ON

MEDICAL ELECTRICITY.

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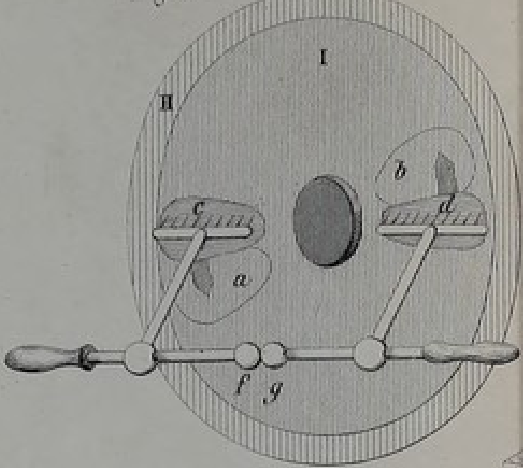

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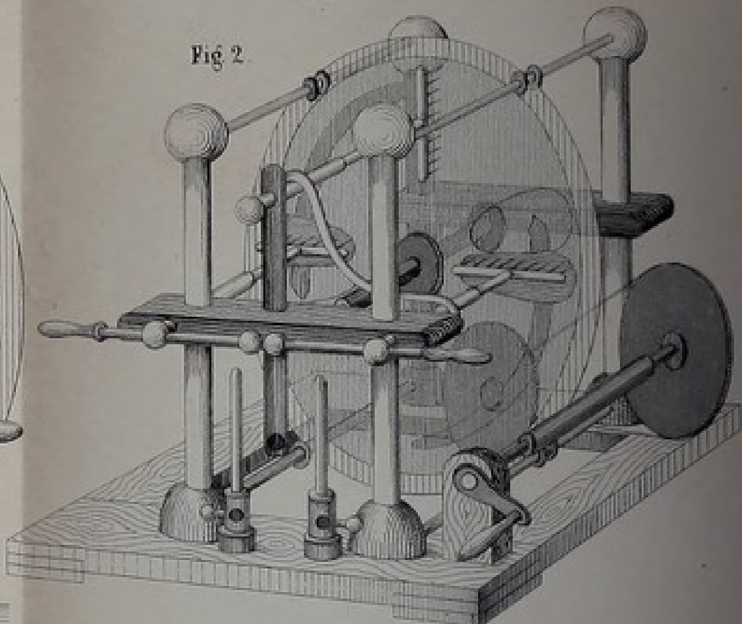

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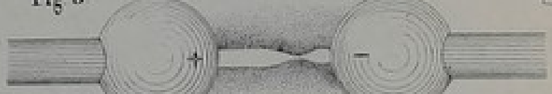

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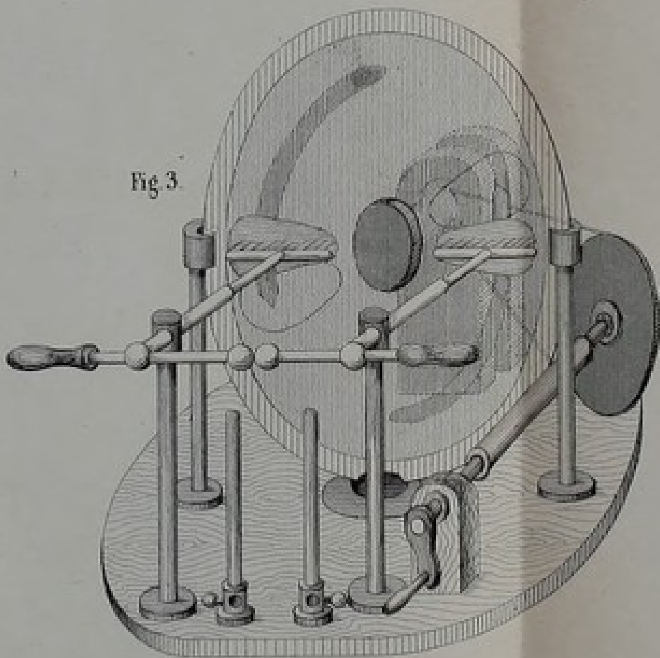

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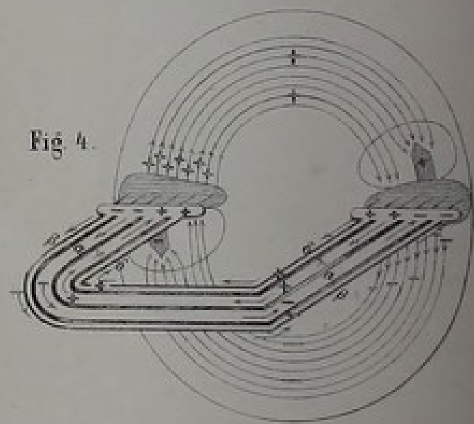

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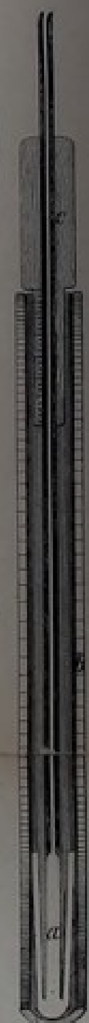

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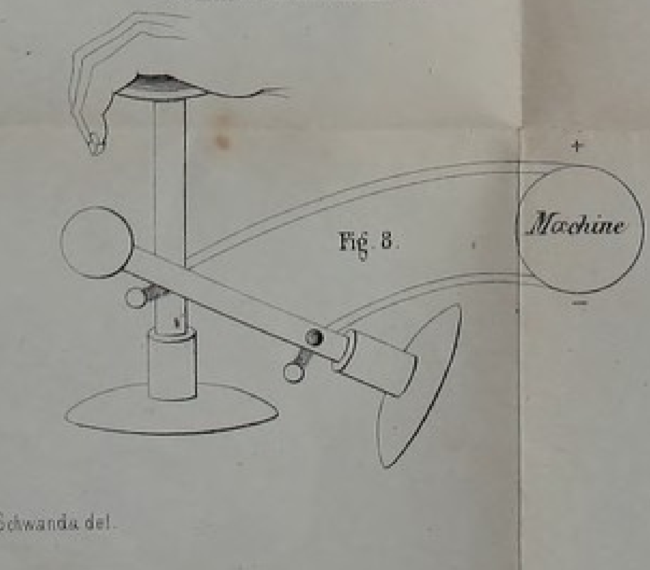

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A TREATISE

ON

MEDICAL ELECTRICITY

THEORETICAL AND PRACTICAL

AND ITS USE IN THE TREATMENT OF

PARALYSIS, NEURALGIA, AND OTHER DISEASES.

BY

JULIUS ALTHAUS, M.D.

Member of the Royal College of Physicians;
Fellow of the Royal Medical and Chirurgical Society;
Physician to the Infirmary for Epilepsy and Paralysis.

'That which forms the invisible but living weapon of the electric eel; that which liberated by the contact of moist dissimilar particles circulates through all the organs of animals and plants; that which flashing from the thunder-cloud illumines the wide skyey canopy; that which draws iron to iron, and directs the silent recurring march of the guiding needle;—all, like the several hues of the divided ray of light, flow from one source, and all blend again together in one perpetual force, which is diffused everywhere.'

ALEXANDER VON HUMBOLDT, *Aspects of Nature.*

SECOND EDITION,

REVISED AND PARTLY REWRITTEN.

LONDON:

LONGMANS, GREEN, AND CO.

1870.

PREFACE

TO

THE SECOND EDITION.

In looking back to the time when the first edition of this work appeared, I cannot help feeling considerable satisfaction at the progress which the subject treated of in this volume has made since then, both scientifically and professionally. Ten years ago medical men held galvanism in very low estimation; reports of cures by electricity were received with an incredulous smile; there was only one hospital—Guy's—where electricity was regularly used; and there it was applied in an antiquated fashion, and its use relegated to nurses or dressers. At the present time not a few hospitals possess the necessary electrical apparatus; able teachers are instructing students in its scientific application; and the first medical society in the kingdom has appointed a committee, composed of some of the most eminent members of the profession, for investigating the therapeutical use of electricity. This is a great change;

but quite as great is the change which has come over the scientific aspect of the subject. The physiological action of the different forms of electricity has been much more thoroughly studied than it ever was before; their place in therapeutics has not only become better defined, but also considerably enlarged, and rests on a firmer basis; and the special indications for the use of the several agents which are comprehended under the name of electricity and galvanism are much better understood. All this must of necessity be a source of gratification to those who have held fast to the remedy in evil times; but just as great and well founded is their hope that the sphere of practical usefulness of this still mysterious power may in future even be further extended than it is at present. Where scarcely a month passes without an accumulation of new facts showing the beneficial results which may be obtained from a judicious use of electricity in various disorders—and not uncommonly just in those which are not amenable to other remedies, such as progressive muscular atrophy, and epileptiform neuralgia—we may well cherish the hope that, as time advances, and our knowledge of the agent becomes more intimate, further improvements in the mode of using it may be made, and further indications for its therapeutical application may be discovered.

The present edition of this work is considerably enlarged; its therapeutical part has been almost entirely re-written, owing to the accumulation of evidence showing the striking remedial effects of the continuous galvanic current, of which only little was known when the first edition appeared.

Another change in the book has been the introduction of a number of illustrations, which, it is hoped, will greatly contribute to a better comprehension of the text. For the loan of some of them I am obliged to Professor Benedict, of Vienna (figs. 9, 10, 43, 46, 47); M. Gaiffe, of Paris (figs. 49–52, 55); Dr. Morell Mackenzie (fig. 57); Dr. Meyer, of Berlin (figs. 24, 25, 29); Professor Schwanda, of Vienna (figs. 1–8), and M. Tripier, of Paris, author of the 'Manuel d'Electrothérapie,' Paris, Baillière, 1861 (figs. 11, 14–23, 30, 42, 44, 45, 48, 53, 54, 56, 58–60, 62). To all these gentlemen my best thanks are due for their readiness in aiding me to make this work more complete than it could have been otherwise. All the other illustrations are original, and have been taken from the instruments introduced and employed by myself.

In conclusion, I beg to express the hope that the new edition of this work, upon which I have bestowed much time and care, under a heavy pressure of both private and hospital practice, may serve to advance this important department of medical science.

18, Bryanston Street, Portman Square:
December 1869.

PREFACE

TO

THE FIRST EDITION.

THERE ARE FEW REMEDIES employed in the treatment of disease on the value of which the professional mind is less settled than on that of galvanism. Enthusiastic panegyrists contended fifty years ago, and contend still, that it is a therapeutical agent superior to all hitherto discovered, whilst the great majority of the profession entertain serious doubts as to the reality of the remarkable successes which are now and then recorded by medical galvanists.

The differences of opinion about the therapeutical value of electricity are readily to be understood if we bear in mind that the mode in which electricity is applied has an all-important bearing upon the results. It is true that even by a careless employment of galvanism a few accidental successes have been obtained; but in ninety-nine cases out of a hundred, empirical galvanists, being unacquainted with the physiological effects of electricity, have been disappointed, and have brought the remedy into undeserved contempt.

We know that, whatever may be the properties of the nerves, they can be called into action by galvanism. But the effects are widely different according to the form of electricity that is used; again, the quantity and intensity of electricity are both of great importance; not less so the mode in which it is transmitted to the human body, and the length of time during which its action is kept up. In fact, we are able, by merely varying the modes of applying electricity, to arouse or to kill the vital power of the nerves, and to diminish or to increase their properties. Hence electricity can only be expected to be of service in the treatment of disease, if we are guided in its use by an exact knowledge of the physiological effects which it will invariably produce. I have, therefore, been most anxious to render the physiological part of my work as complete and comprehensive as possible.

That there is at present so little certainty respecting the physiological and therapeutical effects of electricity, is in some measure due to the vast extent of the field that is to be explored, and to the comparatively short time that has elapsed since scientific researches of this kind have been undertaken; also to the intentional falsehoods that have been published, even in the present time, about pretended cures by means of electricity; and especially to the small number of observers who have devoted themselves to the study of these phenomena. We possess a large amount of valuable information and experience concerning the effects of internal remedies upon the system; we know where to procure and how to prepare most drugs; we know how to combine them, and in what cases and in what doses to administer them with advantage. But in respect to electricity we have no such certainty. What form of electricity should be used? in what cases should it be employed? shall we act indiscriminately upon the different tissues, skin, muscles, and nerves, or shall we limit the action of electricity to each one singly? It is easy to understand that we cannot expect beneficial results from the application of electricity if it is applied by empirical galvanists; if the cases are not well selected; if the apparatus employed does not possess those qualities which are necessary for medical use; if the dose of electricity given is too large or too small, and if, instead of acting upon the diseased part alone, the whole body, or part of the body, is acted upon. If, on the contrary, such mistakes as the above are avoided, electricity will be found a most valuable therapeutical agent, by means of which many morbid states of the system may be relieved, and even wholly cured.

It no doubt sometimes happens that in cases which to all appearance are suited for electric treatment, and in which the agent has even been judiciously employed, it nevertheless produces little or no benefit. In fact, electricity is as little infallible as any other remedy we possess. But nobody will doubt the remedial powers of quinine, if it should happen to leave uncured a few cases of ague; and croton-oil will always be reckoned amongst our most efficacious aperients, although it does not invariably relieve constipation.

There is another important point upon which I feel obliged to dwell: patients are recommended by their physicians to undergo a course of galvanic treatment in many instances only after every other remedy has been tried without success, and when the disease is of such long standing as to afford but little hope of ultimate recovery. What beneficial results might be obtained in certain affections of the nervous system, if the electric treatment were resorted to in an earlier stage of the complaint, may be conceived from a perusal of the chapter in which the effects of faradisation in a number of cases of hysterical aphonia are detailed. I shall be especially gratified if I succeed in inducing more frequent recourse to the electric treatment in certain forms of neuralgia, which defy all other therapeutical treatment, and which are wonderfully amenable to electricity.

Finally, I must allude to the mistake frequently made of employing galvanism alone without any internal remedies. I am quite satisfied that some affections of the nervous system can be cured by electricity alone; but in the majority of cases a simultaneous internal treatment is of the greatest importance, and should not be neglected if we wish to increase the chances of success.

Most of the cases which are reported in this volume have been observed and treated by me either in one of the Metropolitan Hospitals—King's College, St. Mary's, and Samaritan Free Hospital—or in the private practice of eminent members of the profession, to whose kindness in sending me cases for the electric treatment I beg to tender my sincerest thanks.

March 1859.

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ON

MEDICAL ELECTRICITY.

CHAPTER I.

FORMS OF ELECTRICITY.

In the present state of physical science it is generally admitted that all bodies contain a very subtle fluid called Natural Electricity, which is composed of two contrary fluids, termed positive and negative electricity. We suppose these fluids to consist of an infinite number of smallest particles or molecules, each of which possesses attractive and repulsive powers, the molecules of one attracting those of the other, whilst the molecules of the same fluid repel each other. While bodies are at rest, these fluids exist in such proportion that, although they do not destroy each other, their effect is counterbalanced; since at the same distance the attractive power of one of the fluids is equal to the repulsive power of the other. Natural electricity must therefore be decomposed, if an action shall be perceptible. Decomposition of natural electricity is brought about as soon as disturbances of any kind are impressed upon bodies, whereby a derangement is produced in the equilibrium of the molecules; as, for instance, when bodies are subjected to friction, heat, or chemical action. By such and other means an electro-motive force is called into existence, which separates the two fluids formerly united; natural electricity is decomposed and *active electricity* liberated, the nature and intensity of which present certain differences, which depend upon the nature of the body from which it is derived and upon the action by which it is developed; but active electricity, whatever may be its source, is identical in its nature; it exerts attractive and repulsive powers, produces heat, light, shocks, magnetism, and is ready to tear asunder the elements of chemical compounds.

The principal sources of electricity are friction, chemical action, magnetism, and the animal body; they will be briefly considered in the following pages. We shall first take a short glance at static electricity, or electricity produced by friction and inductive action; then proceed to examine dynamic electricity, under which head are comprehended galvanism, electro-magnetism, and magneto-electricity; and finally, sketch the present state of our knowledge in animal electricity, such as is produced by the general metamorphosis of matter in the living body.

I.—STATIC ELECTRICITY.

Above two thousand years ago the Ionian philosopher, Thales, discovered that pieces of amber, when rubbed with dry cloth, attract light bodies which are placed in their neighbourhood; hence he concluded that amber possessed a soul, and was nourished by the attracted bodies. We now know that amber, when rubbed, acquires the property of attracting light bodies, such as bits of paper, merely because by friction the natural electricity of amber is decomposed, and negative or resinous electricity is accumulated in the state of rest upon the rubbed body. If the amber be now approached to bits of paper, the negative electricity with which it is charged, necessarily exercises its attractive and repulsive powers; it decomposes forthwith the natural electricity of the bits of paper, repelling into the ground the negative electricity of these bodies, which, being now charged with positive electricity, immediately obey the attraction exercised upon them by the negatively electrised amber. For amber, glass or sealing-wax may be substituted.

Common Electrical Machine.—The essential parts of the ordinary electrical machine are the rubber, the rubbed body, and the prime conductor. The rubber generally consists of a pair of leather cushions, which are amalgamated with a paste composed of zinc and tin turnings, triturated with mercury, and rubbed up with lard. The rubbed body is a large disc of white plate glass, mounted on an axle of green glass. At the end of the latter a handle is fixed, by means of which the disc may be turned round between the leather cushions. If positive electricity is required, a metallic chain is fixed to the cushions and connected with the ground, in order to carry off the negative electricity of the cushions; positive electricity then accumulates on the glass disc, and may be drawn off by the *prime conductor*, which consists of several hollow brass balls connected by two horizontal glass tubes, which rest on columns of glass, and which is connected with the horizontal diameter of the disc. If negative electricity be required, the chain which touches the ground is connected with the glass disc instead of with the cushions, so as to carry off the positive electricity which is evolved. A portion of the glass disc is generally covered with oiled silk, in order to prevent the electricity set free from dispersing into the atmosphere. When the machine is in action, a peculiar smell is perceived, which is half sulphurous and half phosphoric, and is due to the transformation of the common oxygen of the atmosphere into electrified oxygen or ozone.

Ozone.—In 1848, Professor Schönbein, of Basle, discovered that by the electrolysis of acidulated water an odorous gas was produced at the positive pole, which could be preserved for a long time in well-stoppered vessels. He also noticed the same gas to be developed by the discharges of a common electrical machine through air, and recognised the identity of its smell with that which accompanies a flash of lightning. The properties of this gas were further investigated by Andrews, Williamson and Baumert, Marignac and De la Rive, and Frémy and Becquerel, whose researches have elicited the following facts:—

Oxygen may be changed into ozone by chemical action, by atmospheric electricity, and by the action of the ordinary electrical machine. Ozone is chemically prepared by placing a few sticks of clean moist phosphorus into a vessel filled with air or oxygen, the temperature being sufficiently elevated to render the phosphorus luminous. In the beginning of the experiment a smell of phosphorous acid is perceived, owing to the combination of phosphorus with oxygen; but this smell, after a time, gives place to that of ozone, which is quite different. The sticks of phosphorus should then be removed, and the gas washed with water, in order to remove all traces of phosphorous acid; for if the phosphorus be allowed to remain in the bottle for some hours, the ozone gradually disappears again. Large quantities of ozone may be obtained by electrolysing water which has been previously acidulated with sulphuric acid, or with a mixture of sulphuric and chromic acids.

The peculiar smell which accompanies a flash of lightning is due to the transformation of atmospheric oxygen into ozone, by means of atmospheric electricity. The gas also appears near the common electrical machine when in action; and very abundantly near Holtz's electrophorus machine, which will be presently described. It may be likewise obtained by passing sparks of frictional electricity through dry oxygen; but near voltaic piles and induction machines its odour is hardly ever perceived, which is probably due to the circumstance that voltaic as well as induction sparks are accompanied with a considerable development of heat, by which ozone is destroyed as soon as formed.

The properties of ozone are the same, whether it be derived from the action of the electrical machine, from atmospheric electricity, or from chemical action; and it differs from ordinary oxygen chiefly by the particular odour just mentioned, and by an exaltation of its chemical affinities. Ozone is, in fact, one of the most powerful oxidising agents with which we are acquainted. It oxidises moist silver, iron, copper, and mercury; is readily absorbed by dry mercury and iodine; decomposes a solution of iodide of potassium; changes the yellow ferrocyanide into the red ferridcyanide of potassium; corrodes organic matter, and bleaches most vegetable colours. It is insoluble in water and acidulated water.

Small quantities of ozone are always contained in the atmosphere. They vary according to the season of the year, the temperature of the surrounding air, the evaporation of water, and certain atmospheric disturbances, especially storms. Whether the amount of ozone contained in the atmosphere has any influence upon the public health, has not yet been ascertained.

To show the presence of ozone in the air, small pieces of paper are impregnated with a solution of iodide of potassium and starch. After these have been dried they are placed in the open air; and, if ozone be present, they assume a deep blue colour. In order to determine the quantity of ozone in an approximative manner, a scale of shades is made by mixing known quantities of iodised starch with different quantities of water, and impregnating paper with it; after which, the intensity of the ozone reaction may be compared with the scale, the proportions of which are known to the observer.

Properties of static electricity.—Of all the different forms of electricity, static electricity exercises the most considerable attractive and repulsive powers, even at a distance: the energy, however, with which these attractions and repulsions occur, is always greater in proportion as the two bodies between which they are exercised are nearer to each other. When the natural electricity of bodies has been decomposed by friction, the fluids remain either in a state of rest accumulated upon insulating bodies, or they travel towards each other, to neutralise each other. Neutralisation takes place between them, when bodies charged with contrary fluids are brought near each other; in the neutralisation of the two contrary electricities a spark is produced, the discharge of which is accompanied with a peculiar snapping or crackling noise. If the machine be used in a dark room, streams of fire are seen to issue from beneath the oiled-silk covering, and to disperse over the plate. If the hand be brought near the conductor of the electrical machine in action, a curious streaming or wave-like sensation is experienced; and if it be brought close to it, sparks are seen to pass between the hand and the conductor, which produce a sharp pungent sensation in the skin, and a peculiar eruption on it, which is sometimes surrounded by a little inflammatory blush.

Neutralisation may also be brought about between the contrary electricities, if the bodies charged with them are at a considerable distance from each other; for this it is only necessary that a communication should be established between the bodies by means of an insulated conductor.

In the moment of neutralisation, electricity is no longer at rest, but in motion or the dynamic state. The state of motion is instantaneous, if the two bodies, which were charged with contrary electricities, acquire no more electricity after that which they had before has once become neutralised; and this instantaneous dynamic state is termed the electric discharge.

A discharge is instantaneous; but if the two electricities be constantly renewed, one of the bodies deriving from any source a continuous supply of positive, and the other one a like supply of negative, electricity, there will be, of course, a continuous neutralisation produced either through the air with sparks, or through a conductor. This continuous dynamic state is termed the *electric current.* The essential difference between a discharge and a current is, that a simple discharge, although it produces a number of other effects, has no action upon a magnetised needle ; whilst an electric current is capable of deviating it from its previous position. By a rapid succession of discharges, the magnetised needle of a galvanometer may be deflected just as it is by voltaic or electro-magnetic currents.

