as the proliferation of cell formation. It is not only that electricity may transport fluid particles *en masse* from the positive to the negative electrode; but this transportation of fluids may induce organic changes, by the rapid removal of the pabulum upon which these cells depend for their maintenance and propagation.

The character of the proliferation of cells by the movements of the nucleolus and the karyokinetic formations of the fibrillæ has been carefully detailed in a preceding chapter (p. 118). The effects of interference in these processes must be followed by an interruption in the biological formations. If this hypothesis rest upon a permanent basis, we have grounds for an explanation of the so-called action of living tissue as arresting the hypertrophy of normal tissue. We may assume that any healthy tissue, which depends for its nutrition upon the proliferation of cells, will always be restricted by the presence of too little or too large a quantity of fluid in the intimate structure of these tissues.

The pathological relations upon which depend the growth of neoformations, which we must admit are a degraded form of cell multiplication, have not yet been formulated upon the hypothesis of the karyokinetic movements. We cannot therefore anticipate their application, nor can we explain why the so-called electrolysis should stimulate their cell-multiplication. It may be possible to assume, as in other biological processes, that the presence of too much fluid within their cell structure may accelerate the peculiar cell-growth which makes the distinction between a malignant and benignant hypertrophied mass.

Histology teaches us that a functionally active cell of embryonic type may become by a retrograde process a cell without power of reproduction, and that in these instances it may be changed into a fatty cell, or may form with other retrograde cell-formations, a fluid substance, as for instance that of a secretion. Upon this hypothesis and with a better knowledge of the physical laws of electrical osmosis, we may, at some future period, be enabled to apply in the living tissues the laws of electrical display in such a manner as either to increase, or to diminish, the amount of the fluid within the cell structure.

It must be certainly admitted by careful students of the literature of medical electricity that the application of the theory of true electrolysis, either for the nutrition or destruction of living tissue, has not made much progress, though its chemical relations have been studied by expert physicists and chemists. It would seem advisable to turn our attention to the display of electrical force as effecting the fluids of the body, which is shown in its modification of the physical laws of osmosis, rather than in those of chemical reactions.

The action of electrical osmosis in a porous medium can be shown by a very simple experiment, which can readily be repeated.

If two platinum electrodes should be connected with a constant galvanic current from ten or twelve cells, and then be immersed in pure water, the negative or zinc terminal within a porous vessel, and the positive or carbon terminal outside of this porous medium, the water in the inner vessel will accumulate in two hours to a level about one-sixth higher than that in the outside. If instead of using two platinum electrodes, the negative should be formed of zinc, and the positive of platinum, electrical osmosis will be more than twice as rapidly performed as in the first instance.

By referring to chapter second (p. 18) it will be observed that the chemical combining equivalents of platinum or iridium, as compared with that of zinc, is in the proportion of 197: 65; therefore we might expect that the energetic action between the oppositely charged conductors of platinum and zinc would be three times greater than with the electrodes made of the same kind of metal, provided the diameters and lengths of the conducting mediums be the same. Another factor, that of resistance of the conductivity of the metals should also enter into the problem; the comparative resistance of the platinum and zinc for the same dimensions bears the ratio of 116:72, the conductivity of zinc being the greater. It has been shown that the higher the resistance of the conductors, *within certain limits,* the greater will be the cataphoric action of the transmitted electricity.

The subject of electrical action on electrolytes in solution has recently[1] received renewed attention from E. Semmola, and is of interest in showing that an increase of electrolytical action may take place in a fluid conductor where different metals are used for the introduction of electricity into the solution. In his experiments a third metallic conductor was arranged within the fluid, neither end of which was connected with the terminals from the battery. His voltameter was composed of a vessel partially filled with water acidulated by sulphuric acid, and into the glass sides of which two platinum ribbons were sealed and immersed in the solution; an arc of metallic ribbon in length about two-thirds of the diameter of the vessel was immersed also in the solution, the ends of which were not in contact with the platinum electrodes. Semmola observed that the passage of an electrical force through the solution between the platinum electrodes induced a secondary electrolysis at the poles of the third metallic conductor, the arc above described, but that more hydrogen will collect at the kathodal end of the third conductor, viz., that end which is nearest to the kathode from the battery; while if the third conductor be formed of zinc, the oxygen, which ought to be liberated at the anode in equivalent proportion to the hydrogen at its opposite pole, combines with the zinc, and does not therefore appear as a free gas. It is not necessary to immerse the whole arc, but only its terminals, within the solution.

In some of his experiments with this form of apparatus, where the

[1] La Lumiére Electrique.

galvanic current was that which was generated from a battery of six or seven Bunsen cells coupled for tension, he obtained 5.68 cubic meters of hydrogen with the third conductor, and 5.65 cubic meters without it; 13 cubic meters with this conductor, and 13.2 without it; 10.57 cubic meters with, and 10.75 cubic meters without this third conductor. These experiments were performed, however, on a solution whose acidulation was variable. His conclusions from experimentation lead him to assert that, when the third conductor is employed and in the same strength of solution, the total amount of hydrogen liberated is more than without this conductor; therefore electrolytical decomposition of a solution is increased under these circumstances.

The intensity of "secondary electrolysis," according to Semmola, varies with the chemical nature of the third conductor, with its dimensions and the position it occupies in relation to the primary electrodes; and also with the proportion of acidity of the solution, the strength of the current, and the section of the containing vessel.

If the secondary electrodal arc be made of platinum, a feeble disengagement of oxygen gas appears at its anode, and when a current from ten Bunsen cells is transmitted. If this electrode be made of gold or silver a feeble gaseous decomposition of hydrogen will collect around the negative, but no oxygen appears at the positive pole, when a current from six Bunsen cells is transmitted.

If, on the other hand, an easily oxidizable metal like copper, iron, brass or zinc, be used for the secondary electrode, the hydrogen only will be disengaged, and that at the negative pole of the arc, and this after making due allowance for the action of the acidulated water upon the oxidizable metal. On the latter account, Professor Semmola preferred to use amalgated zinc for the electrode; in this case, the amount of gas liberated increases from the centre, or node of the arc, to the kathodal terminal, where it was abundantly disengaged.

The amount of electrolytical action was determined when a battery of seven Bunsen cells was coupled for tension: a solution of sulphuric acid and water (1:20) in the voltameter, arranged with a zinc arc for secondary electrolysis, decomposed in one minute of time 6.2 cubic centimeters of hydrogen at the primary electrode and 1 cubic centimeter at the secondary electrode. The same apparatus with copper for the arc developed 0.6 cubic centimeters of hydrogen at the secondary electrode, and with silver, 0.1 cubic centimeter. If the secondary electrode be formed of several arcs, arranged in line one with another, a secondary electrolysis will occur at each kathodal end, but the amount of electrolytical action decreases with the decreased length of these electrodes. The best effects of this secondary decomposition is observed when the secondary electrode is in the axial line between the two primary electrodes, and the maximum action decreases in relation to the angle of deviation from this axial line and at a right angle entirely disappears. This effect is similar to that observed in the polarization of magnets.

Another interesting result of his experiments appears to be the most important to our present discussion.

The annexed table shows that in non-acidulated water the proportion of decomposition of gas at the secondary electrode is greater than in the stronger acid solution, and that this increased ratio is due to the increased amount of gas liberated at the primary electrode in the case of the stronger acidulated water.

Strength of acid solution.	Quantity of Hydrogen gas liberated at kathode of primary electrode.	Quantity of Hydrogen gas liberated at kathode of secondary electrode.	Ratio of amounts liberated between the two electrodes.
Non acidulated water.......	1.7	0.6	0.35
One part in fifty parts.	6.	1.4	0.23
One part in twenty parts...	9.5	1.8	0.19
One part in ten parts.......	12.	1.0	0.08

Semmola remarks, however, that there is a certain limit in which the primary electrolysis alone increases, while the secondary electrolysis decreases.

The explanation of this induced action in the secondary electrode is an illustration of polarization, and the tension of the current in the electrolyte is shown by means of a sine-galvanometer to vary in proportion to the nature and dimensions of the third electrode.

This author presents these experiments as proof of the principle advocated by Becquerel that

STRONG CHEMICAL AFFINITIES MAY BE OVERCOME BY THE SIMULTANEOUS USE OF VERY FEEBLE ELECTRICAL FORCE AND APPROPRIATE SELECTION OF THE GIVEN CHEMICAL AFFINITIES.

We submit that the above case will explain some of the peculiarities in the selection of zinc electrodes for physiological polarization of the tissues, and that probably the cataphoric action of electricity is another name for induced electrical action within soluble electrolytes, and that the increased electrical action in these more resisting fluid mediums of conduction will be displayed under the head of motion of its molecular composition.

We might make a rude illustration, which, though not exact, may be an apt way of helping us to understand the case; cataphoric action represents what active agitation or stirring in a chemical fluid of composite character will do in assisting molecular action.

An extended investigation of the laws of electrical osmosis in a conducting medium would be an important consideration of this question of the resolutive action by electricity upon living tissues. This inquiry should be directed not only to the conductors of electricity used in the apparatus, but also to the kind of tissue within the interpolar zone comprised between the points of contact of the electrodes. The question of variations in temperature should also be considered.