The Leyden Jar.—The Leyden jar was invented in 1745, by Kleist, of Cammin, and some time afterwards, independently of Kleist, by Muschenbroek, of Leyden. It consists of a rather wide-mouthed glass jar, which has an inner and outer coating of tinfoil. The inner coating is connected with a brass rod which passes through the stopper of the jar, and terminates above in a brass knob, two or three inches above the stopper ; while it terminates below in a brass chain, which rests on the bottom of the jar. The jar is charged by connecting the outer coating with the ground, and the knob with the prime conductor of the electrical machine. If this be done, the positive electricity of the machine passes down the brass rod to the inner coating of the jar, on which it accumulates. The jar is discharged by establishing a connection between its outer and inner surfaces. The metallic discharger which is generally used, consists of two brass rods terminating in balls, and connected at the other end with a glass rod by which it is held. If one of these balls be made to touch the brass knob of the jar, and the other its outer coating, a brilliant spark is perceived, and the usual snapping noise is heard. The jar may be discharged through the human body by holding it in one hand by the outer coating, and then touching the brass knob by the other hand. If a jar has been strongly charged with electricity, it will give a violent shock, which may be transmitted through a file of men joining hands.

Electric Battery.—A number of jars, of which all the outer coatings are connected with one another, and the inner coatings likewise, forms an *electrical battery*, the power of which is proportionate to the size and the number of the jars. A jar or a battery, however, cannot be charged infinitely with electricity, as, when a certain quantity of it has been accumulated, the tension becomes so high that it either shatters the jar or is discharged spontaneously.

The *quantity* of frictional electricity which may be accumulated in a Leyden jar depends upon the extent of the coated surface, and its *intensity* on the thinness of the glass. *Tension* is the actual force of an electric charge to break down any non-conducting medium between two terminating electrified planes.

The Electroscope.—The electroscope is an instrument by means of which the presence and kind of electricity, whether positive or negative, are indicated. The most simple kind of electroscope is a pith ball suspended by a silken thread. This is first charged by touching it with a glass rod on which positive electricity is accumulated, and then approached to the object which is to be examined. If no effect on the pith ball be produced, the object is not electrified; if the ball be repelled by it, the electricity is positive, but if the ball be attracted it is negative. The instrument most generally used, however, is the gold-leaf electrometer, which was invented by Bennett, and perfected by Singer and Buff. The essential parts of this instrument are two slips of gold-leaf suspended in a glass, which show, by their divergence or collapse, the electrical conditions of bodies which are examined with it.

Velocity of Electricity.—The velocity with which electricity is propagated is greater than that of any other agent with which we are acquainted, light not excepted; for while light moves at the rate of 192,000 miles in a second, electricity travels over a distance of 288,000 miles in a second. This velocity is so great that any artificial motion which can be produced appears to be rest itself when compared with it. The light of the electric discharge lasts, according to Wheatstone, hardly the millionth part of a second. If a wheel, which is made to revolve so rapidly that its spokes become invisible, be illuminated by a flash of electric light, all the spokes are for an instant seen perfectly distinct, as if it were in a state of rest. Insects on the wing appear fixed in the air; and an apparently continuous stream of water is seen as a succession of drops; the cause of these phenomena being, that, however rapid the motion of bodies may be, the electric light has come and passed away before the motion has gone over a perceptible portion of space.

The following table shows the rate at which electricity, light, sound, nervous force, and other agents are transmitted :

	Mètres in the Second.
Electricity	464,000,000
Light	300,000,000
Shooting star	64,380
Earth in orbit round the sun .	30,800
Sound in iron	3,485
Sound in water	1,432
Cannon ball	552
Earth's surface at Equator . .	465
Sound in air	332
Eagle's flight	35
Nervous force	26–30
Railway engine	27
Greyhound	25
Racehorse	25
Stone thrown by hand . .	21·9
Arterial wave	9·25
Blood in dog's carotid . . .	0·2 to 0·3
Blood in dog's capillaries . .	0·0006 to 0·0009
Particles moved by cilia . .	0·00007

The fact that electricity moves at a rate of 288,000 miles in a second, while nervous force travels in the same space of time only over a distance of about twenty-six yards, is sufficient to prove that *electricity and nervous force are not identical*, as some physiologists are inclined to believe.

Chemical Effects.—That frictional electricity has certain chemical effects, was discovered by Priestley, who succeeded, by passing a succession of shocks through air, in forming an acid out of oxygen and nitrogen. This subject was, however, most elaborately investigated by Faraday, who found that the chemical action of frictional electricity is very feeble, as the quantity of matter decomposed is not proportionate to the tension, but to the quantity of electricity employed, and the quantity of frictional electricity is small. The voltaic pile, on the other hand, yields an enormous quantity of electricity, and is therefore most energetic in producing chemical decompositions. Faraday has calculated that a Leyden battery would require to be charged by 800,000 turns of a powerful plate machine of fifty inches in diameter, to supply electricity sufficient to decompose a single grain of water, which, by a cell of Grove's battery, can be done in five seconds.

Inductive Action; Electrophorus.—Static electricity does not only produce certain effects when two bodies are in contact with each other, but also at a distance; and these latter effects are said to depend on inductive action. The most important instrument for showing inductive action is the Electrophorus, which was invented by Wilke, and improved by Volta. It consists of a cake of resinous matter, contained in a metallic plate with a rim round the edge, and a metallic covering, which is furnished with an insulating handle of glass. The surface of the cake may be negatively electrified by striking it briskly several times with a fox-tail or a piece of fur; the cover is then laid on, and acquires by contact a feeble charge of negative electricity. The negative electricity of the cake now decomposes the natural electricity of the cover; positive electricity is attracted, but negative electricity repelled, and therefore positive electricity accumulates by induction in the lower, and the negative fluid in the upper, portion of the cover. If the finger be approached to the cover, a spark passes between them; and if the finger be made to touch the cover, all the negative electricity is repelled, and the cover is charged merely with positive electricity, which is confined by the negative electricity of the cake, as long as the cover remains on the cake. But when the cover is removed from the cake by the insulating handle, positive electricity is set free, and a spark of positive electricity may be drawn from the cover. From this it may be concluded that the electricity of the movable plate is not derived as a charge from the resinous cake, but is the result of inductive action. This process takes place not through the metal, but through the air, and is an action of the contiguous particles of the insulating body thrown into a state of polarity and tension, whereby they are rendered capable of communicating their forces in every direction.

Holtz's Electrophorus Machine.—The principle of inductive action has been barren of results until recently, when it was utilised almost simultaneously by M. Holtz, of Berlin, and M. Töpler, of Riga (1865), both of whom have constructed inductive machines of extraordinary power, and by means of which the science of static electricity has been most materially advanced.*

(See Lithographic Plate, figs. 1–8.)

The electricity furnished by these machines is in all respects identical with frictional electricity, except that it is not developed by friction, but by inductive action, as in the electrophorus. They are called electrophorus machines, or rotation-multipliers—a multiplier being a name given to every apparatus the object of which is to multiply by successive transmissions any feeble electric charge which has once been communicated; such transmissions taking place in these machines by means of a rotatory movement.

The essential parts of Holtz's machine are two glass discs, one of which may be turned round its axis, while the other is fixed, and a variable number of conductors. There are three sizes of the disc, namely, 12, 21, and 30 inches. The movable disc I, fig. 1, has a diameter of about thirty-two centimètres, and is two millimètres thick; it consists of plate glass, and is fixed centrically and perpendicularly on an axle of vulcanite, by means of which it may be put into rotation. The fixed disc, II., has a diameter of thirty-six centimètres; it consists likewise of plate glass, and has an opening in the centre, so that the axle, which

* Holtz, in Poggendorff's 'Annalen,' April and September 1865; Clemens, in 'Deutsche Klinik,' 1867, No. 48; and chiefly Schwanda, in 'Medicinische Jahrbücher,' 1868, Heft iii.; and Poggendorff's 'Annalen,' vol. cxxxiii. p. 126.

has just been mentioned, may be put through it without friction. It is fixed at a small distance from the movable disc, and parallel with it. This fixed disc is interrupted towards the two extremities of one of its diameters by two oval incisions, *a*, *b*, which are 8½ centimètres long and six centimètres wide. On that surface which is turned away from the movable disc, it is furnished with an equally long paper-coating, *c*, *d*, along each longitudinal side of the incisions; and from these paper-coatings a pointed piece of cardboard proceeds into the middle of the corresponding incision. Both glass discs and paper-coatings are covered with sealing-wax.

The metallic conductors are shaped somewhat like a comb with ten finely-pointed teeth, and are fixed as near as possible to the rotating disc, but without touching it, and parallel to the longitudinal direction of the paper-coatings. Each of these combs has a metallic stem, which is placed parallel with the axle, and perpendicularly to the rotating disc. The metallic continuation of the conductors are the electrodes of the machine, fig. 1, *f* and *g*.

Holtz calls the incision in the fixed disc, with the corresponding paper-coating and conductor, an *element*. According as there are two, four, six, or eight such incisions in the fixed disc, there are also two, four, six or eight conductors; and the machine is then called one of two, four, six, or eight elements.

The machines with two elements are, according to

Professor Schwanda, best suited for physiological and therapeutical purposes.

In order to put this machine into action, the two electrodes are connected with one another, and the movable disc is turned round by the vulcanite handle, while at the same time a plate of vulcanite which has been rendered electric by friction is approached to one of the paper coatings, and again removed from it as soon as a crepitating noise is heard. The rotation must be so performed that the several portions of the movable disc pass first the incisions, and afterwards the paper coatings of the fixed disc. As soon as this is done, both coatings are charged with opposite electricities, the density of which grows rapidly, and reaches its maximum within a few seconds. At the same time an electric current is established in the closing arch of the conductors: in fact, there are two electric currents flowing in opposite directions, just as in a galvanic battery; but, in order to avoid mistakes, only one of the two currents is taken into consideration. This current is produced in the following manner:—The metallic closing arch commences with one comb and finishes with another. If we now suppose that the paper coating (*a*, fig. 1) of the fixed disc, is charged with negative electricity by means of the vulcanite plate, or in any other manner, this begins to act upon the natural electricity of the neighbouring part of the movable disc and comb—that is to say, negative electricity appears upon the conductor, and positive electricity on both surfaces of that part of the movable disc which is situated between the paper coating and the comb ('double induction,' according to Riess). In this case, therefore, the comb is the negative pole, and the corresponding electrode the negative electrode. If the movable disc remained quiet, there would be only a quantity of negative electricity corresponding to the electric charge of the paper coating *a*, in the negative conductor, as well as in the other conductor, which is connected with the former by means of the electrodes which are in contact with one another; and there would be an equally large quantity of positive electricity bound on both sides of the movable disc, within the sphere of the inductive action of the paper coating.

But if the disc be turned from the right side to the left, further portions of the same come within the sphere of induction, and consequently further quantities of negative electricity are set free in the negative conductor, while positive electricity travels towards the disc. A current of negative electricity, therefore, goes from the negative pole, through the closing arch, to the positive pole, while further quantities of positive electricity issue from the paper coatings. The positive electricity which is thus set free is partly lost in the atmosphere, but the largest portion of it remains fixed on the disc until better conductors offer than the surrounding air. Such a conductor for the positive electricity of the *posterior* surface of the turning disc is furnished by the pointed process of the second paper coating *b*; while the positive electricity of the *anterior* surface of the turning disc is drawn off by the second comb, which is opposite to the paper coating. By means of these the movable disc is completely discharged, inasmuch as the positive electricity of the *anterior* surface, passing through the air between this and the comb, is neutralised partly by the negative electricity derived from the negative conductor, and then passes on to the comb, where it forms part of the positive current which circulates in the closing arch *d*. At the same time the positive electricity of the *posterior* surface passes through the pointed process of the second paper coating *b*, which then becomes charged.

It is therefore easy to perceive the analogy between the function of the cover of the electrophorus and that of the movable disc in Holtz's machine. The paper coating is analogous to the cake of the electrophorus, which is charged with negative electricity, while the corresponding part of the movable disc answers to the cover of the electrophorus, and the corresponding comb to the finger, which conducts the electricity away from the cover of the electrophorus while it is lying on the cake. In the electrophorus, however, the negative electricity which is conducted away by the finger is lost in the ground, while in Holtz's machine it is condensed in the conductor, and may be further utilised. The next thing done with the electrophorus is to remove the cover, which then becomes charged with positive electricity that may be used for experiments. The corresponding act with Holtz's machine is to remove that part of the disc which represents the cover of the electrophorus, by rotation, from the sphere of action of the paper coating, which will then be charged with positive electricity on both its surfaces. That accumulated on its anterior surface passes on to the positive conductor, and is used for experiments; while the electricity of the posterior surface charges a second electrophorus cake—viz. the second paper coating *b* —with positive electricity. This may, in Holtz's machine, be used in the same manner as the first cake. It therefore appears that the rotating disc of Holtz's machine does the same service by one rotation as the covers of two electrophori would do if they were close together and charged with opposite electricities—only with this further advantage, that the electricity derived from the covers is not lost, but may be utilised for experiments.

The qualities of the electrophorus machines vary according to the amount of electrical tension, and according to the quantity of electricity which passes in a unit of time through the transverse section of the conducting wire. Other circumstances being equal, the machine will be more effective, both as regards tension and quantity, the larger the diameter of the rotating disc. But as, whenever a considerable quantity of electricity is required, a galvanic battery will always be preferred, small machines appear, from a therapeutical point of view, preferable to large ones. It is tension of electricity for which the electrophorus machine is remarkable, because the tension which is possessed by galvanic batteries and induction machines is very small when compared with that of the electrophorus machine. As regards the tension of electricity, we have to consider the length of the electric sparks which may be produced, and the rapidity with which the discharges take place, or the number of sparks which are produced within a certain unit of time—for instance, a second. The length of the spark increases with the size of the surface: with a disc of 12 inches in diameter, sparks 4 inches long may be produced; where the disc is 21 inches in diameter, the sparks are 6 inches long; and where it is 30 inches, the sparks are 10 inches, or even longer. The concussion which is produced by the smaller sparks being transferred to the human body is, however, so great, that it will always be advisable to use only the smaller kind of machine.*

We have now to consider the question, how Holtz's machine becomes a rotation-multiplier.

When the rotation is so slow that all the positive electricity which is present at the upper portion of the disc, and likewise all the negative electricity which is accumulated at the lower portion of the same, may be lost in the atmosphere, an increase of the density of the electricity of the coatings is

* Schwanda, *l. c.* p. 177.

impossible; on the contrary, the quantity of electricity which is there set free by the vulcanite plate, or by any other means, continually becomes smaller by being lost in the air, so that after a time there will be no electricity at all. In order that the machine may have an equable action, such a rapidity of rotation is required as will compensate for the loss of electricity into the atmosphere by fresh supplies of electricity from the movable disc. If this, for instance, may be effected with one rotation in a second, there will be, as soon as the rapidity of rotation is increased, more electricity set free on the paper coatings than is lost in the same space of time; and therefore the density of the electricity, and the inductive action of the machine, will be rapidly increased, until at last the tension of the electricity becomes so high that the resistance to passage which is offered by the surrounding air is easily overcome, and that from all the electrically active parts of the machine sufficiently large quantities of electricity pass into the air to establish equilibrium between the increased development and loss of electricity—that is to say, a maximum of the density of the electricity is arrived at. If the capability of the air for carrying off the electricity increases, the rapidity of rotation must also increase, if the machine is to remain equally active, and *vice versâ*. Other circumstances being equal, the machine may therefore, by increasing the rapidity of rotation, be brought to the maximum of its action.

The part played by the fixed disc in the action of the machine will become clear from the following remarks :—

If the paper coatings were kept in their places by some other means than this disc, it would not be absolutely necessary to have this disc at all ; for the machine could be put into action without it, and be brought to a certain maximum of force. But this maximum would be considerably less than that which can be obtained with the aid of the fixed disc ; for it is a well-known fact, that an insulating plane gives off its free electricity much less easily to the surrounding air, if there is another insulating plane charged with opposite electricity in its neighbourhood. This principle has been utilised in Holtz's machine by the employment of the fixed disc, which is larger than the movable one. In this disc the natural electricities are likewise separated by inductive action, partly in consequence of the action of the positive electricity which adheres to the upper half of the posterior surface of the movable disc, and of the negative electricity which accumulates on the lower half of the same, inasmuch as, by the former, the negative electricity of the upper half of the fixed disc is attracted on its anterior surface, while the positive electricity is repelled on its posterior surface —the reverse taking place in the lower half of the fixed disc—and partly by the action of the paper coatings, inasmuch as, in the neighbourhood of that paper coating which is charged with negative electricity, the positive electricity is attracted to the posterior surface of the fixed disc, while the negative electricity is repelled at the anterior surface, the reverse taking place in the neighbourhood of the positively charged paper coating. It appears from this that the transmission of electricity takes place in the same manner, both as far as the movable disc and the paper coatings are concerned, in consequence of which the opposite electricity on the anterior surface of the fixed disc preponderates over the electricity at the posterior part of the movable disc ; and therefore a new quantity of the natural electricity of the movable disc is separated—positive electricity being attracted to the upper half of the posterior surface of the movable disc, and negative electricity being repelled at the anterior surface, the reverse taking place at the lower half of the movable disc.

When the machine is in action, a rather loud crepitating noise is heard at the pole where the charge takes place, which increases in intensity with the force of the charge, and continues in the same manner as long as the conducting arch is closed; but if this latter be opened, the force of the noise is diminished. At the same time the resistance offered to the hand which moves the handle is likewise increased, and remains so as long as the electrodes are not too far removed from one another. The smell of ozone is perceived at both poles of the machine, but most considerably at the negative pole. This smell spreads rapidly through the air, so that, after the machine has only acted for a few minutes, a large room will be completely filled with it. It is a curious fact that a strip of paper impregnated with iodised starch is not rendered blue in the close proximity of the negative pole, even if it remains there for a long time, while the blue colour is immediately produced if the sparks passing between the electrodes are directed through it; another singular circumstance being, that the smell of ozone over the electrodes or in their immediate neighbourhood is much more feeble than in the neighbourhood of the negative pole. Luminous appearances take place at both poles as soon as the machine is put into action, which increase rapidly in force and extent. By daylight they become only perceptible if a dark object is held behind the glass discs, while in a dark room they at once appear in all their brilliancy. It is then noticed that, as soon as the crepitating noise is heard, a reddish-blue light issues from the points of the comb opposite to that paper coating where the charge takes place, and that waves of light pass from there in a quarter-circle towards the movable disc, opposite to the direction in which rotation is performed, from whence they proceed farther and farther until they reach a maximum of length, which is about 8 or 10 centimètres. At the same moment when light appears at the points of the negative pole, a similar light is perceived at the points of the positive one; but this has a more reddish hue, and is not quite so dazzling, while the points of light are more numerous and larger than at the negative pole. If the finger be approached to the anterior surface of the movable disc, feeble streams of light pass from it towards the disc, in a direction opposite to that of rotation; while, if the finger be approached to the posterior surface of the fixed disc, streams of light are likewise seen to pass from the finger towards the disc, but with this difference, that the intensity of the light is much more considerable, especially round the positive pole.

When the electrodes are removed from each other, a loud singing noise is heard, the pitch of which rises and falls rapidly by one or two octaves, in the same ratio as the rapidity of rotation. If the distance between the electrodes be increased, the pitch of the tone becomes deeper and gradually discontinues, so that at last only feeble indistinct sounds are heard, which disappear if the distance between the electrodes be large. If they are then again rapidly approached to one another, the singing tone returns likewise, and changes its pitch as before.

The luminous appearances which occur between the electrodes when these are somewhat removed from one another, are remarkable for their variety and the intensity of colouring. They are scarcely perceptible in direct sunlight, but fully so in ordinary daylight. If the distance between the electrodes is very small, a brilliant white light with a greenish hue is seen, whatever may be the size or the shape of the electrodes; but if the distance be increased, streams of a violet light pass from the positive to the negative electrode, while, if they are very far from each other, a feeble violet glow is seen, especially if the electrodes be pointed. The violet light is probably due to incandescent nitrogen, while the white light arises from incandescent oxygen.

The physiological and therapeutical effects of static electricity will be considered in subsequent chapters of this volume.

II.—DYNAMIC ELECTRICITY.

(A) GALVANISM.—If two heterogeneous metals be connected by a conductor moistened with water, various phenomena are produced, the cause of which is ascribed to an agent developed by the connection of the metals, and called galvanic electricity, after Luigi Galvani, of Bologna, who discovered this form of electricity in 1786.

Up to a recent time galvanism was also termed electricity by contact, since natural philosophers had generally adopted Volta's theory, that the liberation of galvanic electricity was entirely due to the contact of the two different metals, whilst the liquid between them merely played the part of a conductor. Volta's theory, however, has been refuted by the experimental researches of Davy, Becquerel, M. de la Rive, and Faraday, who have established the fact that the real source of galvanic electricity is not contact, but the chemical action of two heterogeneous conducting bodies; that contact is only a condition most frequently necessary, but not always indispensable to the manifestation of the electric signs; that galvanic electricity may be produced by any chemical action, not only by the action of a liquid upon a solid—which, it is true, produces the most remarkable electric phenomena—but likewise by the action of two liquids upon each other, or even by gases acting upon solids and liquids. The electricity yielded by the voltaic pile is, therefore, not dependent, either in its origin or in its continuance, upon the contact of the metals with each other, but is entirely due to chemical action, and is proportionate in its intensity to the intensity of the affinities concerned in its production, and in its quantity to the quantity of matter which has been chemically active during its evolution. In fact, every chemical action is accompanied by a disturbance in the equilibrium of the molecules of a body, and consequently by a liberation of electricity. Where there is no chemical action, no electricity will be liberated. We may thus, for instance, establish the most perfect contact between a pair of iron and copper, and immerse it into a well-conducting liquid, such as a solution of potash; but nevertheless the pair remains inactive, because the liquid is incapable of exercising a chemical action upon either of the metals of the pair.

Voltaic Pile.—The original voltaic pile consists essentially of three substances: viz. two metals which may become charged with electricity, and an indifferent conducting body. It is built up in the following way:—A copper disc is placed upon a glass plate, a zinc disc upon the copper disc, and a circular piece of cloth, flannel, or pasteboard, well moistened with water or salt water, upon the zinc disc. A second similar pair is piled on the first, a third on the second, and so on. With twenty pairs of plates thus arranged, striking electrical effects may be produced.

If a little sulphuric acid be added to the water, the galvanic current will be much stronger, because the acidulated liquid conducts better than ordinary water, and furthermore because the oxide of zinc is removed as soon as formed, as it combines with sulphuric acid to form sulphate of zinc.

The top or zinc end of the pile is called the *positive pole*, the bottom or copper end of the pile is termed the *negative pole*. If the two poles of the pile are connected with conducting wires, these latter become charged with the electricity of the poles, and we therefore have a positively and negatively charged conductor.

When the two conducting wires are approached to one another, a continuous stream of small sparks is seen to pass between them; when they are made to act on the electroscope, the gold leaves diverge—the zinc end showing positive, and the copper end negative, electricity; when they are touched with the fingers, a galvanic shock is felt through the arms;

when they are immersed in a vessel containing water, an ebullition of gas takes place, the water is decomposed—oxygen being attracted to the positive and hydrogen to the negative pole; when they are connected with a magnetised needle, this is seen to suffer a deflection; when they are made to touch a piece of soft iron, this acquires magnetic properties; when they are connected with a thin wire of low conducting power, the latter becomes incandescent.

All metals are good electro-motors—that is to say, they give rise to copious development of free electricity if properly arranged. There are, however, considerable differences in this respect, according to the nature of the metal. Thus, for instance, zinc, if combined with platinum, becomes more strongly charged with positive electricity than if in contact with copper; on the other hand, copper, which if in contact with zinc becomes negatively electrified, acquires positive electricity if combined with platinum. The following table shows the metals arranged according to their electric tension, the preceding one being positively electrical to all the following ones :—

+	Iron.	Platinum.
Zinc.	Copper.	Carbon.
Lead.	Silver.	—
Tin.	Gold.	

The greater the distance between these several substances, the more considerable will be the galvanic intensity—a combination of zinc and carbon being the most active pair of all.

It is inherent to the construction of the voltaic pile that the electric current furnished by it is subject to considerable variations, and that, although it may be very strong at first, it soon diminishes in strength, and at last completely disappears. This is due to the circumstance that as soon as the pile is put into action, the water with which the conductor is moistened becomes decomposed, whereupon hydrogen in the nascent state accumulates on the copper, while oxygen goes to the zinc. By this process the surface of the metals is altered, and their heterogeneity more or less destroyed. When in this condition, the metals are said to have acquired polarisation. If a liquid were used that is incapable of decomposition, no effect would be caused: so that polarisation is inevitable. In consequence of this, a fresh current is produced—the *polarisation current*—which flows in a direction contrary to that of the battery, and has, therefore, the tendency to neutralise the original current. The longer the action of the battery continues, the more considerable is, of course, the decomposition which takes place; and the polarisation current, therefore, becomes at last so strong that it completely neutralises the original current—when the effect of the battery is, of course, reduced to zero.

Constant Batteries.—The effects of polarisation may be to a great extent avoided by using two conducting liquids which are separated by a permeable membrane or a porous vase, instead of one liquid only. In such batteries the water is decomposed, just as in the ordinary voltaic pile; but the hydrogen is bound again as soon as set free, in consequence of which the polarity of the plates is preserved for a much longer time than in the original voltaic pile. Batteries of this kind are therefore called constant batteries. Each constant battery consists of five substances:—viz. 1st, a metal which is attacked, and at the expense of which the electricity is produced; this is generally zinc, and forms the negative pole of the battery; 2nd, a substance which attacks the zinc, and which is generally an acid; 3rd, a porous diaphragm; 4th, a depolarising body, generally a solution of sulphate of copper; and 5th, a collector which is not attacked, such as copper, platinum, or carbon, and which forms the positive pole of the battery. Any number of such pairs may be combined to form a pile.

Becquerel's Battery.—The merit of having constructed the first constant battery belongs to M. Becquerel, who proposed to immerse copper as well as zinc in a special liquid, both being separated from each other by a porous diaphragm which allows communication between the two liquids. Becquerel's pair is contained in a cylindrical vessel of glass or porcelain; a cylinder of zinc is placed in this vessel, and acidulated water poured into the space between the vessel and the zinc. In the interior of the cylinder of zinc is placed a bladder, containing a copper cylinder and a concentrated solution of sulphate of copper. When the poles of this pair are connected, both the water and the solution of sulphate of copper are decomposed. One part of the liberated oxygen combines with zinc to form oxide of zinc, which combines again with sulphuric acid to form sulphate of zinc; another part of the oxygen combines with hydrogen to form water; besides, a thin film of copper is deposited on the surface of the copper cylinder, which is, therefore, not altered. It is easy to understand that Becquerel's battery will furnish a much more constant current than the original voltaic pile. In Becquerel's battery zinc is the negative, and copper the positive pole.

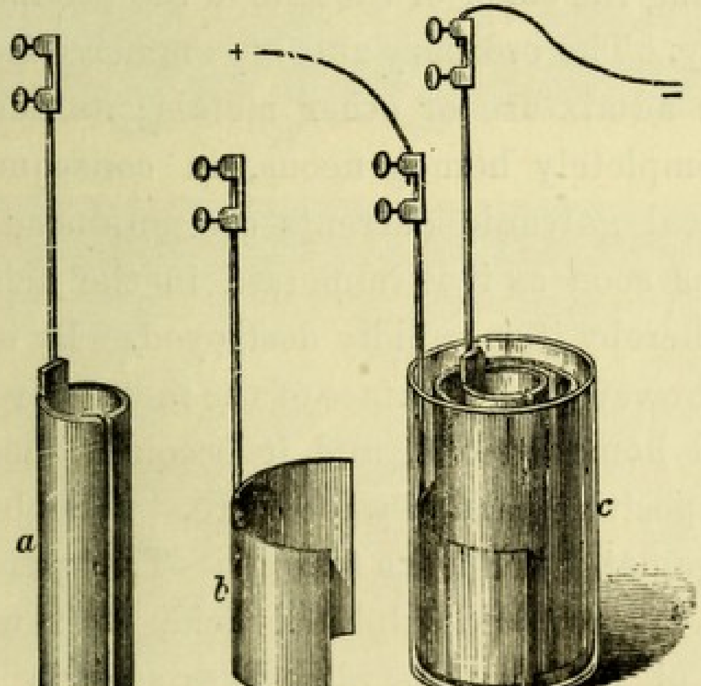


Fig. 9.

Daniell's Battery.—Very similar to Becquerel's battery is Daniell's arrangement (fig. 9, *c*), which consists of a cylinder of zinc, *a*, immersed in salt water or acidulated water, and a copper plate *b*, immersed in a solution of sulphate of copper. The chemical decomposition which takes place in this pair is exactly the same as in Becquerel's; but there are two important ameliorations introduced into Daniell's arrangement. On the one hand, it has a diaphragm of porous earth, which is not so easily spoiled as one made of organic substances—such as bladder, sail-cloth, or pasteboard—would be, and which can be conveniently employed in the form of a vessel; on the other hand, the zinc of the pair is amalgamated, which prevents its being attacked when the poles of the battery are not united by a conductor, without diminishing the effect of the zinc in the production of electricity. The ordinary zinc of commerce is impure from the admixture of other metals; its surface is never completely homogeneous, in consequence of which local galvanic currents are produced on its surface as soon as it is immersed in the acidulated water, whereby it is rapidly destroyed. By amalgamation, however, the surface of the metal is rendered pure and homogeneous, and it becomes then more strongly positive than it was before. The best way to amalgamate zinc is as follows:—The metal is at first put into diluted sulphuric acid, after which a solution of mercury in nitro-hydrochloric acid is painted over it with a camel-hair brush. The solution of mercury is made by gently heating four parts of mercury in five parts of nitric and fifteen parts of hydrochloric acid, after which twenty parts of hydrochloric acid are added to the mixture.

Daniell's battery is distinguished for its great constancy, and the ease with which it is kept in

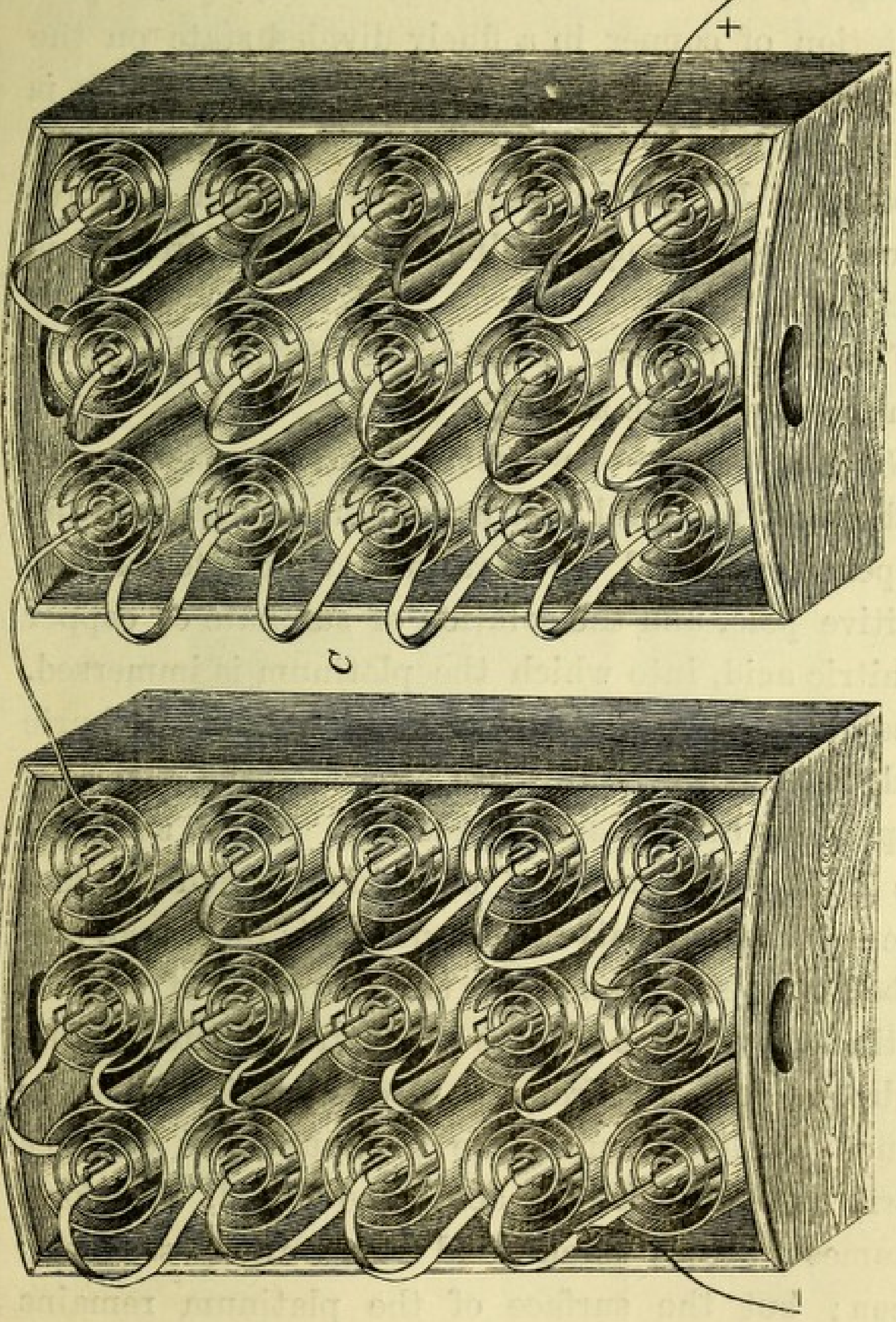


Fig. 10.

order. It is, therefore, one of the best batteries for medical use. In course of time, however, the porous diaphragm becomes obstructed with metal salts, and therefore offers a more considerable resistance to the passage of the current; besides which, by the precipitation of copper in a finely divided state on the zinc, local currents are formed, by which the zinc is further attacked, and the constancy of the battery impaired. It has therefore to be cleaned, and requires a fresh supply of sulphate of copper, from time to time.

Fig. 10 shows two batteries of fifteen pairs each, combined with one another.

Grove's Battery.—In Grove's battery, which is one of the most powerful that have been constructed, the copper is replaced by platinum, which forms the positive pole, and the solution of sulphate of copper by nitric acid, into which the platinum is immersed. Amalgamated zinc is placed in diluted sulphuric acid, and both liquids are separated by a porous diaphragm of unglazed porcelain. Nitric acid has the double advantage of containing much oxygen, whereby the intensity of the current is increased, and of being a better conductor than sulphate of copper, so that the current is more easily transmitted. The hydrogen resulting from the decomposition of water is not developed upon the platinum, but changes nitric acid into nitrous acid; the liquid, therefore, assumes a brown colour, and afterwards passes into green; but the surface of the platinum remains always clean. On the other hand, zinc is oxidised by the nascent oxygen, and sulphate of zinc remains in solution. The action of the battery is arrested after a certain time by further chemical changes which take place in the nitric acid, and result from the development of hydrogen, whereby at last the acid enters into ebullition. Grove's battery is therefore not suited for medical practice.

Bunsen's Battery.—Bunsen's arrangement differs from Grove's only in this particular, that carbon, which is more negative and much cheaper than platinum, is substituted for the latter metal. In

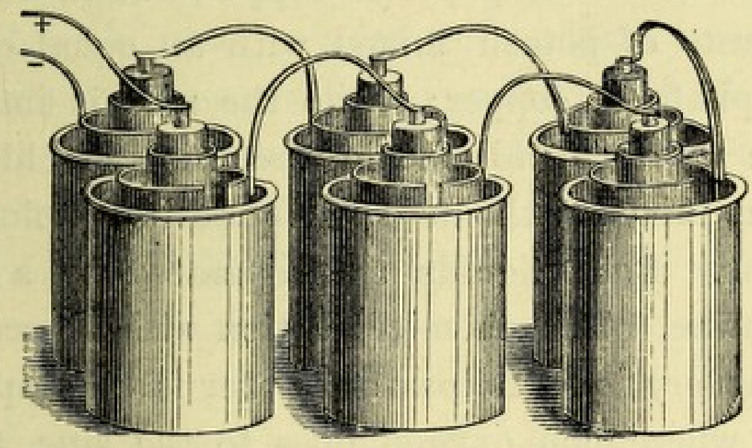


Fig. 11.

the original battery a cylinder of carbon, which is open at the bottom, is placed in a cylinder of glass, and a porous diaphragm of unglazed porcelain, containing the zinc, is placed in the cylinder of carbon; nitric acid is then poured between the glass and the carbon, and diluted sulphuric acid into the porous diaphragm containing the zinc. This form, however, has lately been simplified, so that the porous diaphragm of unglazed porcelain is no longer used, carbon itself being porous; and in its stead a cylinder of carbon is employed, which is closed at the bottom, filled with powdered carbon and moistened with nitric acid.

In Bunsen's battery carbon is the positive, and zinc the negative pole.

In Smee's pair, plates of platinised silver are substituted for carbon, and only one exciting liquid is used, viz. diluted sulphuric acid. In this battery silver is the positive, and zinc the negative pole.

In Boulay's battery the copper is immersed, not in a solution of sulphate of copper, but in a solution of nitrate of potash mixed with an equal quantity of sulphate of copper; while the zinc is immersed, not in diluted acid, but in a solution of chloride of sodium mixed with an equal quantity of flowers of sulphur. Both liquids are separated by a porous membrane. The chemical action which goes on in this battery is as follows:—Water is decomposed as usual, whereupon oxygen goes to the zinc, to form oxide of zinc, and to the sodium, to form soda; while chlorine goes to the zinc to form chloride of zinc. The hydrogen which is set free is attracted to the copper; but before it arrives there, it is met by the mixture of sulphate of copper and nitrate of potash. The sulphate of copper is then decomposed as in Daniell's battery, the reduced copper being deposited on the copper pole, while oxygen and part of the sulphuric acid proceed towards the zinc, which they transform into sulphate of zinc; another portion of the sulphuric acid, however, combines with the potash of the nitre, forming sulphate of potash, whereby a certain quantity of nitric acid is set free, which has considerable power as an electro-motor. M. Boulay affirms that this battery will remain in working condition for eighteen months consecutively, without there being any necessity to recharge it, and it is used for working the great organ of the church of Notre-Dame de Paris, with satisfactory results.

Poggendorff and Jacobi have proposed to immerse the zinc in a solution of bichromate of potash in diluted sulphuric acid; and this principle has been utilised with great success for medical purposes in Stöhrer's machine, which, together with the other medical electric apparatus, will be described in the third chapter of this volume.

Marié-Davy's constant battery consists of carbon, C, immersed in a paste of protosulphate of mercury contained in a porous vase, D, and of an external cylinder of zinc, Z, which is contained in an external vase, V, surrounded by water. Protosulphate of mercury is not easily soluble, but sufficiently so that a small quantity of it may pass out of the porous vase, and keep the zinc constantly amalgamated, the mercury being reduced on the surface of the zinc. The consequence of this decomposition of the salt is that oxygen and sulphuric acid are formed, which

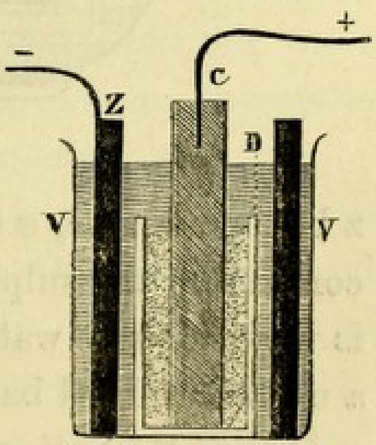


Fig. 12.

latter combines with the zinc, while part of the former combines with the nascent hydrogen to form water, metallic mercury and oxide of mercury being precipitated at the bottom of the porous vase.

Marié-Davy has also proposed a constant battery containing sulphate of lead. This salt, being completely insoluble in water, will absorb the hydrogen that is formed, and thus prevent the polarisation of the plates. Fig. 13 shows five pairs of this battery;

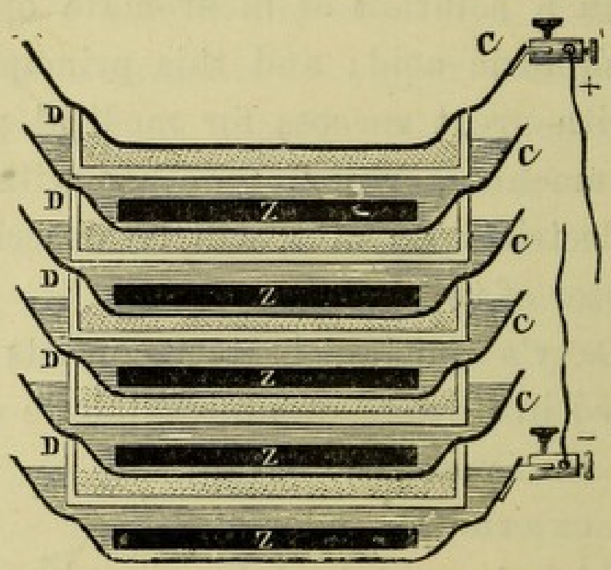


Fig. 13.

Z being the zinc, C the copper, and D the porous vases containing the sulphate of lead. The exciting liquid is water or salt water. M. Tripier recommends it as a useful medical battery.*

Prince Bagration's constant battery consists of zinc and copper immersed in a vase full of earth moistened with a solution of chloride of ammonium.

Quite recently a chloride of silver battery has

* Manuel d'Électrothérapie. Paris, 1861, p. 101.

been described almost simultaneously by Dr. Warren De la Rue,* of London, and M. Pincus,† of Königsberg. This consists of rods of zinc and silver wire surrounded by chloride of silver and salt water or dilute sulphuric acid. No diaphragm is used. The hydrogen which is set free in this battery is absorbed by the chloride of silver, whereby the polarisation of the silver is prevented. As no acid is used in this battery, and it moreover occupies only a small space, it is probable that this battery, if properly arranged, will come to form the best portable constant battery for medical use. The electrolyte being solid and little soluble, the battery can be used for months without perceptible changes occurring in the positive metal. Dr. Warren De la Rue and M. Pincus have entered into an animated controversy with regard to the priority of this discovery, each claiming it as his own—which appears not a little singular, as the battery they have described was invented ten years previously by M. Marié-Davy,‡ to whom, therefore, all the honour of the discovery belongs.

The Water Battery. — Extensive water batteries have been constructed by Messrs. Crosse, Noad, and Gassiot. Crosse's battery consists of 2,500 pairs of copper and zinc cylinders, immersed in water, enclosed in glass jars, insulated on glass stands, and well protected from dust and light. Thirty pairs of

* Comptes rendus, 1868, vol. lxvii. p. 794.

† Poggendorff's Annalen, vol. cxxxv., 1868, p. 167.

‡ Comptes rendus, vol. xlix. 1859.

this battery give a slight spark; 130 pairs open the gold leaves of the electrometer about half an inch; 250 pairs cause the gold leaves to strike their sides; 500 pairs slightly cauterise the skin; 1,200 pairs give a powerful shock. When the opposite poles of 2,400 pairs are connected with the inner and outer coatings of a battery of Leyden jars, a continual charge is kept up, each discharge being accompanied with a loud report which may be heard at a considerable distance. The discharges pierce stout leather paper and deflagrate silver leaf, while light substances are attracted from a distance of some inches. Gassiot's water battery consists of 3,520 pairs of zinc and copper cylinders.

These batteries require nothing but the addition of ordinary water to make up for that which is lost by evaporation, and will keep in good condition for years. They are, however, totally unfit for medical use, partly because they take up a very large space and are very troublesome to build up, and partly because their electrolytic and catalytic effects are very insignificant, owing to the bad conducting power of the water. The current has therefore to overcome an immense resistance in order to arrive at the poles; and thus by far the largest part of the electricity that is developed is checked in its passage, while the small quantity which passes has a high state of tension. For medical use, however, just the opposite is required, viz. a large quantity and comparatively little tension.

A combination of two metals immersed in or moistened by a liquid, is called an *open circuit*. The circuit is *closed* if the two metals are connected, apart from the liquid, by means of a metal wire, which latter is called the *conjunctive wire* or *arch*. This wire is a better conductor of electricity than the liquid, and the two contrary electricities, therefore, which are liberated by the electro-motive force, travel towards each other through this wire to neutralise each other. The production of electricity in a galvanic pair being continuous, the conjunctive wire will therefore be traversed by a *continuous galvanic current*, as long as any chemical action takes place in the pair.

Direction of the Current.—In each galvanic pair there are two currents, viz. a positive one travelling towards the negative pole, and a negative one travelling towards the positive pole. In order to avoid mistakes, however, it has been generally agreed to take only the positive current into consideration. Zinc is positively electrified when in contact with copper, and is therefore called the positive metal, while copper is termed the negative metal. But while the current travels in the liquid from the positive to the negative metal, its direction is reversed in the conjunctive wire, so that the negative metal (copper) forms the positive pole, while the positive metal (zinc) forms the negative pole. In order to show at once the direction of the current in any galvanic pair, the easiest way is to decompose by it a mixture of iodide of potassium and starch; it is then seen that at one of the wires an effervescence of hydrogen takes place, and this is the negative pole; while at the other wire a deep blue colour is produced, and this is the positive pole.

Electrolysis.—When the conducting wires of a galvanic battery are immersed in a vessel containing water, the water is decomposed, whereupon oxygen appears at the positive, and hydrogen at the negative pole. In the same manner, if a solution of table-salt is subjected to the action of the current, chlorine and oxygen accumulate at the positive, and hydrogen and sodium at the negative pole. This may be shown by immersing a piece of litmus paper in the salt solution, when the blue colour will be rendered more intense at the negative pole, while the paper is reddened at the positive pole.