It may be found that the lower grades of cell-life are endowed with different resistances of conductivity as compared with those of healthy tissue. This question is touched upon here as offering an important field for investigation, which is certainly within the scope of this treatise, but is not within the power of the author to present at the present time.

The elucidation of such an inquiry would probably bear strongly in explanation of the so-called electrolysis in living tissue, and afford a more fruitful field than the true electrolysis based solely upon chemical problems. A correct explanation of the modus operandi of electricity in living tissue would lend material aid in showing the true therapeutical applications of the so-called electrolysis, and lift the latter from the dangerous and unsatisfactory grounds of empiricism to the more trustworthy domains of fact. It might, also, assist us in extending these therapeutical applications to other abnormal growths, which at present seem beyond our skill.

So far as we know at present, the so-called electrolysis is a satisfactory means of treatment in every form of hypertrophic normal growth, which are not amenable to the surgical use of the knife; and the resulting cicatrices should not be deformities, because the destructive action of the so-called electrolysis is not attended with secondary inflammations or healing of tissues by "secondary intention."

If the cataphoric action of electricity is the agency used for the cure of certain diseases, we can see the utility in not penetrating deeply into the tissues from which we wish to abstract water, or into the tissues within which we wish to convey water; we can also see why the introduction by means of electro-puncture need not be requisite for both poles, but why it is essential that one electrode should be introduced under the subcutaneous tissue of an hypertrophied mass, the other being applied to the cutaneous surface; we can also see why the combined use of medicines may assist in stimulating the emunctories to absorb and remove accumulation of fluids.

It will have been observed in the discussion concerning the cause of destruction of living tissues by electrolysis (see Chapter Fifth), that the proportion of water varies in the different tissues of the human body. The application of the theory of electrical osmosis to these may suggest that, as water will collect around the negative electrode, these tissues will be in a relatively impoverished condition, which is the result of deficient nutrition. Consequently, we may suppose that the multiplication of the normal cell growth has been diminished.

The corium of the skin is naturally much drier than the overlying subcutaneous tissue ; and if too large a quantity of water is poured out in the former tissue, we may readily infer a disturbance of its functions of nutrition. So, again, in regard to the nerve tissue, which in health contains only sixty-four to eighty-four per cent. of water; an increase of the watery character of this tissue may be accompanied with a disturbance of its nutrition and active functions.

Thus it will be seen that the explanation of the destroying action of an electrical current within the normal tissues of the human body, is susceptible to the formation of other theories than that of simple decompositions of its chemical structure.

It would seem appropriate in this summary of the action of the so-called electrolysis of living tissues to present a compendium of those kinds of abnormal tissue growth in which its application is indicated.

Undoubtedly it would add much to the value of this treatise if it was within our power to lay down precise rules, which would guide us in the use of this remedial measure. The state of our knowledge has not yet warranted the presentation of any such rules, though the reader may gather from the preceding chapters many important facts which will prove a useful guide in the application of electrolysis.

Though running the risk of repeating much that has been previously mentioned a certain allowance should be made in order to present this practical information in concise language.

Aneurisms. These are undoubtedly amenable to the action of electrolysis, but if they have proceeded to such an extent as to have eroded the adjacent tissues or bones, it might naturally be supposed that the aneurism will cover too much extent to receive a permanent cure. Again, if the communication between the aneurysmal sac and the artery runs obliquely in the direction of the arterial flow, or is a very large opening, even a firm coagulum will not remain *in situ* and so occlude the communicating opening. The action of electrolysis is only that which causes the establishment of a clot which in favorable cases may become adherent to the walls of the blood vessel; consequently, the after treatment should consist in perfect rest in a horizontal position, and the circulation will naturally be much benefitted by the use of large doses of iodide of potassium, and further control of the loosening of the clot will be accomplished by the application, when practicable, of compresses over the region of the aneurism.