This electro-chemical decomposition has by Faraday been termed *electrolysis*, in order to distinguish it from the ordinary chemical decomposition, which is called *analysis*. Chemical compounds which may be directly decomposed by the galvanic current, the same philosopher has termed *electrolytes*; the metallic ends of the conducting wires through which the current enters into, and passes out of, the electrolyte, he has called *electrodes* (ways of electricity), the positive electrode being named the *anode*, and the negative the *cathode*. The constituents of the electrolyte are called *ions*; that one which appears at the positive pole being termed the *anion*, and that one which appears at the negative pole, the *cation*. Thus, water is an 'electrolyte;' the electrode at which the oxygen appears is the 'anode,' and the oxygen itself an 'anion;' the electrode at which the hydrogen appears is the 'cathode,' and the hydrogen itself a 'cation.' The electrolytic effect increases in proportion to the number of pairs of which the battery is composed.

Substances which consist of one equivalent of one element, and of two or more equivalents of another element, are no electrolytes. Chlorides, for instance, such as chloride of sodium or potassium, can be easily decomposed, while perchlorides, such as the perchloride of platinum, resist the electro-chemical decomposition. Sulphuric acid, nitric acid, ammonia, are no electrolytes, for the same reason, but they may be decomposed if water is added to them. Thus, for instance, if diluted nitric acid is subjected to the action of the current, the water is decomposed, and the hydrogen, which is developed at the negative pole, at once combines with part of the oxygen contained in the nitric acid, to form water and nitrous acid; while oxygen appears at the positive pole. In the same manner, diluted ammonia may be decomposed, as the oxygen which is liberated at the positive pole combines with the hydrogen of the ammonia to form water, whereby nitrogen is set free. This is, however, not direct, but *secondary electrolysis.*

On the whole, very few chemical compounds can transmit a galvanic current without being decomposed by it; but in order to be electrolysed, the smallest particles of these bodies must be freely movable in all directions, so as to be able to obey the laws of electrical attraction and repulsion; and they must therefore be gases, liquids, or semi-solids.

Unpolarisable Electrodes.—A necessary consequence of the fact that the most feeble electric current cannot traverse an electrolyte liquid without decomposing it, is, that the surface of the electrodes immersed in such a liquid is soon covered with deposits, either gaseous or solid. Thus, if copper wires are immersed in a solution of table-salt, bubbles of hydrogen are seen rapidly to encircle the negative wire, while the positive wire is oxidised by the oxygen developed. The liquid then at once exercises a chemical action on the deposits with which the surfaces of the electrodes are covered; and thus secondary currents are produced. Electrodes are called polarised, if they develope a secondary current in consequence of having been traversed by a primary current. Polarisation of the electrodes has offered considerable impediments to the study not only of animal electricity, but also of the physiological action of artificial electricity upon the animal tissues. It may be to some extent prevented by frequently wiping the electrodes, but is completely avoided only by using as electrodes pieces of pure zinc immersed in a solution of sulphate of zinc. This was discovered by M. Regnauld,* and all circumstances connected

* Comptes rendus, 1854, p. 891.

with it have been further investigated by Matteucci * and Du Bois-Reymond.†

Electric Endosmosis.—M. Reuss, of Moscow, has discovered that when a porous diaphragm is placed in a liquid traversed by a galvanic current, the liquid will pass through the diaphragm in the direction of the positive current. M. Porret has called this process 'electric endosmosis,' and it has been studied chiefly by Heidenhain, Jürgensen, Wiedemann, and Quincke. The latter found that there are two modes of propagation of solid particles which are suspended in liquids, caused by the action of the galvanic current; for, while the particles near the sides of the tube move towards the positive pole, those in the centre of the tube move towards the negative pole. By increasing the intensity of the current, those particles which are in the centre are caused to move more rapidly towards the negative pole, while those near the sides move partially towards the negative, and partially towards the positive pole; the larger ones taking the direction towards the positive, and the smaller towards the negative pole. By further increasing the intensity of the current, all particles are made to move towards the negative pole, whatever may be their size or position.

Galvanometer Multiplier.—If a magnetised needle be placed below the conducting wire of a battery, it remains quiescent as long as no current passes

* Comptes rendus, 1856, p. 1054.

† Monatsberichte der Berliner Akademie, 1859.

through the wire, but as soon as the circuit is closed the needle is deflected, so that its north end points westward; and if it be placed above the wire, it is deflected eastwards. The amount of deflection obtained is proportionate to the intensity of the current. If the current be extremely feeble, no deflection will be obtained unless we take care to increase the effect of the current on the magnet, which may be done in the following way:—The conducting wire is coiled round the needle several times, and the several convolutions of the wire are insulated from one another, so that the current cannot pass directly through them, but has to traverse the whole circuit of the coil. The more numerous the convolutions of the wire, the greater will be the effect of the galvanic current on the needle. A contrivance of this kind has been termed a multiplier, as it effects a multiplication of the effects of the galvanic current. For investigating the electric current circulating in the nerves of animals, Professor Du Bois-Reymond, of Berlin, found it necessary to use a multiplier of 11,000 convolutions; and for showing the current proper of the muscles in the living man, one of 24,000 convolutions of a fine copper wire was required.

Quantity, Intensity, Density.—The intensity of the galvanic current corresponds to the quantity of electricity which traverses the circuit, and is the same in all the different parts of the circuit. This intensity, or, in other words, the quantity of electricity which circulates in a given space of time, is proportionate to the surface of the galvanic pair, and to the degree of chemical affinity which exists between the different substances composing the battery.

The intensity of the galvanic current is the same in all points of the circuit, and in all parts of the transverse section of the conjunctive wire. The intensity of the current undergoes no alteration if the transverse section of one portion of the wire be diminished; but, on the other hand, it is obvious that the electricity which moves within a given space of time through a reduced transverse section of the wire, must be in a state of greater *density* than that passing through the larger transverse section of the wire. Thus, if I denotes the intensity of the current, D its density, and T the transverse section of the conjunctive wire, the formula obtained will be $D = \frac{I}{T}$; that is to say, the density of the electricity is equal to the intensity of the current divided by the transverse section of the conjunctive wire.

Resistance; Conducting Power.—We have seen that when the poles of a pair are connected by a conducting wire, the two contrary electricities, which are liberated by the electro-motive force, travel towards each other to neutralise each other; but in no battery do we ever obtain, in the form of a current, the whole amount of electricity which is produced by the chemical action of the substances in circuit—the quantity of electricity in circulation being always less than that which would traverse a perfectly-conducting conjunctive wire. While, therefore, the quantity of electricity *produced* depends upon the intensity of the electro-motive force, the quantity of electricity that is *travelling*, and may be collected, depends upon the resistance offered to the passage of the electricity through conducting bodies, and upon the tension with which the electricity is driven through the conjunctive wire.

All bodies through which an electric current is propagated, offer a certain resistance to the passage of the current, and consequently diminish its intensity. There are no absolutely perfect conductors of electricity. If the magnetised needle of a galvanometer be brought into the circuit of a battery, the needle is to some extent deflected by the current; if we then interpose copper or silver wires, which are the best conductors of electricity, between the poles, the deflection of the needle appears less considerable than before—showing that the power of the current has been diminished by the interposition of the wires into the circuit.

Ohm's Law.—Professor Ohm, of Nuremberg, has mathematically investigated the circumstances which influence the quantity of electricity that may be obtained from a galvanic circuit, and has established the law, *that the intensity of the current is directly proportional to the electro-motive force divided by the resistance in the circuit.* Thus, if I denotes intensity, E the electro-motive force, and R the resistance, the following formula is obtained: $I = \frac{E}{R}$.

The resistance of a galvanic battery is composed of two different kinds—viz. of the resistance of the pair itself, and of the resistance offered by the conjunctive wire. The resistance of the pair is always the same, and is therefore called *essential resistance*; while the resistance of the conjunctive wire may be diminished or increased *ad libitum*, and is therefore called *non-essential resistance.*

Thus, for instance, a pair of Grove's battery has only half the resistance of a pair of Daniell's battery of the same size, because nitric acid is a better conductor than a solution of sulphate of copper (essential resistance). On the other hand, if the galvanic circuit is closed by a copper wire, there will be very little non-essential resistance, because copper is an excellent conductor of electricity; while, if it is closed by the human body, there will be a very large non-essential resistance, because the human body is a very bad conductor of electricity.

It appears that if the surface of the metals is increased, the essential resistance of the circuit is proportionately diminished, since the transverse section of the circuit is correspondingly decreased. If, therefore, the non-essential resistance is small, a few large pairs will be most serviceable; while if the non-essential resistance is great, a considerable number of pairs, with small or medium surface, will be preferable. Thus, if the circuit is closed by the human body, or by liquids which it is intended to decompose, a large number of cells, which increase the tension of the electricity, should be employed; while if a wire is to be rendered incandescent, as for the purpose of cauterisation, a few cells with large surface will best answer our purpose.

The resistance of bodies varies according to their chemical nature, temperature, and form. Resin, glass, and sulphur are the worst conductors, while metals offer only little resistance to the passage of a current; they are, therefore, termed good conductors, as they permit of tolerably rapid propagation of electricity. The conducting power of the several metals is different. Silver is the best, and mercury the worst conductor; after silver ranks copper, which conducts better than gold; gold conducts better than iron; iron better than platinum; platinum better than lead. The resistance offered to an electric current is especially great, if it passes from a liquid to a solid, or from a solid to a liquid. Liquids conduct much worse than metals, but elevation of temperature increases their conducting power, whilst heat diminishes the conductivity of metals. To give some instances: the resistance offered by a concentrated solution of sulphate of copper to the passage of an electric current is sixteen million times greater than that offered to it by metallic copper; the resistance of distilled water is four hundred times greater than that offered by a solution of sulphate of copper. Therefore, an electric current will pass more easily through a copper wire ten thousand miles in length than through a layer of water one inch in length.

The conducting power of bodies does not only depend upon their chemical nature and temperature, but also upon their form. If an electric current of the same intensity be made to pass through wires of the same metal and diameter, but of different length, we find that the current loses power in proportion to the length of the wires through which it is caused to pass. If, on the other hand, the current passes through wires of the same metal and length, but of different diameter, the power of the current is increased in proportion to the diameter of the wires. Thus, for instance, a copper wire a hundred feet long and the twelfth of an inch in diameter, offers the same resistance as a copper wire two hundred feet long and a sixth of an inch in diameter. To give another example: the resistance offered by the arm of a man is nearly the same as that offered by the leg; since both the length and the diameter of the leg are nearly double those of the arm.

The researches of Volta, Baron Humboldt,* and Ritter † have established the fact that the human body is a conductor only on account of the warm saline solution it contains, and that its resistance is chiefly due to the epidermis.

Professor Edward Weber, ‡ of Leipzig, made, in

* A. von Humboldt, Versuche über die gereizte Muskel- und Nervenfaser. Posen und Berlin, 1797. Vol. i. p. 152.

† Beiträge zur nähern Kenntniss des Galvanismus. Weimar, 1805. Vol. i. p. 258.

‡ Quæstiones physiologicæ de phænomenis galvano-magneticis in corpore humano observatis. Lipsiæ, 1836.

1836, a series of experiments on the conducting power of the human body, from which he concluded that it conducts about ten to twenty times better than distilled water at a temperature of 98° F., and fifty million times worse than copper. He corroborated Humboldt's statement that the resistance of the human body was chiefly due to the epidermis; affirmed that it was greatest where the skin was thick and dry, and least where it was thin and moist; that the mucous membranes conducted better than the skin, and that the resistance of the whole body could be very much diminished by blistering the skin, or by applying warm instead of cold conductors.

A few years later, Lenz and Ptschelnikoff, of St. Petersburg, investigated the same subject.* They used for their experiments Clarke's magneto-electric rotation machine, and employed as measurer of the current a multiplier placed at a distance of eighteen feet from Clarke's apparatus, in order to avoid any action of the horse-shoe magnet upon the magnetised needle of the multiplier; the deflections of the needle being observed by means of a telescope. Two vessels were then filled with water slightly acidulated with sulphuric acid; one of the vessels was connected with one of the poles of Clarke's machine, by means of a short and thick copper wire, which did not present any resistance to passage worth mentioning; one of

* Ueber den Leitungswiderstand des menschlichen Körpers gegen galvanische Ströme; in Poggendorff's Annalen, vol. lvi., 1842, p. 429.

the ends of the multiplier was then immersed in the other vessel, the other end of the multiplier being connected with the other pole of the magneto-electric machine. Now, a man whose resistance to the passage of the electric current was to be measured, was ordered to immerse his hands in the two vessels, in order to close the circuit; when the magneto-electric current passed through his body to the magnetised needle of the multiplier. At first the deflection was noticed which occurred when the extremities of the multiplier were connected with the coil of Clarke's apparatus without the intervention of any foreign body; afterwards the deflection obtained when the human body was enclosed in the circuit; and, finally, the deflection obtained when the human body was removed from the circuit. From the first and third deflections the medium was taken, and the result compared with the amount of the second deflection.

Lenz and Ptschelnikoff made their experiments on a working man, two persons of rank, a boy of seven years, a girl of nineteen, and a young man of seventeen. It appeared immaterial whether the immersed part was near the conducting wire, or at some distance from it, since the differences produced in the deflections of the needle by changing the position of the wire did not amount to one-tenth of a degree; but it was shown that the amount of surface of the immersed part of the body was of the greatest influence. Thus the resistance was 34°·09 if only the first finger was immersed into the liquid; the resistance was diminished to 19°·20 if the middle finger was also immersed; it was only 6°·06 if the whole hand was plunged into the liquid.

One of the results of these experiments was, that the conductivity of the human body is shown to be altogether different according to the conducting liquid that is used. Thus, if water from the Neva was put into the two vessels, the resistance amounted to 16°·53. If one part of sulphuric acid was added to a hundred parts of water, the resistance was diminished to 6°·06. A little scratch made on the hand further reduced the resistance to 4°·81; and if four parts of sulphuric acid were added to a hundred parts of water, the resistance was only 4°·37; that is to say, four times less than if ordinary water was employed as a conducting liquid. The greatest part of the resistance of the human body is therefore due to the epidermis, the removal of which notably diminishes resistance, which is also much reduced by the use of a well-conducting liquid.

Besides, it appeared that the resistance offered by young people is greater than that of elderly persons; that the resistance offered by the hands of working men is greater than that of the hands of persons of rank; that the resistance offered by the right hand is greater than that of the left. Lenz and Ptschelnikoff have calculated the resistance of the whole body to be equal to a copper wire of one millimètre in diameter and 300,010 feet long, if water diluted with one per cent. of sulphuric acid was used as the conducting liquid: but if four parts of sulphuric acid were added to a hundred parts of water, the resistance appeared to be equal to a copper wire 213,000 feet long.

The fact that the conducting power of young persons should be less than that of elderly people, is, by Du Bois-Reymond, attributed to the smaller transverse section of their fingers, which, next to the epidermis, offer the greatest resistance to the passage of electricity. Ranke,* however, thinks it rather more dependent upon the different chemical composition of the liquids and tissues of young and elderly people. Youthful tissues contain a greater proportion of water, and adult or senile structures a more considerable quantity of salines, other things being equal; and this would sufficiently explain why the youthful body must conduct less well than the adult one. There can, however, be little doubt that both the circumstances mentioned by Du Bois and Ranke contribute towards this result.

There are certain differences in the conducting power of different persons, and of the same individuals at different times, which have not yet been satisfactorily explained. It is well known that some persons are naturally better conductors of electricity than others; and this must be in some measure due to the great variety which exists in the quantity of perspiration in different individuals. But this circumstance alone is not sufficient to explain all the

* Tetanus. Eine physiologische Studie. Leipzig, 1865, p. 13.

phenomena which have been observed. Thus, for instance, when shocks from a Leyden jar are transmitted through a number of persons forming a chain, there are people in the chain who will feel the shock very slightly, or not at all, and some will even stop the propagation of electricity; while other individuals will feel the shock very severely. Now, this might be readily understood if the hands of such persons who stop the shock should happen to be quite dry, or the epidermis very thick; but, in many instances, such is not the case: sometimes persons will stop the propagation of electricity whose epidermis is very delicate, and even if it be purposely moistened in order to facilitate the transmission of the shock; while at other times, the same persons will feel the shock very distinctly. Similar observations have been made with regard to lightning. Thus, a single person has been struck in the middle of a group of men, while all others remained untouched; and, on the other hand, a number of persons standing together have been killed by the stroke, while one of them escaped without injury. It is also understood that certain Indians and negroes can handle the electric eel without experiencing shocks; and Mr. Flagg asserts,* that if a number of persons join hands and one touch the eel, they are all equally shocked, unless there should happen to be one of the number incapable of being affected by the eel, which

* Transactions of the American Phil. Society, held at Philadelphia, 1786, vol. ii. No. 13.

is, he says, 'the case of a very worthy lady of my acquaintance, who can handle this fish at will.' (It is said that this lady suffered from hectic fever.)

Conductivity of Tissues.—Researches on the relative conducting power of the different animal tissues are of recent date. The old physiologists, who had not experimented on the subject, believed that the nerves were the best conducting tissue of the animal body, carrying the orders of the will with the rapidity of lightning to the muscles. But it resulted from the first experiments which were made on this matter by Heidmann, in 1805, and again from those of Person,* in 1830, that the nerves are no better conductors than the muscles and other moist animal substances; and that their conductivity is not changed through any mechanical injury being inflicted upon their substance.

In 1843 this subject was investigated by Matteucci, who was led to the conclusion that the muscles are the best conducting tissue of the animal body, that the brain, the spinal cord, and the nerves are not very different from each other in this respect, and that they conduct four times worse than the muscles.†

Matteucci's views were almost generally received by the Profession, but we shall see presently that the method he employed in his researches is open to objections, and does not yield correct results. In

* Sur l'hypothèse des courans électriques dans les nerfs; in Magendie, Journal de la Physiologie expérimentale. Paris, 1830.

† Traité des phénomènes électro-physiologiques des animaux, etc. (Paris, 1844), p. 47; and Comptes rendus (1843), p. 23.

order to ascertain the relative conductivity of nerves and muscles, he took a layer of the cerebral substance, a piece of the sciatic nerve, and a piece of a muscle from the thigh of a rabbit recently killed; he then reduced these substances to slices of the same thickness, and caused a continuous current of twelve pairs to pass through this chain of animal substances lying on an insulating plane. He employed two different ways for comparing the resistance separately offered by nerves and muscles. At first he touched pieces of nerves and muscles of equal length with the extremities of a sensitive galvanometer multiplier, which were held at equal distances from each other; and obtained more considerable deflections of the magnetised needle when he touched the muscle than when he touched the nerve; the amount of deflection being inversely proportional to the resistance offered by the different substances to the passage of the current. He afterwards altered the distance of the extremities of the galvanometer multiplier, so as to obtain equal deflections of the magnetised needle, by touching either the nerves or the muscles; the resistance to passage being in this instance inversely proportional to the length of the animal substances comprised between the extremities of the multiplier. He thus found that, in order to obtain the same deflection of the needle, he had to approach the extremities of the multiplier when he touched the nerves; whilst when he touched the muscles, he was obliged to increase the distance between the extremities of the multiplier. From this Matteucci calculated that the muscles conduct four times better than the nerves, whilst the nerves conduct rather better than the brain and the spinal cord. The experiments of Matteucci were repeated, and on the whole, confirmed, by Dr. Schlesinger, of Vienna.*

Several objections, however, must be made to Matteucci's experiments. In the first place, it has been pointed out by Du Bois-Reymond, that the slices of the different tissues can never be exactly of the same length and diameter. Besides, Matteucci neglected to measure the intensity of the current of the battery; and finally, it seems strange that he should have obtained exactly the same results by both of his methods—as in the former of them an influence must have been necessarily exercised by polarisation, whilst there was no such influence in the latter proceeding.

We therefore cannot accept Matteucci's researches as conclusive, and need not be surprised that other results have been obtained by means of an ingenious method devised by Professor Eckhard, of Giessen.† The result at which this observer has arrived is, that the resistance offered to the passage of an electric current by the muscles, tendons, nerves, cartilages, and bones, is not always the same, because the amount of water in these tissues is variable. Indeed,

* Die Elektricität als Heilmittel. Zeitschrift Wiener Aerzte, 1852, July.

† Beiträge zur Anatomie und Physiologie. Giessen, 1858. Vol. i. p. 57.

there are not only differences in this respect between different individuals of the same species, but the same tissues taken from different parts of the same body present differences in the amount of water they contain. Thus it is a fact well known to anatomists, that the median nerve at the fore-arm contains fewer blood-vessels than the sciatic nerve immediately after it has emerged from the pelvis. Therefore, the median nerve does not conduct so well as the sciatic nerve. Finally, it must be considered that a more or less active evaporation of water is always going on during the time that the tissues are reduced to such a shape as to be fit for observation; whereby certain variations must invariably occur, according to the temperature of, and the amount of moisture contained in, the air.

As the different animal tissues, with the only exception of the nerves and the lumbrical muscles, cannot be well reduced to such a shape that the longitudinal and transverse sections are perfectly alike, this being a necessary condition for the exact calculation of their resistance to passage, M. Eckhard did not compare directly the resistance offered separately by the tissues themselves, but first determined the resistance offered by any piece of animal tissue; from this he afterwards took a cast in plaster of Paris, by means of which he formed a piece of glue perfectly like the piece of animal tissue already examined; and then measured the resistance offered by the piece of glue. The glue used for these experiments was always of the same strength, and the experiments were not commenced before the different pieces of glue had cooled down to the same temperature; the cooling was effected in a room filled with moisture. For ascertaining the conductivity of muscular substance, Professor Eckhard took fibres from a dead body, after the rigor mortis had disappeared; because, before this period has elapsed, it is not possible to form a piece of glue perfectly similar to the piece of muscle. In order to avoid the shrinking of the muscle that might be occasioned by the hygroscopic property of plaster of Paris, he covered the muscular fibres with a layer of fat before he took the cast. After having determined the comparative resistance offered by the different animal substances and glue, it was easy to calculate the relative difference in the conductivity of the animal tissues themselves.

As measurer of the current, a galvanometer multiplier of 8,000 convolutions was employed, and, in order to avoid the influence of polarisation as much as possible, copper wires, cemented in glass tubes, were taken as electrodes, the free extremities of which were immersed in a concentrated solution of sulphate of copper. The current itself was furnished by a single cell of Daniell's battery, the constancy of which had been tested before; cushions of blotting paper, well moistened with the white of an egg, were immersed with one extremity in the liquid, their other extremity serving as electrode.

M. Eckhard first ascertained the deflection suffered by the magnetised needle if the circuit was closed by the cushions alone. He then interposed a piece of muscular substance, whereby the deflection was diminished to a certain extent; if a piece of tendon was interposed, the deflection was further diminished. He afterwards noticed the deflections of the needle produced by the interposition of different pieces of glue corresponding to the pieces of muscles, tendons, etc. In this way he found that the muscles are the best conducting tissue of the animal body; that there is no remarkable difference in the conductivity of nerves, cartilages, and tendons; and that the bones are very imperfect conductors of electricity.