Effusions. These are susceptible of treatment by means of electrolysis, provided that we bear in mind that its action is by osmosis. Since the osmotic current is directed towards the negative electrode, it would seem advisable to apply this electrode to those tissues which can absorb the fluid and carry it onwards to the emunctory system. This latter can then be stimulated by appropriate medicinal remedies, which will favor the discharge of watery excreta by the eliminating organs. These medicaments are hydragogue cathartics and diuretics; iodide of potassium, also, in large doses appears to assist in eliminating these secretions. This theory of electrical action and method of application involves the necessity of inserting the positive electrode into the interior of the fluid mass, and the application of the negative electrode as near as practicable over the tissues which contain the fluid. There is no record of the application of electrolysis to the collection of serous fluids between the pleural membranes, but there is every reason to suppose that its use in these cases is indicated, provided that the explanation of its action by the promotion of osmosis is correct. The effusion having primarily occurred through the reversal of the natural laws of osmosis, any method which seeks to restore the osmotic current to its normal condition would be entirely rational. Probably the explanation of tapping the chest to relieve the pressure of fluid from between the pleura surfaces is based on the counteraction of the tendency to a continuance of the effusion. It is equally plausible that the beneficial effects of iodide of potassium treatment for effusions is based on the same principle.

HYDROCELES. Undoubtedly some of the cases reported as cures were only temporarily relieved. This is equally true of the palliative treatment by surgically tapping the sac which contains this serous fluid. The introduction of iodine into the emptied sac completes the cure in many of these last-named cases. The same benefit could be obtained by the proper use of the electrolytical method, provided the same object be attempted, viz., to cause an irritation on the fluid side of the serous membrane, which will reverse the pre-existing condition of exosmosis. The reported cases of cures by means of electrolysis can rationally be explained on this hypothesis, and the failure of cures are equally susceptible of explanation.

HÆMATOCELES AND VARICOCELES should likewise be amenable to the same treatment, but in these cases we have a more complex condition of the contained fluid. The blood should be coagulated, and by the process of reversing the osmotic current this ought to be accomplished by a rational use of the electricity.

ORCHITIS. It would seem plausible to expect the favorable action of electrolysis in these and all other cases of swollen testicle, where there is no suppuration, but simply a lymphatic deposit between the healthy tubular structure of this organ, or an interstitial deposit of lymph.

HYPERTROPHY or ELEPHANTIASIS of the SCROTUM ought under the same theory of action to be susceptible of cure by the so-called electrolysis.

NÆVI. The history of the cases which have been reported of the use of electrolysis in these and other similar vascular tumors unmistakably proves that they are entirely curable, provided that the strength of the electrical current shall be correctly guaged.

VARICOSE ULCERS. In these cases the local action of metallic electrodes removes the vitiated secretions and stimulates the underlying tissues to a deposit of healthy granulations.

ECZEMA. It would seem as if this form of a defective nutrition of the subcutaneous layers of tissue might be subjected to the effects of electrolysis, by restoring the abnormal conditions of osmosis. The selection of the proper terminal for application would depend upon the condition of the tissues; where there is an excess of moisture, the positive electrode should be applied; where there is a deficiency of moisture, the negative should be applied.

The application to other skin diseases, such as acne punctata, lupus, or those of a different character, would depend largely upon the causes at work in the tissues which result in these affections.

WARTY growths are very readily destroyed by the electro-puncture. Many needles may be used, connected as negative, and inserted in various portions of the growth, lateral to its surface and not below its base. The positive electrode may be either a zinc needle inserted into the centre of the wart, or may be held in the palm of the hand as a moistened and covered piece of carbon.

WENS. Small sebaceous wens can very readily be destroyed in one sitting, when they are seated under the dry skin, but when they are situated in the scalp, several sittings are required, because the moisture of the hairy scalp dissipates by its more ready conductivity the electrical current. It would be of advantage in the latter condition to apply to the surface of these tumors powdered chalk or moulder's clay before transfixing the scalp with the needles, and thus render the scalp surface less ready of conductibility.

FISTULÆ and SINUS. In these cases the use of electrolysis has been satisfactorily attempted, but its advantages would be largely dependent upon the object desired. If the surface of the tract is covered with vitiated secretions due to an increase of the watery fluids from a depraved surface, the application of a metallic positive electrode would cleanse the wound, dry up the moisture and stimulate the surface to deposit healthy granulations. The result should be a dry scab, under which healing would occur, and a slow separation of the eschar.

GOITRE, HYPERTRICHOSIS, URETHRAL STRICTURE, CYSTIC TUMORS and a list of diseases on pages 150 and 151 have been sufficiently enumerated not to require separate mention in this place.

EXTRA-UTERINE FŒTATION certainly presents one of the most promising fields for the application of electrolysis, but great caution should be exercised to use currents of feeble strength, one to three milliampères, for three to five minutes at a sitting, and repeated at intervals of seven or eight days. The use of the faradaic current cannot be relied upon to destroy the life of the ovum. If the operator desires to use great caution, he should confine electrical treatment to the surface application of galvanism. One electrode, the positive, should be applied over the supposed habitat of the ovum, and the other, negative electrode should be applied by a wad of absorbent cotton wound around a carbon cylinder and passed into the vagina. By this method the cataphoric action of electricity would set the osmotic current towards the vaginal orifice. This is simply offered as a suggestion upon pure theoretical grounds, which would also prompt the physician to combine the hydragogue and diuretic action of drugs, to increase the action of osmosis in the abdominal viscera. It would seem advisable to repeat this treatment daily, unless some untoward symptom should contra-indicate its use. It is difficult to imagine that any injurious effects would accompany such a procedure.