Having put the resistance of fibres taken from the sartorius muscle of man = 1, Eckhard found the resistance of the tendon of the gastrocnemius = 1·7 to 1·9; of the tendon of the semitendinosus = 2·2 to 2·4; and of the tendon of the extensor carpi radialis = 2·3 to 2·6; therefore the medium resistance offered by tendons would be 2·1. The resistance offered by the cartilages of the ribs varied from 1·7 to 2·4; medium = 2. The resistance of nerves taken from the brachial plexus was 1·9 to 2·4; that of the sciatic nerve 2·2; medium 2·1. The compact substance of the bones appears to conduct 16 to 22 times worse than the muscular substance. It is, however, difficult to make conclusive experiments as to the conductivity of the bones, because the bones must be sawn through if we wish to procure pieces fit for observation. If this be done without using a fluid, the small quantity of liquid contained in the bone will evaporate from the surface, in consequence of the heat produced by friction; and if the bone be sawn through, the surface being continually kept moist with the white of an egg, it might be feared that the amount of liquid would be artificially increased.

The results of Professor Eckhard's researches may therefore be summed up in the following:—

The resistance of muscles is	=	1.
of cartilages	=	2.
of tendons	=	2·1.
of nerves	=	2·1.
of bones	=	19.

These numbers correspond with the amount of water contained in the animal tissues; for if we take the medium of all trustworthy chemical analyses of animal substances which have yet been made, we find that—

The muscles contain	76 per cent. of water.
The tendons	62.
The cartilages	62·5.
The nerves	52·5.
The bones	5.

The apparent incongruities in the numbers may be understood, if we consider that the conductivity of tissues is not exclusively due to the amount of water, but also to the quantity of salines contained in them.

Although Eckhard's researches were carefully made, it should be understood that their results cannot be considered as final, firstly, because he did not experiment directly on the tissues themselves;

secondly, because dead tissues must have a different conducting power from living ones; and, thirdly, because the influence of polarisation was not thoroughly avoided in his experiments.

Du Bois-Reymond* was the first who gave his attention to the question whether the different conditions of living muscle had any influence upon its conductivity, and whether the negative variation of the muscular current discovered by him had anything to do with an alteration of the resistance of muscular fibre when contracted, from that which obtains when the fibre is quiescent. He found that during contraction there was increased resistance, owing to the alteration in the shape of the muscle; while if this alteration in the shape was excluded, the contraction seemed to be accompanied with a slight diminution of resistance.

Dr. Ranke,† of Munich, has recently made a series of experiments on the resistance of muscular fibres which have given some interesting results. He used the adductor muscles of the frog's thigh, which, as they consist of longitudinal fibres, do not evolve a current of animal electricity in their natural longitudinal section, both ends being at the same distance from the equator. As it appeared from Du Bois-Reymond's observations that alterations of shape have a certain influence on the galvanic resistance of the muscle, such alterations were, as far as possible, excluded by

* Untersuchungen über thierische Elektricität, vol. ii. p. 174. Berlin, 1853.

† L.c., p. 27.

using the "muscle-clamp." This is an instrument consisting of two branches, one of which is fixed on one end of a glass rod, while the other branch is freely movable on the rod, and may be fixed at any point of the same by means of a screw. The upper part of these branches is of ivory, and the lower one of brass. The ivory is smooth and thin, and has in the middle a small excavation for receiving the terminal bones of the frog's limb. It is easy, by means of this contrivance, to give to a muscle fixed in it any degree of tension which may be required. The other instruments used were a single cell of Daniell's battery, a galvanometer multiplier, a rheochord, a rheostat, and unpolarisable electrodes, such as are used by Du Bois-Reymond in his experiments on animal electricity, and which will be described in the section on animal electricity. The difficulty which had always been experienced by previous observers, of giving to the animal tissues a stereometrically definite shape, Ranke endeavoured to overcome in the following manner :—The elasticity of the tissues allowed him to draw them into a small glass tube, which was completely filled up by them, the terminal surfaces of the preparation being made parallel with both openings of the tube. By this proceeding he could not only give a definite shape to any tissue, but also give the same shape to all sorts of different tissues, so as to exclude errors which would otherwise necessarily arise from measuring the dimensions of the different tissues.

The chief results of Ranke's observations are the following:—Living muscle conducts 3,000,000 times worse than mercury, and about 115,000,000 times worse than copper. The resistance of dead muscle as compared with living muscle is as 56 to 100; it therefore conducts 1,680,000 times worse than mercury, and 64,400,000 times worse than copper. This diminution of resistance in dead muscle is owing to the accumulation of certain products of decomposition, the most important of which seems to be lactic acid; for, other circumstances being equal, an acid muscle naturally conducts better than one which is not acid. Boiling diminishes the resistance of the muscular fibre for the same reason, and contraction has the same influence. Eckhard's proposition that tendons, cartilages, and nerves do not show any considerable differences in their resistance to passage, should be so far modified as to express that all the different animal tissues show only very slight differences of conduction, the epidermis alone excepted.

With regard to the conductivity of bones, the resistance of which Eckhard has put down as varying from 16 to 22, direct observations have hitherto been wanting. Dr. Friedleben, of Frankfort,* has shown that almost all analyses of bones which have been made until now, concern only osseous tissue which has been carefully dried. Indeed, chemists as well as pathologists and histologists have generally considered that the quantity of water in bones was

* Wunderlich's Archiv. der Heilkunde (1861), p. 139.

something accidental and unimportant. Their analyses therefore teach us nothing at all about the actual composition of osseous tissue in the living body. Nasse has incidentally mentioned that the average amount of water in the ribs is 42·8 per cent. Becquerel found in the skull-bones of a rickety child, who had died of pneumonia, 35·2 per cent of water. J. Stark * says that on the whole the bones of fishes contain most water, viz., from 50 to 80 per cent; that the bones of young birds contain more than that of old birds (from 12 to 25 per cent); that the flat bones of mammalia contain generally more water than the round bones of the extremities (the former from 12 to 20, the latter from 3 to 7 per cent); that the more spongy the substance of bones, the greater is the amount of water, and that as far as the mammalia are concerned, the human bones contain more water than the bones of any other mammalia. All these assertions, however, are contradicted by Friedleben, who has shown that several sources of error are inherent to Stark's method of investigation. He justly contends that most bones which have hitherto been analysed were not fair specimens, as they were taken from persons who had by previous illness suffered from more or less considerable disturbances of nutrition, and that consequently the chemical composition of the bones must have been altered likewise. This holds good

* Chemical Constitution of the Bones of the Vertebrated Animals; Edinburgh Med. and Surg. Journal, vol. lxiii. (1845) p. 308.

especially for young people, in whom the composition of bones appears to be rapidly affected whenever the nutrition of the system generally suffers; in rickets, for instance, the amount of water in the bones is greatly increased. Further observations are therefore required to elucidate the conducting power of bones in the living subject.

The question whether the galvanic current can be safely transmitted to the nervous centres in the living man, will be discussed in a subsequent chapter.

(B) Electro-Magnetism.—Phenomena showing the close relation that exists between electricity and magnetism, have been observed centuries ago. By the fall of lightning masses of steel and iron have been magnetised; watches have been stopped in consequence of the magnetisation produced by lightning in the pieces of steel of the balance; the poles of mariner's compasses have been reversed by the fall of lightning upon ships—an occurrence which has, in some instances, been attended with fatal results to sailors, who being guided in a contrary direction were cast upon rocks, from which they thought they were receding at full sail.

In 1819, a Danish philosopher, Oersted, made the first scientific observation on the action of electricity upon a magnet. He found that when the two poles of a galvanic battery are united by a metal wire, placed closely above or below a magnetised needle, the needle immediately suffers a deflection, the extent of which is directly proportional to the power of the battery, and inversely proportional to the distance between the needle and wire. The needle tends to place itself at a right angle to the conjunctive wire, and succeeds in attaining this position when the current of the battery is powerful and the needle very near to the wire.

Astatic Needle.—Ampère then drew the attention of natural philosophers to the fact that the terrestrial magnetism prevents the magnetised needle from entirely obeying the action of the current, as that influence continually tends to reduce the needle to the plane of the magnetic meridian. To obviate this inconvenience he constructed the so-called *astatic needle*, composed of two magnetised needles placed in a parallel direction, whereby the influence of the globe is more or less counter-balanced. But the two needles cannot, under any circumstances, be perfectly alike, nor placed in two directions exactly parallel, nor possess absolutely the same quantity of magnetism; and therefore the globe will always exercise a certain amount of action upon the astatic system. But the effect of an electric current is certainly much stronger upon a double than upon a single needle; and a very feeble current which is not able to deflect the latter, will produce a marked effect upon the astatic system, especially if the wire by which the current is transmitted be bent, so that it is no longer above or below the needle, but forms two parallel branches, between which the needle is suspended; it being of course necessary that the current should not be allowed to pass from one coil to the other, which is prevented by covering the wire with an insulating envelope of silk or gutta percha. If there be two such coils, the action of the current upon the needle is twice as powerful as if the wire had been only above or below the needle, and each further convolution of the wire will proportionately increase the action of the current upon the needle. This principle has been applied to the construction of the galvanometer multiplier, which was invented by M. Schweigger, and first employed in electro-physiological researches by M. Nobili. Du Bois-Reymond has constructed multipliers of the utmost sensitiveness (with more than 24,000 convolutions), by means of which he was enabled to detect the presence of electric currents in almost all the tissues of the living animal body.

Soon after Oersted's discovery had been made known, Arago found that the electric current imparted a strong magnetic force to pieces of soft iron, steel, and other magnetic bodies, which did not possess it previously. He saw that when a fine iron wire was traversed by the current, it acquired the property of attracting iron filings, which dropped again as soon as the current ceased to pass. Arago succeeded likewise in magnetising needles by discharges from a Leyden jar. He showed that, if a copper wire covered with silk or gutta percha be coiled round a bar of soft iron, and an electric current be made to pass through the wire, the soft iron becomes a powerful magnet. Such temporary magnets are termed *electro-magnets,* in order to distinguish them from permanent magnets of steel. Soft iron is rapidly magnetised and demagnetised by an electric current. In order to show the magnetic power produced in the soft iron by the passage of an electric current, the bar should be shaped like a horse-shoe, the poles of such a magnet being very near to each other.

Induction Currents.—Science had advanced thus far when Faraday discovered, in 1831, that a galvanic current is able by induction to develope electric currents in conducting wires. This is proved by the following experiments:—Two conducting wires are placed on an insulating plane, parallel with, and very near to, each other; the two ends of the first wire are then connected with the poles of a galvanic battery, and the two ends of the second wire with the extremities of a galvanometer multiplier, in order to enable us to ascertain the electric movement in the wire by the deflection of the needle. At the moment when the current of the battery is made to pass through the first wire, the needle of the multiplier communicating with the second wire is deflected, then suffers some oscillations, and finally returns to rest, which remains undisturbed so long as the current of the battery continues to pass through the wire. But as soon as the communication between the battery and the first wire is interrupted, the needle suffers another deflection in a contrary direction to that in which the former had occurred. From this it appears that the galvanic current which traverses the first wire determines in the second wire an instantaneous current at the moment when it begins to circulate, and another equally instantaneous current at the moment when it ceases to pass. The multiplier, however, indicates not only the existence of such instantaneous currents, but also their direction; showing that the current induced in the second wire on *making* the circuit flows in a direction contrary to that of the current of the battery, while the direction of the current induced in the second wire on *breaking* the circuit is *equal* to that of the current of the battery. We may notably increase the intensity of these instantaneous currents by employing two copper wires of great length covered with silk or gutta percha, and rolled round a wooden cylinder or bobbin, so as to form two coils, the convolutions of these wires being as near to each other as possible.

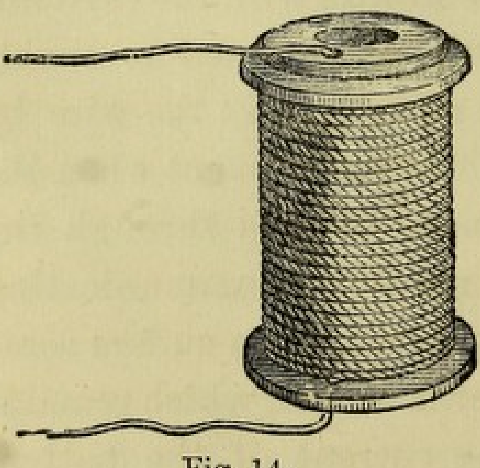


Fig. 14.

The intensity of induction currents is further increased by introducing into the cavity of the bobbin pieces of soft iron, which become magnetic under the influence of the battery current, and thereby produce other electric currents in the two wires. The currents produced by the magnetism of the soft iron are equally instantaneous as the currents developed by the inducing current of the battery. They are not produced whilst the soft iron is magnetic, but only at the moment when it acquires and loses its magnetism. Therefore the demagnetisation of the soft iron has the same effect as breaking the current of the battery, in the production of an instantaneous induced current.

The power of the electro-magnet to increase the intensity of induction currents differs according to the shape and quantity of iron. It is sufficient for producing a remarkable effect, to have a single piece, or a hollow cylinder, of soft iron round which the copper wires are coiled, but the effect is increased if we take a bundle of iron wires; and yet more, if these wires are insulated from each other by a layer of varnish. It was formerly believed that the increased effect was due to the circumstance that the iron wires are softer than a solid cylinder, and therefore would become more strongly magnetised. But it has been proved by the researches of Professor Magnus, of Berlin, that such is not the case, the magnetism of a solid cylinder being equally powerful with that of a bundle of wires of the same volume; and that the increased effect is due to the bundle of wires conducting less well than the solid cylinder. If the poles of the battery are in connection with the coil of wires, instantaneous currents are produced in the central soft iron, as well as in the wires that are coiled round it. Now the current produced in the soft iron on breaking the circuit retards notably the demagnetisation of the soft iron; the magnetism of the soft iron will, therefore, disappear much more easily and rapidly if the production of currents in the soft iron is prevented as much as possible. The more rapid the demagnetisation of the soft iron, the more notable will be its inducing effect. It is clear that electric currents will be most easily produced in a solid bar of soft iron, less easily in a bundle of iron wires, and least easily if these wires are insulated by varnish.

Professor Dove, of Berlin, has shown that the intensity of an induced current is very much diminished by covering the electro-magnet with a closed tube of a non-magnetic metal (brass or copper). This is due to the development of induced currents in the metal tube, whereby the effect of the magnetism in the soft iron is counterbalanced. The tube does not prevent the action of the current upon the galvanometer, but it greatly diminishes the magnetising as well as the physiological effects. From this it follows that a metal tube covering the electro-magnet may be employed as a regulator of the intensity of the current in physiology and therapeutics; and that the galvanometer does not indicate the intensity of the physiological effects of induction currents.

The first wire of the bobbin of induction, the ends of which are connected with the poles of the battery, is comparatively short and thick, as the inducing current of the battery, which is propagated in it, is generally that of a single pair, and the resistance of the conducting wire must be slight, if a powerful electro-magnet is to be produced by the current. But in the short and thick wire we have not only the inducing current of the battery, but another current which is much stronger, and is developed by the mutual action of the convolutions of the short and thick wire upon each other—an effect which only takes place if these convolutions are very near to each other; they therefore serve at the same time as inducing body and as induced body. This current, which has been termed *extra-current* by Faraday, is produced not only when the circuit is broken, but also at the moment when it is established. Its direction is contrary to that of the current of the battery on closing, and equal to it on opening the circuit. Its energy is also notably increased by the presence of soft iron in the interior of the bobbin; it is capable of deflecting the needle of a galvanometer, it produces sparks, shocks, and heat, and decomposes water. The extra-current is due to induction by its own convolutions and by the temporary magnet; while the current induced in the second wire arises from induction by the current of the battery and by the electro-magnet.

It appears from the researches of an American philosopher, Mr. Henry, of Princetown, that the action of induction is not confined to two coils; but, that a current induced in the second wire may again induce another current in a third coil, if this be placed near to the second; that the current produced in the third wire may give rise to a current in a fourth coil, etc. Mr. Henry has also endeavoured to determine the direction of these induced currents of the second, third, and fourth order, and found that if the current induced in the second coil be positive, that induced in the third wire would be positive again, whilst that induced in the fourth would be negative, that in the fifth positive again, etc.

The intensity of induced currents depends, in the first place, upon the intensity of the inducing current of the battery; if this be feeble, it will not be able to develope a powerful magnetism in the soft iron, and the extra current, as well as the current induced in the second wire, will be of low tension. It depends besides upon the transverse section, and the number of convolutions of the wires; the intensity of the current being directly proportional to the number of convolutions and inversely proportional to the diameter of the wire; the current will, therefore, be stronger in proportion to the length and fineness of the wire. Finally, the intensity of the induced current depends upon the quantity, and the more or less insulated state, of the soft iron in the centre of the bobbin.

An induced current differs from a continuous galvanic current, in the first place, by its being instantaneous. To this circumstance is due the remarkable physiological effect of the induced current, especially upon the motor nerves and muscles; as we shall see hereafter, that motor nerves and muscles are not excited by a closed circuit, but by variations in the density of the current. On the other hand, induction currents differ from the continuous galvanic current in so far as the direction of the latter is always the same, whilst the former move alternately in different directions; indeed, the deflections of the magnetised needle show that the current induced in the second wire, on closing the circuit of the battery, has a direction contrary to that of the current induced on opening it. This circumstance gives rise to a peculiarity in the chemical action of the induced current. We have seen that when water is decomposed by a continuous galvanic current, the hydrogen appears invariably at the negative, and the oxygen at the positive pole. But such is not the case if we decompose water by induction currents; for, as each wire alternately serves as the positive and negative pole, both hydrogen and oxygen appear at either of the poles; the gases, therefore, represent an explosive mixture, and if the induction currents succeed each other very rapidly, both gases appearing simultaneously, and both being in the nascent state, they immediately combine again to form water, so that the water is apparently not at all decomposed by the induced current. If platinum plates be immersed in water, and induction currents be sent through them in rapid succession, the water is decomposed and oxygen liberated; this nascent oxygen produces oxidation of the platinum; but oxide of platinum is immediately afterwards reduced to metallic platinum by the nascent hydrogen. Thus, a series of oxidations and reductions takes place in the metal, in consequence of which the platinum plates become at last covered with a black powder, which is finely-divided metallic platinum. Another experiment to show that induction currents move alternately in different directions, is, to bring a solution of iodide of potassium and starch into the circuit; the blue colour indicating the liberation of iodine will then shortly appear at either of the poles, while if we cause that decomposition by the continuous galvanic current, the blue colour is only noticed at the positive pole.

It would, therefore, appear erroneous to speak of a permanent positive and negative pole in an induction apparatus employed for physiological or therapeutical purposes. Such is, indeed, the opinion of the author of a celebrated treatise on the physical properties of electricity,* who explains the difference in the therapeutical and physiological action of the extra-current, which he considers as produced only on breaking the circuit, and of the current induced in the second wire, partially by the circumstance that the extra-current always moves in the same direction, whilst the current induced in the second wire alternately moves in contrary directions. But M. de la Rive seems to have disregarded the fact, that the physiological effect of the extra-current, as well as of the current induced in the second wire on *closing* the circuit, is scarcely perceptible; while it is very

* A Treatise on Electricity, in Theory and Practice, by M. A. de la Rive. Translated by Charles Walker. London, 1858. Vol. iii. p. 603.

powerful on *opening* the circuit. We are, therefore, allowed, if we employ induction currents in physiology and therapeutics, to take into account merely the current induced on opening the circuit, which has a direction equal to that of the inducing current of the battery.

We have now considered in their principal features the phenomena of induction brought about by voltaic electricity, and proceed to take a short glance at Faraday's discovery of electric currents induced by a permanent magnet of steel.

(C) MAGNETO-ELECTRICITY.—If the pole of an ordinary magnet be approached to one of the extremities of a copper wire covered with silk or gutta percha, and coiled round a wooden cylinder, the needle of a galvanometer, communicating with the ends of this wire, is immediately seen to suffer a deflection. As long as the magnet remains in the same position, the needle is not further disturbed: but as soon as the magnet is withdrawn, another deflection of the needle takes place, which indicates the existence of another instantaneous current produced in the wire, and moving in a direction contrary to the first. The current produced by a permanent magnet of steel is called the *magneto-electric* current, in order to distinguish it from the *electro-magnetic* current induced by voltaic electricity. For producing a succession of such currents, the magnet must be continually approached to, and withdrawn from, the spirals of the wires. To effect a very rapid succession, the permanent magnet is not made to act immediately upon the wires, but an armature of soft iron, having the form of a horse-shoe, is surrounded by the wires, and set in rotation before the two poles of a fixed permanent magnet, by means of a wheel connected with an endless cord. By each turn of the wheel, the two branches of the armature are made to pass before the poles of the permanent magnet; at each passage there is magnetisation and demagnetisation of the soft iron, and an electric current is produced by the sudden change in the magnetic state of the armature at the moment when it is approached to, and when it is withdrawn from, the magnet.

The intensity of the magneto-electric current depends upon the power of the permanent magnet; upon the number of convolutions and the diameter of the wire coiled round the armature of soft iron; on the distance of the armature from the poles of the magnet; and finally on the velocity with which the wheel is turned. The physiological effect is produced on breaking as well as on making the circuit; in the former case the effect is stronger; but the difference is not so great as with the current induced by voltaic electricity. If we wish, therefore, to avoid the continuous change in the direction, and to operate with a succession of currents all guided in the same direction, we may employ a wheel, the teeth of which are alternately of metal and ivory, so that only one of the two induced currents which are produced is collected.

Derived Currents.—Finally, a few words upon the meaning of the term 'derived current.' If in a closed circuit two points are connected by an additional conductor, a portion of the current is drawn off or 'derived' by the latter. The current as it existed before the derivation was established is termed the primitive current; the additional conductor, derivation wire; and the portion of the current that passes by this wire, the derived current. The intensity of a derived current is, of course, always infinitely more feeble than that of the primitive current.

III.—ANIMAL ELECTRICITY.

Life is not possible without a continuous disturbance taking place in the equilibrium of the molecules of the body; and as every such disturbance is accompanied with a liberation of electricity, the existence of electric currents in the animal body during life appears a necessity.

That certain fishes, when touched, give shocks, was already known to the Romans, who employed them for the cure of headaches and gout. The best known among these fishes are the *Torpedo*, or *electric ray*; the *Gymnotus*, or *electric eel*; and the *Malapterurus*, or *electric shad*. The Torpedo is frequent in the Mediterranean, and has been examined by Dr. John Davy,*

* Philos. Trans. 1832, vol. ii. p. 276. And, Researches, Physiological and Anatomical. London, 1839.

Matteucci,* Kölliker,† and Max Schultze;‡ the Gymnotus is to be found in Surinam, in the ponds of Bera and Rastro, and has become known chiefly by the graphic descriptions of Baron Humboldt,§ and the able researches of Professor Faraday;‖ while the structure and properties of the Malapterurus, which is found in the Nile, have been investigated by Bilharz¶ and Max Schultze.**

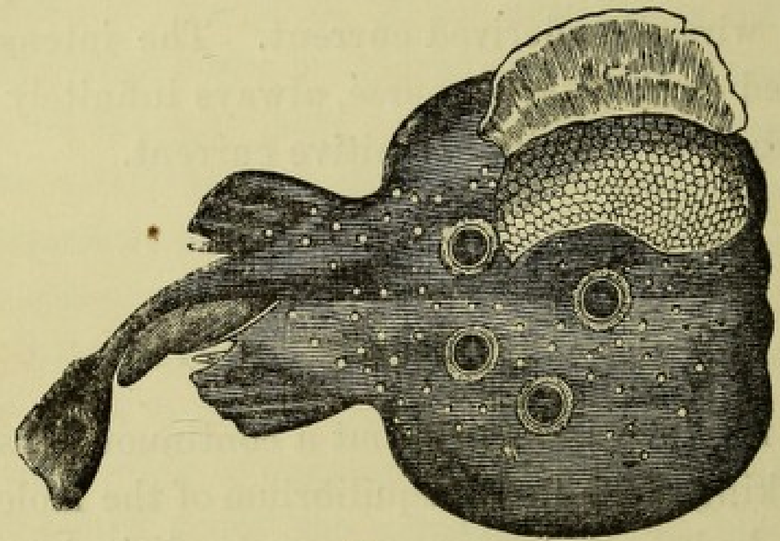


Fig. 15.

If an electric fish be touched at any part of its body, especially at the fins, it gives a violent shock, analogous to that yielded by a Leyden jar. In order to experience the shock, we may touch the fish either with the hand or with a good conductor of

* Essai sur les phénomènes électriques des animaux. Paris, 1840.

† Verhandlungen der Würzburger physikalisch-medicinischen Gesellschaft, vol. viii. p. 8.

‡ Zur Kenntniss des elektrischen Organs der Fische. Leipzig, 1859.

§ Tableau physique des régions équatoriales. Paris, 1807.

‖ Experimental Researches in Electricity, Philos. Trans. 1844, vol. ii. p. 6.

¶ Ueber das elektrische Organ des Zitterwelses. Leipzig, 1857.

** *L. c.* p. 45.

electricity, such as a metal rod. The discharges are also diffused to a considerable distance in the liquid in which the fish is contained; but if we touch the fish by glass or resin, no shock is perceived.

The electricity produced by these animals possesses all the properties of electricity, such as we develope it by artificial means:—It exercises attractive and repulsive powers; the sparks drawn from the fish are sufficient to melt the leaflets of the electroscope; steel needles and soft iron may be magnetised; water, nitrate of silver, iodide of potassium, may be decomposed by it; and the needle of a galvanometer, when brought into the circuit, suffers a considerable deflection, by which we are enabled to determine the direction of the current. The quantity of electricity liberated in these fishes is in direct proportion to the energy of circulation and respiration in the animals. After they have given numerous and powerful shocks, they require rest and nourishment, in order to enable them to store up again a new amount of galvanic force.

The discharges are voluntary and entirely under the control of the fish, just as the squirting of sepia from the cuttle-fish; and they are given in any direction the fish may desire. If metals be placed in the vessel containing the fish, the latter becomes extremely excited, and attempts to bite them.

It seems singular that the fish should not be injured by its own shocks. According to Du Bois-Reymond's observations, the Malapterurus even possesses a certain immunity against electricity foreign to itself; nevertheless, the fish seems to resent strong shocks which are applied to it, and, in order to avoid them as much as possible, it places itself at the greatest distance attainable from the electrodes, at a point where the density of the current is least considerable, giving at the same time shocks of its own in self-defence.

Torpedo.—The electric ray, which is generally of inconsiderable size, possesses a peculiar organ, by which the electricity is produced. This consists of small membranous prisms, packed one against the other, like the cells of a honeycomb. These prisms are divided by horizontal diaphragms into small cells, which are filled with an albuminous fluid. It is impossible not to be struck by the close resemblance between this arrangement of the electric organ, and that of the voltaic pile; indeed, the electric organ of the Torpedo constitutes a veritable pile, forming a series of solid diaphragms, positive on one of their surfaces and negative on the other; a conducting electrolytic liquid being interposed between the diaphragms.

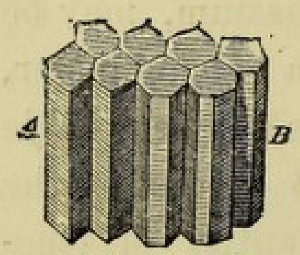


Fig. 16.

Max Schultze discovered that the reaction of the electric organ of the living Torpedo is acid. It is, however, not yet known whether it is always acid, or only so after the fish has become exhausted by violent discharges of electricity.

The cells of the electric organ are traversed by numerous nervous filaments, arising from four large nerve-trunks, which take their origin from the fourth lobe of the brain, in which the electric power resides. When this lobe is irritated, powerful discharges follow, even if the animal be to all appearance dead; that is to say, if by cutting, pinching, or squeezing it, no more shocks or movements can be produced. When the lobe has been destroyed, the electric discharges cease soon afterwards; they cease likewise when the connection between the brain and the organ has been interrupted by division or ligature of the nerves, although upon irritating the delicate nervous filaments animating the organ, electric effects may still be obtained some time after that connection has been destroyed. The terminal branches of the nerves are very pale and slender; they anastomose in all directions, and form a delicate network, which is destroyed by almost all chemicals which are employed in microscopical observations. The richness and density of this network has an important bearing upon the explanation of the function of the electric organ. The electric action disappears forthwith when the albumen contained in the cells of the organ is artificially coagulated by boiling or by the application of acids, but as long as the albumen remains fluid, shocks will be perceived, even if the organ be lacerated.

When the Torpedo is fresh, shocks are felt wherever the animal is touched; but when it has become weary, and prepared frog's limbs are then placed upon different points of its body, it is easy to perceive that only those limbs suffer commotions which are in contact with the part of the skin corresponding to the electric organ. The direction of the current is from the back to the belly of the animal; the upper surfaces of the prisms being all charged with positive electricity, the lower ones with negative electricity.

The shocks are given by the fish, either voluntarily, in order to kill animals necessary for its nourishment, or they are due to reflex action. Thus, if the fish be touched at any point of the skin, the stimulus is instantly transferred from the sentient nerves of the skin to the brain, and from the fourth lobe of the brain back to the electric organ, by way of the four nerve-trunks connecting the electric lobe with the electric organ; just as in other animals muscular contractions are produced either by the will of the animal, or by reflex action, on the sentient nerves being irritated.

M. Robin has discovered that, when the fish is placed fully under the influence of ether, or is poisoned by woorara or strychnia, the shocks cease completely. When the electric organ is at rest, it does not seem to possess any electro-motive properties, nor does it seem to acquire them when traversed by a continuous galvanic current.*

* Eckhard, Beiträge, etc., vol. ii. p. 157.

Gymnotus.—The shocks given by the Gymnotus, or Surinam eel, which is from five to six feet long, are more powerful than the discharges of the Torpedo. Humboldt relates that this fish may kill at a blow horses and mules, and that some time ago it became necessary to change the road from Uritucu through the Steppe, because the electric eels had accumulated in a rivulet in such large quantities, that year after year a great number of horses were benumbed by the shocks and drowned in the passage. If the discharge takes place through a chain of persons, all of them feel a violent concussion.

The Gymnotus possesses an electric organ like the Torpedo, composed of a great number of prisms similar to voltaic piles. But while in the Torpedo the direction of the current is from the back to the belly, it is in the Surinam eel from the head to the tail; positive electricity being accumulated on the anterior part, and negative electricity on the posterior part of the body. If the animal be touched at the head and the middle of the body, or at the tail and the middle of the body, the shock has only half the intensity of that experienced when both head and tail are touched.

In the Torpedo there are 940 series of diaphragms, each separate series containing 2,000 diaphragms; in the Gymnotus there are only 96 series of diaphragms, each containing 4,000 diaphragms. We have, therefore, 1,880,000 diaphragms in the Torpedo, and only 384,000 in the Gymnotus. Nevertheless, the shocks given by the latter are much more powerful than the discharges of the former; which is due to the larger surface presented by the diaphragms of the electric organ of the latter. Its electric power resides likewise in the brain.

Malapterurus.—The electric organ of the Malapterurus forms a tube surrounding the fish in its entire length, from head to tail. It is intimately united with the skin of the animal, and divided into two symmetrical lateral halves, by a dorsal and ventral longitudinal septum. Numerous tendinous lamellæ traverse the organ, and form a sort of net-work, in the bi-pyramidal alveoli of which the electrical plates are found, which consist of membranous expansions of the electrical nerves. The net-work just described forms a support for these plates, the intermediate spaces between the tendinous and nervous membranes being filled with a viscid substance, which is probably albuminous. Bilharz has discovered that the electric organ of the shad is animated by a single primitive nerve-fibre emanating from each side of the spinal cord, at a point intermediate between the second and third spinal-nerve roots, and originating in a single nerve-cell of comparatively colossal size, it being visible to the naked eye as a small yellow point in the interior of the cord. The electric nerve, however, does not, as Schultze found, end in the corresponding half of the electric organ, but passes through an opening in the same, and turns backwards, spreading in the opposite surface.

The electric current of the Malapterurus moves, in the organ and the water surrounding it, in a direction from the head to the tail, and in the wire of the galvanometer, from the tail to the head.

The difference in the arrangement of the electric organs in the Torpedo on the one hand, and the Gymnotus and Malapterurus on the other hand, is, to some extent, explained by the fact of their living in media of different conductivity. The Torpedo lives in salt water, which is a comparatively good conductor, and has, therefore, a short and thick electric organ, while the Gymnotus and Malapterurus, which live in fresh water—that is, in a comparatively badly-conducting medium—have long, but thin organs.

Nervous and Muscular Electricity.—The electric currents circulating in other animals are not so easily perceived as those produced by the electric fishes; but we have reason to believe that there exists a vast multitude of well-determined electric currents, both in the nerves and in the muscles of all living animals, which have for the most part only local circuits; that the presence of these currents is not due to any physical or chemical action, but is subordinate to the life of the animal, and that the currents disappear soon after life has become extinct.

It is very difficult to make conclusive experiments of this kind, because the currents which we may collect are merely derived currents, the intensity of which is infinitely more feeble than that of the principal nervous or muscular current: in fact, the electro-motive elements in the nerves, as well as in the muscles, must be considered as in the condition of a closed circuit, and every current *collected* from a nerve, as *derived* from a current circulating in the nerve itself. Besides, it is absolutely necessary to avoid any liberation of electricity arising from other sources than from the animal body itself; indeed, without this precaution all experiments may be considered worthless. Thus, for instance, if we wish to examine the nerves or muscles with regard to their electric properties, it will not do to connect two conducting wires with the extremities of a galvanometer, and then to touch with them the tissue that is to be examined. By experimenting in this way, we should always find indications of electricity, for no two pieces of metal can ever be completely identical; and they would therefore, if placed in contact with the same liquid, give rise to an electric current, the intensity of which would be sufficient to deflect the needle of a sensitive galvanometer. But even if the metals were identical, it would suffice to touch the tissues a fraction of a second sooner with one than with the other, for producing an electric current which could be made perceptible by the deflection of the needle.

Galvani's Discovery.—Galvani was the first who proved by experiments the existence of electric currents in a frog, which he had prepared in a peculiar manner. He killed the animal, then rapidly skinned it, and passed the point of a pair of scissors beneath the two lumbar nerves, which appear like white threads on each side of the vertebral column. The second and third lower vertebræ were then removed, so that the lumbar nerves were laid bare, and now formed the only link between the hinder extremities of the frog and its upper vertebræ. He then connected the nerves and muscles of the frog by means of an arc composed of two metals, and

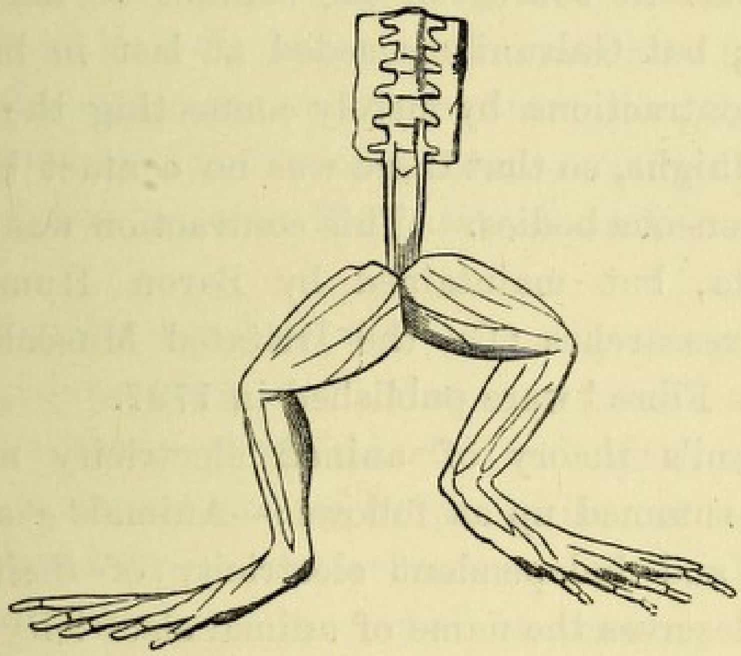


Fig. 17.

immediately perceived powerful contractions of the muscles. Volta objected to this experiment, that the electric current thus liberated was due to the contact of the two heterogeneous metals. Galvani therefore connected the nerves and muscles by means of an arc of homogeneous metal, and even thus produced contractions. But Volta contended that any difference, however slight, in the homogeneity of conducting bodies in contact was sufficient to produce an electric current made perceptible by the contractions of the frog. Galvani then divided the nerves of the frog at their exit from the vertebral canal, raised them with a glass rod, so as to bring them in contact with the external surface of a frog's thigh, on a single point of the muscle, and the muscles contracted as before. Volta now endeavoured to prove that the electric current thus produced had its source in the contact of nerve and muscle; but Galvani succeeded at last in bringing about contractions by merely connecting the nerves of two thighs, so that there was no contact between heterogeneous bodies. This contraction was denied by Volta, but maintained by Baron Humboldt,* whose researches 'On the Irritated Muscular and Nervous Fibre' were published in 1797.

Galvani's theory of animal electricity may be shortly summed up as follows:—Animals possess a special and independent electricity of their own, which deserves the name of animal electricity. The organs in which this animal electricity resides are the nerves, and it is secreted chiefly by the brain. The electricity is conducted along the internal substance of the nerves, probably the thinnest lymph; thus, it may freely and rapidly circulate in the nerves, while the fatty envelope of the latter prevents its dispersion, and allows it to accumulate. The chief receptacles of the electricity are the muscles;

* Versuche über die gereizte Muskel- und Nervenfaser. Posen und Berlin, 1797.

they represent, as it were, a Leyden jar, their external surfaces being negative, while the inner ones are positive. The conductor of the jar is the nerve, which, together with the blood-vessels, supplies the muscle with electricity. The mechanism of motion consists of drawing the electricity from the interior of the muscle, and conducting it along the nerves to the external surface of the muscle, where it passes out. Each contraction is, therefore, as it were, accompanied by a discharge of the muscular Leyden jar, and this again causes a fresh contraction, through the stimulation of the irritable muscular fibre by the electricity flowing over the external surface of the muscle.*

Volta's views, however, were generally accepted by natural philosophers, and it was not until thirty years later that Galvani's and Humboldt's experiments were again taken up by M. Nobili,† of Reggio, who employed for his researches a sensitive galvanometer multiplier, and succeeded in showing undeniably the existence of an electric current in the frog, which he believed to be proper to the frog. He prepared a frog's limb as usual, and immersed both ends in two separate vessels filled with water or salt water; and found that if one of the ends of the galvanometer was placed into each vessel, the needle showed by its deflection the existence of a current

* Pfaff, über thierische Elektricität und Reizbarkeit (Leipzig, 1795), p. 329.

† Annales de Chimie et de Physique, 1828, vol. xxxviii. p. 225.

moving from the foot to the head, or from the muscle to the nerve. This current deflected the needle to an angle of 30°; and its action on the multiplier was not unfrequently seen to last for several hours. Nobili found that if he touched the nerve and the muscle of one frog with the nerve and the muscle of another frog, there was no effect on the magnetised needle, one current being opposed to the other; but if he placed the nerve of one frog in contact with

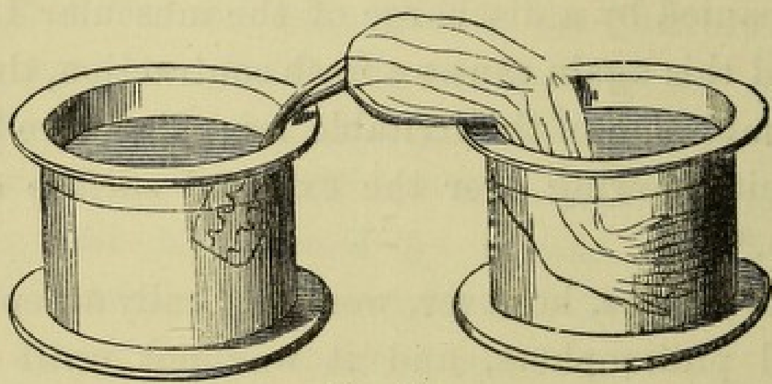


Fig. 18.

the muscle of another frog, a powerful contraction took place.

These researches were further pursued by Matteucci,* who discovered that animal electricity is capable of decomposing iodide of potassium, of giving signs of tension with a delicate condenser, and of deflecting the needle of the galvanometer; but it was a German philosopher, Du Bois-Reymond,† who devised the most ingenious and unobjectionable

* Comptes rendus, 1837, vol. v. p. 520. And, Essai sur les Phénomènes électriques des animaux (Paris, 1840); and Cours d'Électro-physiologie (Paris, 1858).

† Untersuchungen über thierische Elektricität. Berlin, 1848 and 1853.

method of investigating this matter; by means of which he was enabled notably to enlarge our knowledge on the interesting phenomena of animal electricity. His views are now universally received by the Profession.

For demonstrating the electric properties of nerves and muscles, Du Bois-Reymond selected a galvanometer multiplier brought to the highest degree of sensitiveness, and the physiological galvanoscope, or galvanoscopic frog.

The multiplier (G, fig. 19, p. 99) is made very sensitive, partly by employing astatic needles of the utmost possible perfection, and partly by a large number of convolutions of the wire. A multiplier possessing less than 11,000 turns of a fine copper wire is not applicable for investigating the current proper of the nerves: for demonstrating the muscular current in the living man, a multiplier of 24,000 convolutions is necessary. This multiplier indicates not only the presence and direction of very feeble electric currents, but also certain changes in their intensity. There is, however, this inconvenience, that the magnetised needle is too slow to indicate a current of instantaneous duration, and that it is not able to follow all the variations in the intensity of the current, which sometimes succeed each other very rapidly—indeed, it will only tell the resultant of such variations. Therefore it is necessary to have another more delicate indicator of the current; this is the galvanoscopic frog, or the rheoscopic limb, which is prepared in the following way:—A frog is killed, then rapidly skinned, and its thigh-bone cut off just above the insertion of the gastrocnemian muscle; after this has been done, all the muscles by which communication is kept up between the upper and lower piece of the thigh are removed, and the sciatic nerve is prepared as high up as possible towards its origin, and afterwards divided at its upper end, so as to remain in connection with the leg. The galvanoscopic frog thus prepared indicates the presence of currents of instantaneous duration, without the intervention of metals, even when the currents move in contrary directions, and succeed each other very rapidly. It has, however, the disadvantage that it soon loses its irritability, and that it contracts only when the circuit is made or broken, but not while the circuit remains closed; so that it does not help us to decide whether there is a continuous current or a momentary discharge. It is, therefore, obvious, that both the multiplier and the galvanoscopic frog are equally necessary for investigating the phenomena of animal electricity.

We have already seen that it is of paramount importance to avoid bringing into the circuit any heterogeneous substances, which might possibly give rise to a liberation of electricity. In order to avoid this, the following arrangement was adopted by Du Bois: both extremities of the wire of the multiplier were connected with platinum plates, which were made as homogeneous as possible; as the slightest difference between the two platinum plates would of itself cause a current if the circuit were closed, and the plates dipped into a vessel filled with water. To render the platinum plates quite similar to each other, they were first cleaned with a mixture of alcohol and ether, then washed with nitro-hydrochloric acid and afterwards with distilled water, and finally heated to incandescence for half a minute, by means of a

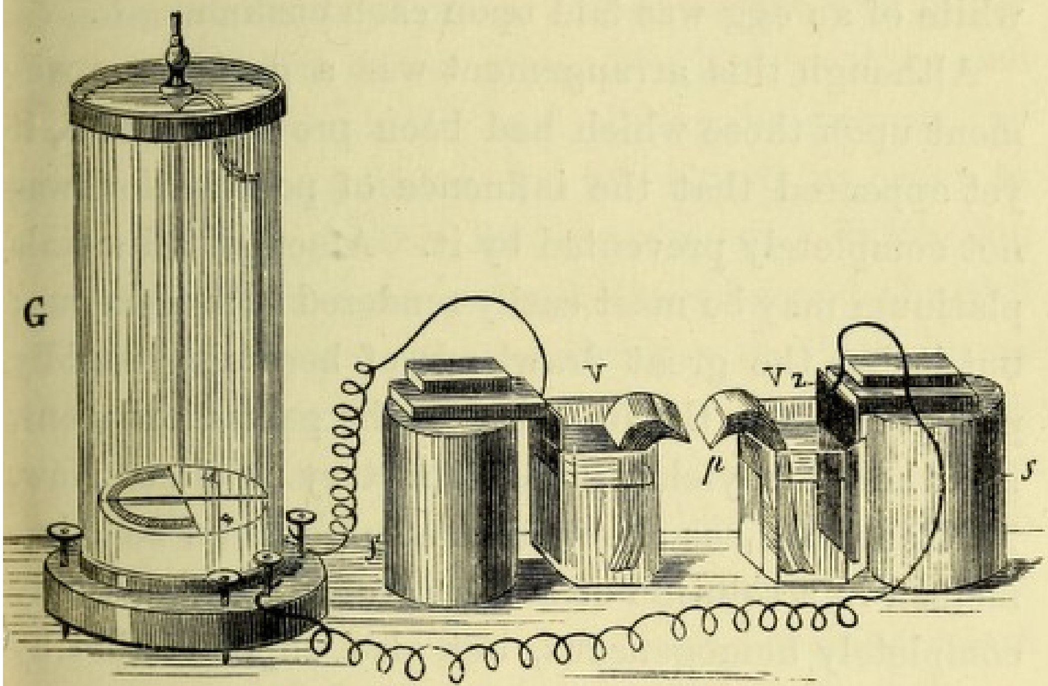


Fig. 19.