The applications of this method to other forms of disease are sufficiently indicated by the assumed mode of action of electrolysis which has been presented in this treatise. A comparison of the many cases reported under this treatment, especially by a reference to the two tables enumerated on pages 150 and 151, will enable the reader to judge in advance of the probable success which would attend its application.

It should be specially remembered that the transmission of electricity through a conducting medium, partly fluid and of a complex structure like that of living tissues, must be followed by some changed condition of this organism. Electricity is not a fluid, nor is the body arranged for transmission of a force without changing the physical conditions of the organic composition. As mentioned in the introductory chapter, the display of force may be transmuted into chemical decomposition, elevation of temperature, or into a motion of the fluid particles of which an organic body is composed. The transference of this force into a motion of the fluid particles of a liquid conductor of high electrical resistance is in an inverse ratio to the result of the chemical decomposition.

An increase in the strength of the current necessary for conduction in a resisting medium, would naturally be followed by an increase in the varying degrees of potentials of its component parts. Electrical conductivity is from a higher to a lower potential, and consequently where this difference is greatest, the manifestation of the force in the conductor will be more intense, and the effects of the display more evident. This portion of our study needs very careful investigation at the hands of our physiologists, for a more perfect knowledge of the physical laws which govern the increase or diminution of the organic structures of living tissues. Therapeutical application depends upon the position and certainty of physiological laws, and it is useless to speculate in advance of the establishment of these facts. We must be satisfied to test our applications of electricity to empirical knowledge. It is hoped, however, that the object of the writer in collecting the results of empiricism and the facts of physical and chemical science may lead to further researches, because the promise of each of these methods of observation is fruitful of advantage in their application to disease.

The pathological conditions which accompany, or ensue as secondary effects to the action of the local application of electricity called electrolysis, have only received a superficial examination. As an example of this, attention is directed to the conditions under which a coagulum is formed within the blood vessels under the local influence of electrolysis; here it is seen that the clot becomes adherent to the walls of these vessels; occasionally also after currents of greater strength, inflammation and suppuration may supervene which result in a destruction of these limiting tissues, and hemorrhage occurs through the broken wall. Again, too, the use of strong currents of electricity may set up an irritation and inflammatory action in the neighboring serous and mucous membranes. In the latter case the foci of inflammatory action may radiate by extending beyond the point of contact of the electrodes. In the former case, the action appears to be limited very closely to the position chosen for the metallic contact with these tissues. These observations are important in the application of electrolysis to uterine and pelvic surgery. On this account empiricism has apparently suggested the use of the faradaic or induced current of electricity in these cases. We have seen that the action of so-called electrolysis is very slight in the presence of this latter form of current, and that its power in producing chemical decomposition and physical osmosis within the tissues is very feeble. The promise of harm is as great as the promise of cure is small. Even with this form of electrical display within the tissues some gynecologists have been tempted, and with apparent success, to treat uterine fibroid tumors. Probably if feeble currents of the constant battery were applied in these gynecological cases instead of the uncertain and immeasurable currents from the induction coil, the results of treatment would be more promising, and a definite advance made in our clinical experience.

The mode of action by which electrolysis facilitates the absorption of lymphatic engorgement and interstitial deposits of lymph, is susceptible of an extended use in medicine. The lymphatic enlargement of the lymph glands in leucocythemia, perhaps also in the more modern disease called pernicious anœmia, should theoretically be improved under a proper application of the electrical current through the tissues.

In drawing this work to a close, the author begs an indulgence from his readers for the discursive way in which the subject of electrolysis has been treated. It will be justly said in extenuation, that no electrical work to which he has had access has dealt with this subject exclusively, and that the various works on electricity which he has consulted do not present the matter of electrolysis in a clearly defined manner. It is the author's hope that the facts of clinical experience, of chemical science and of physical knowledge, which he has gleaned from the best authorities, will atone for any shortcomings of his original suggestions.

ERRATA.

Page 37.—"decomposition" should read "evolution."

Page 38.—First line of second paragraph should read "by electrolysis" instead of "of electrolysis."

Page 108.—Paragraph headed by "5" carbolic dioxide should read carbonic dioxides.

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