Berzelius lamp. The plates were held in a clamp fixed on a horizontal brass rod, which could be fixed and moved in every position; the free extremities of the plates were then immersed in two large vessels (v v, fig. 19) filled with a saturated solution of table salt. But as the salt water would exercise an injurious action upon the tissues if in immediate contact with the same, two cushions (*p*) made of many layers of fine blotting paper, well moistened with salt water, were immersed with one of their extremities into the liquid, and rested against the edge of the vessel—their free extremities being outside of the vessel, and the circuit being closed by connecting the two conducting cushions by a third cushion. To avoid the corroding action of the salt water upon the animal tissues, a piece of bladder well moistened with the white of an egg was laid upon each cushion.

Although this arrangement was a great improvement upon those which had been previously used, it yet appeared that the influence of polarisation was not completely prevented by it. Amongst all metals platinum may be most easily rendered homogeneous; but it has the great drawback of becoming rapidly polarised under the influence of the galvanic current, and therefore yielding unsatisfactory results. Now, M. Regnauld has shown that amalgamated zinc immersed in a solution of sulphate of zinc, is not only completely homogeneous, but also unpolarisable by the galvanic current. Du Bois has therefore recently adopted the following modification of his original arrangement:—Two vessels of zinc are used which contain a solution of sulphate of zinc, and upon which the edges of the cushions are laid. These latter are soaked in a solution of sulphate of zinc, and kept in their places by plates of ebonite connected with the zinc. The inside and edges of the zinc vessels are carefully amalgamated, while their outside is thickly coated with a varnish formed of asphaltum dissolved in turpentine; and the clamp which connects one end of the multiplier with the deriving vessel is varnished with shellac dissolved in alcohol.

The whole is enclosed in the 'moist chamber,' which consists of a mahogany floor resting on four blocks of wood, which are raised up on well-varnished pieces of plate-glass. The roof and sides of the chamber are made of glass. The interior wall of the chamber consists of two pieces of glass touching one another in the middle, and sliding in grooves, so as to allow the hand to be introduced in order to arrange the apparatus for experiments. With the exception of the anterior wall, the sides and the roof of the chamber are covered inside with thick layers of moist blotting paper, so as to fill the chamber with vapour. Two porous cells filled with water are placed on the bottom plate, in order to maintain the moisture of the chamber and to receive any water which may flow off from the cushions. A closing cushion is laid over the two deriving cushions. The animal tissues which are examined are protected from the corrosive action of the zinc solution by interposing between the cushions thin layers of sculptor's clay, which is moistened with a solution of chloride of sodium, in order to increase its conducting power. This is likewise unpolarisable.

The following is the way in which the experiment is conducted:—The two deriving cushions are placed in close contact with one another, and the closing cushion is laid over them; the multiplier is then tested, and if the apparatus is in order no deflection of the needle ought to occur. If there be any deflection, there must be some fault either in the zinc vessels, or in the conducting liquid, or in the cushions, which must be rectified previous to the experiment being commenced. If there be no deflection, the closing cushion is removed, and the part to be examined placed on the clay-guards; the circuit of the multiplier is then opened, and if there be any current of animal electricity in the part, the needle suffers a deflection indicating the presence, direction, and kind of electricity inherent to the part examined.

Dr. Radcliffe * has lately recommended the use of electrodes consisting of platinum wires flattened at the end, and thickly coated with moist sculptor's clay; but this would appear to be a step backwards in experimental precision, as it has been indisputably proved that platinum is a most polarisable metal, and should therefore be eschewed in all delicate electro-physiological observations.

Nervous Current.—If the multiplier has been arranged in Du Bois-Reymond's fashion, and we now take a fresh piece of the sciatic nerve (*p*, *c*) of a frog, and bring various parts of it in connection with the two cushions, we notice the following phenomena: if any two symmetrical parts of the longitudinal or of the transverse section of the nerve are

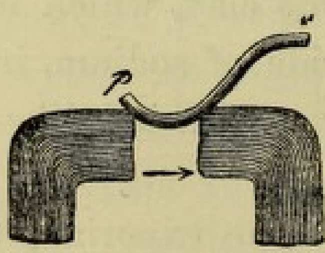


Fig. 20.

* The *Lancet*, April 24, 1869, p. 574.

placed upon the cushions, there is no deflection of the needle; if two dissymmetrical points of the longitudinal section are taken, we obtain a feeble deflection of the needle, varying from 6° to 7°; and if the nerve be in contact with the cushions on one side by its longitudinal section, and on the other by its transverse section, the needle suffers a deflection varying from 15° to 30°. The current thus indicated moves from the longitudinal section of the nerve through the galvanometer wire to the transverse section of the nerve; and the points which are nearest to the middle of the nervous fragment are positive in respect to those which are nearer to the extremities. The results are the same if we employ the galvanoscopic frog; and whether we employ nerves of sensation or of motion, or mixed nerves, or pieces taken from the spinal cord; as to the brain, every artificial section of it is negative to every point of its natural surface.

Electrotonus.—Remarkable changes are produced in the intensity of the nervous current if a part of the living and excitable nerve of a frog be subjected to the action of a continuous galvanic current, another part of the same nerve being placed upon the cushions. The intensity of the nervous current is increased if the galvanic current, which is made to act upon the nerve, moves in the same direction with the nervous current (*positive phase of the nerve*); on the other hand, it is diminished if the direction of the galvanic current be opposed to that of the nervous current (*negative phase of the nerve*). The alteration thus produced in the nervous current has been termed by Du Bois-Reymond the *electrotonic state.* This state commences as soon as the circuit of the battery is closed; it then remains unchanged all the time that the galvanic current continues to circulate in the nerve, and disappears immediately when the circuit is opened. The electrotonic state is not due merely to the transmission of the galvanic current through the nerve, but to a real alteration in the electrical properties of the nerve; for the electrotonic state is not induced if a wet thread be interposed between the two parts of the nerve, and tightly drawn together, since now both parts are no longer connected by nervous matter, but only by the neurilemma and the wet thread, which offer little resistance to the transmission of the galvanic current. Besides, the electrotonic state is not induced if the nerve has lost its excitability. From these facts Du Bois-Reymond has concluded that the nerves consist of an innumerable multitude of electrical molecules, which are differently arranged according to the different states of the nerves. Indeed, the electric currents in the nerves show, in some instances, such sudden variations both of intensity and of direction, as to make it impossible to account for them by any change of larger heterogeneous elements, or in any other way than by assuming corresponding changes of position in almost infinitely small centres of action. When the living nerve is at rest, Du Bois supposes these molecules to be turned towards each other with equal extremities, so that two molecules form, as it were, only one molecule, possessed of one positive zone, and two negative poles. This he calls the *peripolar arrangement.* In the electro-tonic state, however, the molecules are thus arranged that unequal poles are turned towards each other; this he terms the *dipolar arrangement.*

Negative Variation of the Current.—There are other important changes induced in the nervous current, as soon as the nerve enters that active state which enables it to cause motion, sensation, and secretion, whatever may be the means by which the nerve is excited. For demonstrating this, we may tetanise the nerve by strychnia, or excite it by burning, or by bruising its free extremity, which is placed between the cushions. When this has been done, the needle, which had been deflected by the nervous current during the peripolar arrangement, returns immediately more or less towards its previous position of equilibrium: that is to say, the nervous current suffers a great and sudden diminution, which is called by Du Bois the negative variation of the current. This lasts only as long as the nerve is kept in an excited state; if it be no longer excited, the previous effects of the nervous current again become perceptible. The negative variation of the current, however, is not permanent, even when the contraction seems to be so, as in the state of tetanus; but, like the contraction, it is always composed of a very rapid succession of single and sudden variations.

When the nerve is no longer able to cause motion, sensation, or secretion, the nervous current appears very feeble, or its original direction becomes inverted, the negative surfaces being now positive, and the positive surfaces negative. If we now again endeavour to cause the electrical phenomena inherent to the living nerve, we may perhaps succeed in producing the electrotonic state to a trifling degree, but we shall always fail to induce the negative variation of the current. Moreover, the electrotonic state ceases so shortly after the cessation of the excitability of the nerve, that we may just as well say that all the electrical phenomena in the nerve disappear at the same time with its vitality.

Moleschott,* who has lately made a series of experiments on this subject, found that, if a nerve had been submitted to the influence of a powerful continuous current and was then tetanised by strong induction currents moving alternately in different directions, there was not unfrequently a positive, instead of a negative variation of the current; and he was therefore led to believe that the active state of the motor nerve was not always accompanied by a negative, but sometimes by a positive variation of the current. To this Du Bois replied† that the positive variation which had been observed by Moleschott had nothing to do with the active con-

* Untersuchungen zur Naturlehre, 1861, vol. viii. p. 1.

† Positive Schwankung des Nervenstroms, etc., in Reicherts und Dubois' Archiv., 1861, p. 786.

dition of the motor nerve, but was owing to the natural preponderance of the positive over the negative phase of electrotonus, which is chiefly observed when the nerve has already to some extent lost its excitability, in consequence of having been for some time separated from the body of the animal, and of having been subjected to injurious influences. It seems that Moleschott had omitted to take this fact into consideration. Du Bois, however, was thereby induced to show, by other than electrical means, that the active condition of the nerve is really, and under all circumstances, accompanied by a negative variation, and he has succeeded in proving that the negative variation also appears when the nerve is excited mechanically, chemically, or by heat, and that it must therefore be looked upon as the electrical expression of the state of activity in the nerve.

The nervous current may be weakened, diverted, or even totally destroyed by repeated and strong electrical shocks. Opium, morphia, strychnia, prussic acid, and most substances which have a decided chemical effect on the nerve, such as ether, alcohol, and mineral acids, rapidly destroy the nervous current; the only exception to this rule being formed by a concentrated solution of arsenious acid, which has only a slow and feeble action on the same. Extremes of cold and heat, desiccation, and imbibition of a large quantity of water, are also deleterious to the nervous current.

Muscular Current.—For investigating the electric properties of the muscles, Du Bois-Reymond selected likewise the multiplier and the galvanoscopic frog. But as the muscles produce currents of far greater intensity than the nerves, the multiplier must not possess so many convolutions as that intended for demonstrating the nervous current (4,000 to 6,000 instead of 24,000).

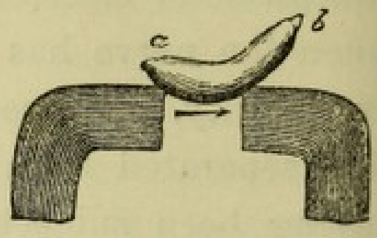


Fig. 21.

The muscular current appears to be perfectly analogous to the nervous current, except that it is stronger. We do not perceive a deflection of the magnetised needle if the muscle (*a*, *b*) is placed upon the cushions with two symmetrical points, whether of the longitudinal or of the transverse section; the more dissymmetrical the two points, the stronger will be the deflection of the needle; the current is strongest when a portion of the fleshy surface of the muscle is laid upon one of the cushions, and a portion of the surface formed by cutting the muscles across, upon the other—that is to say, between the natural longitudinal section and the artificial transverse section; whilst the current is very feeble between any two points in the same section, whether longitudinal or transverse.

It should be understood that the tendinous portion of the muscle is its *natural transverse section*, and that the fleshy surface of the muscle is its *natural longitudinal section*. The *artificial transverse section* is produced if the muscle be divided perpendicularly, and the *artificial longitudinal section* if the muscle be torn in the direction of its fibres.

The direction of the muscular current is the same as that of the nervous current. In the living muscle each point of the longitudinal section, whether natural or artificial, is positive in respect to the points of the transverse section, whether natural or artificial. Each time that a conducting arch is established between any point of the longitudinal section of the living muscle, and any point of its transverse section, the needle indicates a current in this arch, moving from the longitudinal section to the transverse section. This law has been established on the muscles of the frog, and verified on the muscles of an amputated leg of a man, on the muscles of rabbits, mice, sparrows, and even of the common earth-worm; it has been verified not only with an entire muscle, but with a single primitive fasciculus; indeed, we may obtain a deflection of 8° to 10° by means of a single elementary bundle, if we connect the transverse and the longitudinal section of a muscle.

The variations in the intensity and direction of the muscular current are, in certain instances, so sudden and so extensive, that we are compelled to assume corresponding changes of position in the molecules of the muscle, which are analogous to those supposed to be in the molecules of the nerve.

Muscular Currents in the Living Man.—It is much more difficult to demonstrate the muscular current in man than in the muscles of a frog. We know, however, that the current in the arm of man travels from the shoulder to the hand, whilst in the frog it travels in a contrary direction. It is especially the resistance offered by the skin of the human body which diminishes the action on the magnetised needle. The deflections of the needle become much more extensive as soon as the cuticle is removed, or the portion of the body subjected to the experiment is placed in communication with the salt water which closes the circuit. For proving the existence of the muscular current in man, a multiplier of 27,000 to 30,000 convolutions is required. Care must be taken to exclude any electric currents arising from other sources, such as from the unequal transpiration of the skin on two points placed in connection with the multiplier, from inequality of temperature, from the want of simultaneity in establishing the contact of the two points placed in the circuit, etc. The intensity of the current produced by the voluntary contraction of the muscles of man may be considerably increased if the cuticle be removed by a blister applied to the arm, and the denuded corium is in communication with the multiplier. By experimenting in this way, Du Bois-Reymond obtained a current of 60° to 70°, whilst, if the skin in its usual state communicated with the multiplier, the deflection of the needle was only from 2° to 3°.

Parelectronomic Layer.—An analogous phenomenon is observed in the frog. If the animal has been skinned, it is very easy to demonstrate its muscular current; but if the skin be left intact upon the muscles, we obtain irregular results, which are partly due to the circumstance that the skin possesses an electromotive force of its own. If we wish to show the muscular current in all its intensity, the surface of the muscle should be moistened with salt water. As long as the tendon of a fresh muscle is touched merely by blood or lymph, the current going from the longitudinal section to the transverse section is very feeble. Its intensity is immediately increased if the tendon be immersed in some other liquid; it is likewise increased if the tendon be totally taken away or destroyed by the contact of a piece of porcelain highly heated. Hence it results, that the fresh muscle, as long as it is touched only with blood and lymph, possesses a superficial layer, which more or less prevents the manifestation of the contrast between the longitudinal and transverse section. Du Bois-Reymond has, therefore, termed it the *parelectronomic layer.*

The parelectronomic layer exists in different proportions in different animals. It is most complete in frogs which have been for some time subjected to the temperature of melting ice; in the muscles of these animals there is either no current at all, or an inverse current, due to the preponderance of the parelectronomic layer. But even under these circumstances, the current may be instantly revived if the tendon be touched by water, albumen, alcohol, acids, alkalies, or salt water. The muscles of mammalia, birds, and fishes, present the same property, although in a less degree.

Secondary Contraction.—The phenomenon comprehended under the name of *induced* or *secondary contraction*, was first observed by Matteucci. He prepared a frog in the manner originally devised by Galvani, and placed upon the thighs of the frog the nervous filament of another rheoscopic limb, uniting both, as it were, by a bridge. He then caused a continuous current to pass into the lumbar nerves of the first frog, and caused a powerful contraction, not only in the muscles of these thighs, but at the same time in the galvanoscopic frog, the nerve alone of which was in contact with the thighs of the first frog to which alone the current was applied. Du Bois-Reymond has succeeded in inducing a contraction of the third, fourth, fifth, and even of the sixth order, in rheoscopic limbs, which communicated with each other merely by the nerves. These induced or secondary contractions are due to variations of the density of the current in the rheoscopic limb. No, or little effect, however, is obtained, if the nerves be made to communicate with two points symmetrically situated in the muscle; if it be intended to produce secondary contractions, it is necessary that the two points of the nerve of that limb which is to suffer a commotion, should be laid upon those points of the muscle in contraction which are as dissymmetrical as possible.

It appears, indeed, that Matteucci's contraction obeys the general law of the muscular current, being strongest when the most effective arrangement for the latter is used; and feeble when a weak arrangement is employed. It is therefore most striking when the nerve of the rheoscopic limb is made to touch the natural longitudinal and the artificial transverse section of the muscle; and it is feeble when the nerve is made to touch other sections.

The diminution of the intensity of the muscular current after death is proportional to the degree of excitability possessed by the muscles. It is therefore more rapidly diminished in warm-blooded animals than in reptiles and fishes. As soon as *rigor mortis* sets in, which Brücke has shown to be due to the coagulation of the liquid fibrine contained in the muscles outside of the blood-vessels, both the excitability of the muscles and their electro-motive force disappear in equal proportion, never to appear again, not even when the rigidity has ceased in consequence of the decomposition of the fibrine.

The phenomenon of the muscular current is therefore inherent to the living and excitable animal tissue.

In warm-blooded animals, such as the dog and the rabbit, it sometimes disappears within half an hour after death, while in a frog's limb, which is carefully protected from injurious influences, and kept at a low temperature, it will sometimes continue for a fortnight or even a month. It also varies with the seasons. Cold weather is generally more favourable to the persistence of the currents of animal electricity, while hot weather often causes them to disappear rapidly. In frogs the irritability lasts longer in spring, previous to spawning-time.

The local application of poisons to the nerves and muscles appears to be more effective in altering the muscular current than their introduction into the system. Prussic acid, extract of opium, the acetates of morphia and of strychnia, and veratria, when brought into direct contact with the muscular substance, render it rapidly rigid, and acid, and deprive it of its natural electricity. Substances which have a considerable chemical action on vitalised tissues, such as mineral acids, alcohol, ether, nitrate of silver, and creasote, utterly destroy the texture, and simultaneously with it the physiological properties of the muscular fibre.

Matteucci affirms that poisoning by woorara diminishes the intensity of the muscular current; but this is denied by Claude Bernard, von Bezold and Kölliker *.

Dr. Radcliffe † sees reason to believe that the primary electrical condition of living muscle and nerve during the state of inaction is that of static electricity, and that the muscular current and the

* Comptes rendus, vol. xlviii. p. 1145.—Leçons sur la Physiologie etc.—Reichert's Archiv., 1860, p. 168.

† Lectures on Epilepsy, Pain, Paralysis, and certain other disorders of the Nervous System. London, 1864.

nerve current, which may pass from the muscle or nerve during the state of inaction, are only secondary phenomena. He believes, with Matteucci, that the state of action in a muscle and in a motor nerve is accompanied by a discharge of electricity analogous to that of the torpedo; and that when a muscle is made to contract by means of its nerve, the electrical discharge which accompanies nervous action has reversed the electrical relations of the exterior and interior of the muscular fibres in the part acted upon; that this reversal has led to the discharge of the electricity, which is present in the muscular fibres during the time of rest, and which keeps these fibres in a state of relaxation as long as it is present; and that this discharge of electricity brings about muscular contraction by leaving the muscle free to yield to the action of the attractive force which is inherent in the physical constitution of the muscular molecules. Dr. Radcliffe has supported his views by an ingenious argumentation; but he has failed to shake the force of Du Bois-Reymond's observations and theories, which may be considered as thoroughly established in physiology.

It is not only the nerves and muscles, the brain and the spinal cord of the living animal, which are possessed of electro-motive force, but all tissues in which active nutrition is going on give rise to electric currents. Pieces of lung, liver, and kidney, cause weak currents, which partially obey the laws of the muscular current, and which continue long after death. Currents of animal electricity have also been discovered in the intestines of the frog, the iris of birds of prey, the ovary of the rabbit, the oviduct of the frog, the ureter, urinary bladder, and aorta of the rabbit, and the spleen, testicles, tendons, and bones of the frog. These currents have one point in common with the muscular current, viz. that the external and internal surfaces of these tissues are inversely electrified. In no other tissue, however, is the electro-motive force so strong, nor are there such great and sudden variations in the intensity and direction of the current, as in the nerves and the muscles.

Cutaneous Currents in Frogs.—Du Bois has found that when the two extremities of the galvanometer are made to touch the external surface of the skin of a frog by means of paper cushions moistened with salt water, a strong current is shown to travel from the point which was last touched to that which was first touched. The needle, however, gives no indication of a current, if the contact is as far as possible simultaneous. The current obtained by the first proceeding disappears rapidly, as the salt solution destroys the electro-motive force of the skin. On examining the internal surface of the skin, a regular but feeble current is observed to travel from the point first touched to the one last touched; and, if the extremities of the multiplier are applied at the same time to the external and internal surfaces, a current is noticed to travel from the external to the internal surface. This latter current also disappears rapidly, from which Du Bois has concluded that the skin of the frog possesses an electro-motive force acting from the external to the internal surface, and which is readily destroyed by the application of salt. Solutions of chloride of ammonium, iodide of potassium, sulphate of zinc, sulphate of copper, diluted sulphuric acid, liquor potassæ and liquor ammoniæ, also destroy this electro-motive force in a short time.

Du Bois has found that these cutaneous currents are peculiar to the naked amphibia, and do not occur in fishes; he therefore thinks that they are connected with the secretion from the glands of the skin, which is very abundant in frogs and toads. They are vital phenomena, for the skin taken from a frog in a state of putrefaction does not show any electric currents at all.

Budge * has more recently investigated these conditions, and has come to the conclusion that the longitudinal section of the frog's skin is negative to its transverse section. He found that when a piece of frog's skin is rolled up into a thin cylinder, and a transverse section is made, the needle is deflected to an angle of from 50° to 80°, if the extremities of the multiplier are brought into contact with the longitudinal and transverse section. If the cushions are moistened with a solution of sulphate of zinc, the

* Ueber den galvanischen Strom welcher sich in der Haut des Frosches zu erkennen gibt. Poggendorff's Annalen, vol. cxi. p. 537.

current remains very constant for some hours, but disappears rapidly when a solution of chloride of sodium is used. Budge also found that the rheoscopic limb may be made to contract by this current.

Rosenthal,* who repeated these experiments, has shown that when the cushions are moistened with a solution of sulphate of zinc, a strong current is perceptible in the frog's skin, travelling from without inwards. This current only slowly diminishes in intensity, and even less so if clay-guards are interposed between the cushions for protecting the skin. He discovered another current flowing from the external surface to the transverse section, this being weaker than the one just mentioned; and a third, moving between the internal surface and the transverse section, this latter being the weakest of all. He thinks that these latter currents are artificial productions, and that the electro-motive force really inherent in the frog's skin is the one moving from without inwards. He agrees with Du Bois in assuming that the layer of secreting glands is the source of this electricity, just as the current observed in the stomach of the frog and the rabbit, which also moves from the excretory ducts of the glands to the glandular substance. It might be objected to this view that the origin of this electricity was merely due to chemical action, for the mucus secreted by the glands of the frog's skin, and the gastric juice, are both acid, while the deeper layers of the skin and

* Reichert's and Du Bois-Reymond's Archiv, 1865, p. 301.

stomach are alkaline ; but this objection is removed by Du Bois having proved that these vital electrical currents are much stronger than those of the most powerful acid and alkali pair. The chemical composition of the mucus has therefore little or nothing to do with the glandular electricity, which seems indeed to be entirely owing to the living glandular tissue itself. The circumstance of some other glands not showing any electro-motive signs is explained by Rosenthal as arising from their more complex structure, not allowing the electricity which really exists, making any outward manifestation. Experiments undertaken by Rosenthal and Valentin render it probable that the glandular current, just as the muscular current, experiences certain definite variations when the nerves animating the glands are galvanised. Grünhagen * has lately given a different version of the electrical conditions of the frog's skin ; but Rosenthal's experiments and argumentation recommend themselves more to our acceptance, as sources of error seem to have been more carefully excluded in his investigations than in those of Grünhagen.

Cutaneous Currents in Man.—It is easy to discover indications of electricity on the human skin ; but not every electricity that is observed there is true animal electricity. Thus, a thermo-electrical current can be produced by heating unequally two symmetrical parts of the skin, for instance, the corresponding fingers of

* Ueber die elektrischen Ströme der Froschhaut. Henle und Pfeuffer's Zeitschrift, vol. xxvii. p. 268.

the two hands. A finger at the temperature of 32° F, is strongly positive to one at 90° or 98°; while a finger at 60° is feebly positive to one at 80°, and strongly so to one at 120°. The electro-motive force of these thermic currents is greater than that of a thermic copper and iron pair, and lasts as long as differences of temperature continue to exist.

If two fingers which are of the same temperature are simultaneously immersed into the vessels of Du Bois' apparatus, there does not appear to be complete homogeneity between them; for, after some irregular oscillations of the needle, a feeble but constant current is observed, flowing in the same direction for months consecutively. This current varies considerably in different persons, both in direction and intensity. It is sometimes found that in the same person the direction is suddenly reversed, and the current will then flow for some months in an opposite direction to that which was first observed. This electric current is called *the individual current of the finger*. Again, if two equally warm fingers are immersed into the testing-vessels, not simultaneously, but the one some time after the other, it appears that the finger immersed last is strongly positive to the other. The same may be observed if, instead of the fingers, the two hands, feet, or elbows are immersed. After a time, however, this current gives place to the 'individual current,' unless one part be more deeply immersed than the other, or its position be otherwise changed. This current retains its character, if ordinary water instead of salt water is used, but its direction is reversed in diluted sulphuric acid, and extremely irregular in a solution of caustic potash or of acetate of soda.

These currents due to dissimultaneous immersion are quite different from the thermic currents; the former are stronger than the latter, and the direction of the latter is not changed in diluted sulphuric acid. They may, however, both appear simultaneously in the same experiment. Dissimilar stretching of the skin, and dissimilar sweating, may also give rise to electro-motive action.

After eliminating all these sources of electricity, Du Bois found that, if the electricity inherent to the skin is examined, it appears that the palm of the hand is strongly negative to its back, and the entire hand negative to the elbow and the chest. The elbow is feebly positive to the chest. The sole of the foot is strongly negative to the back of the foot, and the whole foot negative to the chest. The hand is generally negative to the foot, but sometimes the reverse is observed in the beginning of the experiment. All these currents are strong and constant. They are not thermic currents, because their direction is not changed if one of the testing vessels is heated first to 60° and then to 80°, while the other is heated first to 80° and then to 60°. Nor are they traces of the muscular current, for they appear right through the hand and the foot, where it is difficult to conceive that a strong muscular current should exist; and they do not show any negative variation, from which it appears that they must be simply cutaneous currents, similar to those which are observed in the frog's skin.

Gastro-hepatic Current.—We have seen that the electrical properties of the tissues are in direct proportion to the activity with which the general metamorphosis of matter is being carried on in them. Electricity is everywhere manifested where there is a disturbance going on in the equilibrium of molecules; and the more rapidly and extensively this equilibrium is disturbed, the more striking will be the manifestations of electricity. But we must take care not to confound the true animal electricity, which is a vital phenomenon, with electric currents arising merely from chemical action, and which may be observed as well in dead as in living animals, and in vessels filled with heterogeneous liquids as well as in the animal body. A current of this kind is the so-called *gastro-hepatic current,* which has been described by Matteucci.

This philosopher has asserted that metal salts, when brought into the blood, were decomposed; the acids being attracted and excreted by the kidneys as electro-positive organs, while the alkalies were drawn to the liver as electro-negative organ. M. Donné afterwards stated that, if equal extremities of the multiplier were brought into contact with chemically dissimilar organs of secretion (as, for instance, the skin and the mucous membrane of the mouth, or the liver and the stomach), considerable deflections of the magnetised needle were observed. Matteucci then expressed his belief that these currents resulted from the contrary electric states of the organs of secretion, which were the cause of the chemical dissimilarity. In order to prove the existence of a current moving from the stomach to the liver, Matteucci introduced a plate of platinum into the stomach of a living rabbit; placed another plate on the liver, and connected both of them with the extremities of a galvanometer. He then noticed that the needles instantly traversed an arc of 20°, showing the existence of a powerful current between the liver and the stomach. He now endeavoured to decide the question whether this current ought to be considered as the effect or the cause of the chemical differences alluded to, since it is generally known that an electric current is developed, if an alkaline and an acid liquid be separated by permeable structures; and the stomach contains an acid, the liver an alkaline secretion. In order to arrive at a satisfactory result, he divided the nerves and vessels passing into the abdomen above the diaphragm, and observed, that in an instant the needle of the galvanometer deviated to 3° or 4°, instead of 20°; and after he had cut off the head of the rabbit, hardly any deflection was obtained. But if a wire was inserted into the spinal cord, and muscular commotions were produced, the gastrohepatic current was temporarily re-established.

From these experiments Matteucci concluded that the gastro-hepatic current was not the effect, but the cause, of the chemical metamorphosis of the saline ingesta, the decomposition of which furnished acid to the stomach and alkali to the liver; that it was not yet known how this current was excited, but that the existence was definitely proved of an electric current between the stomach and the liver, which would nearly cease on division of the nerves, and completely vanish with the death of the animals. This current should be competent to the evolution of sufficient free acid in the stomach, to enable digestion to go on, an equivalent of soda being determined to the liver.

Both the experiments and conclusions of Matteucci have since been proved to be erroneous by M. Donné, who showed by experiments made on twelve rabbits, that the so-called gastro-hepatic current may be observed on dead as well as on living animals; from the liver of one rabbit to the stomach of another, and *vice versâ*; that neither the section of nerves and vessels, nor cutting off the head, nor the excitation of the spinal cord, whether mechanical or electrical, has any influence whatever on the intensity of the current; that unequal organs, cut out of the body and held in the hands, continue to give rise to electric currents; and that, in fact, the so-called gastro-hepatic current is only an artificial electro-chemical phenomenon, and has nothing whatever to do with animal electricity.

CHAPTER II.

ELECTRO-PHYSIOLOGY.

I NOW proceed to describe the physiological effects produced by the application of electricity to the different tissues of the living body in their normal condition. I shall successively consider the action of electricity upon the brain and the spinal cord, the organs of special sense, the sentient nerves, the motor nerves and the muscles, the sympathetic nerve, the contractile fibre-cells, the heart, the blood, the skin, and the bones. A thorough knowledge of these effects will enable us to form more accurate notions of the value of electricity in its application to disease, than might otherwise be obtained. The literature of this subject is, however, now so extensive that it would be quite impossible to refer, within the limits of the present work, to all the books and papers which have been written upon it; and it must therefore suffice to give the results chiefly of those investigations which are either of historical interest, or have a direct and important bearing on the therapeutical application of electricity.

The physiological effects of electricity are partly dependent upon the electricity itself, and partly upon the property and function of the organ that is submitted to its action. In the first instance, the *form* of electricity which is used is of great importance. Thus, if sparks from the common electrical machine are applied to the skin, they produce a sensation of pricking and pain; if they are large, the skin becomes red, and a papular eruption resembling the lichen urticatus is produced. If a continuous galvanic current is made to act upon the skin, a sensation of heat, redness, inflammation, and even destruction of the skin and the subjacent structures may be caused, especially if the current be powerful and the application prolonged. An induced electro-magnetic current may produce sensations varying, according to its intensity, from a slight pricking to an acute burning pain; but, although the tension of the current may be very high, it will not cause inflammatory effects like the continuous current. To give another instance, if sparks from the common electrical machine are applied to the face, they produce a faint sensation of light; if the continuous current be applied to the face, a decided flash of light is perceived by the one subjected to the experiment, and if the current has a certain intensity the sensations of light become positively dazzling. Again, if an induced current be applied to the face by means of moistened conductors, it produces no sensation of light, but contractions of the muscles of the face and a variety of physiognomical expressions; the retina is only affected by the induced current, if it possesses a high tension, and even then not nearly to the same degree as by the continuous current.

Besides the form, the quantity and tension of the electricity have an important bearing on the production of the physiological effects. A large quantity of electricity causes more striking effects than a small one. If an induced current of low tension is employed, such as is produced in a short and thick wire, feeble contractions of the muscles are produced, but the sentient nerves are not much affected; on the other hand, a current of high tension, as produced in a long and fine wire, causes not only muscular contractions, but also decided sensations; and if the intensity of the current be very high, pain will be felt which surpasses that produced by the application of the actual cautery; and muscular contractions will appear, resembling the violent commotions observed in persons poisoned by strychnia.

The physiological effects caused by electricity are also different according to the mode in which electricity is transmitted to the organs, and to the length of time during which its action is kept up. An induced current, applied to the skin by moistened conductors, produces contractions of those muscles which are beneath that part of the skin to which the electrodes are directed. If dry metallic conductors are used, an effect will be produced on the sentient nerves of the skin, but not on the contractile power of the muscles; provided that the tension of the current is not very high. If the electrodes are firmly pressed against the skin at a point where a motor nerve is superficial, contractions of all the muscles take place which are animated by that nerve; but if the conductors are not pressed against the skin, the current runs along the cellular tissue which envelopes the nerve, and no muscular contractions will take place.

The length of time during which the electricity is allowed to act on the different organs is likewise of much importance. If a continuous current of moderate power is made to act on the skin for a short time, it will enlarge the blood-vessels and stimulate circulation; but if it be applied for several hours successively, as is often done with Pulvermacher's chains, the blood-vessels become paralysed, and sloughs are produced. If an induced current is made to act for a short time on the motor nerves and muscles, it will stimulate their vital energy; but if its action is continued for an hour or more, the motor power of those organs will be more or less exhausted, and temporary paralysis may be produced.

The physiological effects of electricity are further determined by the special property of the organ to which it is applied. The same electric current which produces a flash of light when applied to the eye, causes a special sensation of taste when directed to the tongue; sounds, when applied to the ears; muscular contractions, when directed to a motor nerve, and sensations of pricking and heat when applied to any part of the skin. Finally, the different states of vitality of the organ, at the time when the electricity is applied to it, are of great importance. Thus, a morbid increase of sensibility in a nerve, as is observed in sciatica, tic douloureux, and other forms of neuralgia, may be reduced; while, on the other hand, a nerve, the vital energy of which is gone or materially diminished, may by electricity be restored to its normal condition.

I.—ACTION OF THE ELECTRIC CURRENT UPON THE BRAIN.

The action of the induced current upon the brain of living animals has been investigated by Professor Weber.* He observed no effects if the electrodes were applied to the hemispheres of the brain or to the cerebellum—not even if they were inserted into the depth of the medullary substance—but by directing them to the tubercula quadrigemina, irregular convulsions were produced, which either appeared as clonic cramps, such as are observed in patients suffering from certain diseases of the brain, or resembled reflex movements; that is to say, they did not occur irregularly in all the muscles, but in certain groups of muscles which are naturally combined in action. If the medulla oblongata was excited, tetanic convulsions took place, as in persons poisoned by strychnia. Professor Weber thought we might infer from this that clonic cramps clinically observed in patients pointed to disease of the brain; and that there was

* Article 'Muskelbewegung,' in Wagner's 'Handwörterbuch der Physiologie,' vol. iii. part 2.

disease of the medulla oblongata, or of the spinal cord, if tonic cramps occurred; but these conclusions have not been entirely justified by clinical experience. Another phenomenon observed by him, after the application of the induced current to the medulla oblongata, was stoppage of the action of the heart.

Matteucci has made some experiments on the action of the continuous current upon the brain of living animals.* He observed that when the poles of a pile of sixty pairs were applied to the hemispheres of the brain, the animal did not start, nor was any effect visible if the cerebellum was touched; but when the electrodes were directed to the tubercula quadrigemina and the crura cerebri, the animal cried out lustily, and at the same time all the muscles of the body were contracted. These phenomena lasted for several seconds, but were not observed on the cessation of the current.

The only form of electricity which, if applied in moderate intensity, has a distinct physiological action on the brain of the living man, is the continuous galvanic current. Static electricity, electro-magnetism, and magneto-electricity, only affect the brain if applied so powerfully as to interfere with health, and perhaps life; but a gentle continuous current, directed to the face, scalp, or neck, and which causes no, or scarcely any, sensation of pain, is readily

* Traité des phénomènes électro-physiologiques des animaux. Paris, 1844, p. 242.

transmitted from those parts to the cerebral substance. This is shown by the sensations of light, sound, smell, and taste, perceived on applying the continuous current at a distance from the organs of special sense, from which it appears that the nerves animating those organs are encountered by the galvanic influence at the base of the brain. Furthermore, sensations may be caused which can only be explained by a direct action of the current on the cerebral substance itself, viz. dizziness, giddiness, sickness, fainting, vomiting, and even convulsions. The latter phenomena only appear if the current is one of considerable power; but giddiness and faintness are often felt even when a gentle current is used.

Many physiologists and physicians have denied the possibility of guiding a galvanic current of moderate power through the brain of the living man, thinking that its passage to that organ was prevented by the resistance of the soft parts and the bones of the skull. Professor Erb,* of Heidelberg, however, has justly contended that the obstacles encountered by the galvanic current on its way to the brain are not so great as has been generally supposed. With regard to the conducting power of the bones, we have already seen (p. 68) that it is better than it was formerly believed to be. In fact, the epidermis is a worse conductor than the bones, because it does not contain so much water as they do. It only conducts at all

* Deutsches Archiv, etc. 1867, vol. iii. p. 237.

in consequence of being perforated by numerous small canals, such as the excretory ducts of the sudoriferous glands and the sebiparous follicles, which are, it is true, better conductors than the tissue proper of the epidermis, but do not conduct electricity so well as the bloodvessels which traverse the bones. Moreover, if applied to the skull itself, the current is only slightly diverted from its direction by better conducting soft parts; since the epidermis, the corium, the galea aponeurotica, the periosteum, and the bones form layers directly superposed upon one another, and will not prevent a current of moderate power from entering the cavity of the skull.

The following experiment, made by M. Erb, shows that a portion of the current will follow the shortest way between the two electrodes:—The two forearms of a man are crossed over, so that they touch one another about three inches above the wrist, the anterior surfaces having previously been well moistened. One electrode is then placed on the dorsal surface of the right, and the other on that of the left, forearm, and a current of some intensity sent through the same. After some time, a sensation of heat is felt in the dorsal surfaces, and a sensation of the same kind, but much more feeble, on the volar surfaces. On removing the electrodes, it appears that not only is that part of the skin which was in contact with them diffusely reddened, but that a similar effect has been produced at the point where the volar surfaces touched each other, although it is there not so uniform, and appears more in patches, corresponding to the sebaceous follicles. In this experiment there are two roads open to the current, viz. a longer one through the muscles of the arm and trunk, which offer less resistance; and a shorter one right through the forearms themselves, where more resistance is offered by the epidermis. The result is, that a portion of the current travels by the long road, which has a better conducting power; but a not inconsiderable part of it takes the short way, as is shown by the sensation of heat which is experienced, and the redness which is perceptible, at the end of the experiment. Now, as the resistance of the bones appears to be less than that of the epidermis, M. Erb concludes that a current which is applied to the two opposite surfaces of the skull must, if not wholly, at least partially, penetrate into the cavity of the skull, and act upon the cerebral matter.

The same observer has made experiments on dead bodies which go far to prove that the galvanic current may really be sent straight through the substance of the brain. He opened the skull, removed the brain, and covered the top of the skull with a layer of muscular substance, two inches wide and three-quarters of an inch thick, so that it went from the occipital spina to the glabella. Pieces of skin were interposed between the muscular flesh and the electrodes. The skull-cap was then filled with cerebral matter, but the contact of this with the muscular substance was carefully avoided. The edges of the skull having been well dried, a prepared frog's limb, resting on the cerebral matter, was then interposed between the two electrodes, and a feeble current, which produced only slight pricking when applied to the face, sent through the tissues; when it was observed that, on closing and opening the circuit, the physiological galvanoscope contracted vigorously. M. Erb concludes from this that, in spite of the well-conducting muscular substance which connected the electrodes, a current of sufficient power entered the brain to make the frog's limb contract. The induced current produced the same effect on the frog's limb as the continuous current.

Another experiment, performed by the same observer on the dead body, is the following:—

A rectangular piece of bone was removed from the skull-cap, and the skin and periosteum dissected away from the edges of the bones, and retracted; part of the dura mater was then removed, and the blood and the cerebro-spinal fluid were allowed to escape. The edges of the bone were then carefully dried, and the body was left for three hours in a warm room, so as to remove all the moisture from the edges of the bones. A piece of cerebral substance was then taken out, and the nerve of a frog's limb was placed in the fossa thus formed, while the other parts of the frog's limb were insulated by a thick covering of dry paper. The electrodes were then applied above the ears, the result being that a current which could easily be borne on the face caused distinct contractions in the frog's limb; these contractions became stronger, if one pole was put to one side of the forehead, and the other one to the mastoid process of the opposite side. The application of the induced current produced the same effect.

M. Erb has therefore shown that during the application to the head of a continuous and an induced current, which are so feeble as to be perfectly suitable for therapeutical application, portions of the current traverse the brain in such quantity and intensity as to cause a decided effect upon the frog's limb, although this occupied only a small space in connection with cerebral matter; and he argues that, in the living body, circumstances would be even more favourable for the transmission of the current to the brain, because there the temperature is higher, and circulation active.

It might be objected to these conclusions that a current which is sufficiently powerful to excite the nerve of a frog's limb is hardly sufficiently strong to produce an appreciable therapeutical effect on the brain. But if we consider that the frog's nerve touches only a very small portion of cerebral matter, and that, in all probability, the current, when applied to the head, traverses all portions of the brain equally, this current cannot be quite so feeble as might be imagined. Moreover, it has not been shown that a current must necessarily be very powerful in order to be useful. Such ideas might, perhaps, apply to the induced current, which is nothing but a powerful stimulus; while the continuous current has not only stimulating, but also catalytic, electrolytic, and electro-endosmotic effects.

It is true that the induced current may penetrate into the brain, but it seems to exert only little influence on it, just as on the retina and the other organs of special sense. Induction currents applied to the temples only cause pain and muscular contractions, but no giddiness or sensations of light, except in persons who are unusually sensitive to all forms of electricity.

It is therefore certain that a continuous current of moderate power may be made to traverse the cerebral substance of the living man; and the only question we still have to consider in regard to this is whether the current is directly transmitted to it in the way described by M. Erb, viz. by way of the bloodvessels which penetrate from without to the inside of the skull; or whether the reflex function of the fifth pair of cerebral nerves is the chief medium by which the current is propagated to the brain, as I have always been inclined to assume.

The principal reason for my theory was, that we see cerebral symptoms produced not only by sending the current straight through the head, as, for instance, when one pole is put to the occiput and the other to the forehead, or one to the right and the other to the left temple, but also by applying the poles of the battery to any parts of the face close together, where no portion of the brain is included in the circuit; and this argument has never been refuted. An opportunity has, however, recently been afforded to me of carefully studying this question in the living subject, with due elimination of all sources of error; as I have been fortunate enough to observe, clinically, a case of complete anæsthesia of the entire fifth pair of cerebral nerves. In this patient, the reflex function of the trifacial nerve was completely excluded, and it appeared that no cerebral symptoms could be produced, even if a current which caused intolerable sensations to a healthy person was sent straight through the head. The case alluded to appears to me to have a most important bearing on the settlement of this question, which has for a long time perplexed all those who have occupied themselves with electro-physiology and electro-therapeutics, and I therefore subjoin the following particulars of the same:—

CASE I.—*Anæsthesia of the Fifth Pair of Cerebral Nerves.*

P. G., aged 27, unmarried, a sheep-farmer living in Australia, had been in good health until June 1866, when on riding across a vast plain in Queensland, and being much exposed to a keen wind blowing steadily into his face, he was suddenly seized by severe pain in the left side of the head, eyes, and face. At first, the sensation was as if the face were frost-bitten. The pain then became of a dull throbbing character, and continued so for five weeks. He put himself under the care of a local practitioner, who prescribed iodide of potassium and a blister. Some time after, on a similar exposure again taking place, the right side of the face became affected in the same manner, but the pain was not so severe, and the attack did not last so long as the first. When the pain was quite gone, the corneæ of both eyes became covered with thick opacities, and the patient completely lost his sight on the right side, while on the left he could still faintly distinguish light and objects at a short distance. The power of mastication also became completely lost, and the skin and mucous membranes of the face quite numb. He then went to Sydney, where he was admitted into the Hospital, in which he remained five months. The surgeon under whose care he was there, ordered the eyes to be strapped up, probably with the intention of preventing perforation of the corneæ (Snellen). As time went on, some of the symptoms were rather improved, but as he was still incapacitated from doing any work whatever, he came to England, and placed himself under my care.

I first saw the patient on April 21, when I found him in the following condition:—

His intellect and memory were in no way impaired. He was able to fix his attention on subjects quite as well as previous to this affection; indeed, he complained much of the idleness caused by the loss of sight. This made him occasionally irritable and low-spirited. There was a peculiarly hard, almost statuesque expression of the features, which was due partly to a slight œdematous effusion into the cellular tissue of the face, and partly to the complete loss of muscular sensibility.

On applying Faradisation by moistened conductors to the muscles of the face, these responded readily by contraction to the electric stimulus; but there was a complete absence of that peculiar sensation which in a healthy person always accompanies electro-muscular contractions, and which is caused by the stimulation of the sentient nerve-fibres which are distributed in the muscular substance. This latter was in no way affected, showing that the morbid influence had not reached the portio dura. All the varieties of physiognomical expression could be produced at will, but the effect made was more like that of an automaton than the natural appearance of sentient and animated features.

The sense of smell was quite normal, and had never been impaired. On applying a sufficiently powerful continuous galvanic current to the mucous membrane of the nose, a decided phosphorous smell was perceived by the patient.

Vision was obstructed by thick leucoma of both corneæ, although the optic nerve was not affected. Indeed, the patient was able not only to distinguish light and shade with both eyes, but he could also see near objects, and read single letters of No. 20 (8-line roman) of Jæger's test types, with the left eye, where the leucoma was not so thick as in the right. He was, however, quite unable to guide himself in the streets. He suffered a great deal from photophobia, and had to wear an eye-shade. This was a remarkable circumstance, as, in consequence of the leucoma of both corneæ, only very little light could penetrate to the retina.

Mr. Soelberg Wells has been kind enough to make a careful ophthalmoscopic examination of the fundus of the eye, and has furnished me with the following report of the appearances noticed by him:—

"In both eyes, the pupils became well dilated under atropine. In the right there are very delicate, threadlike adhesions between the edge of the pupil and the leucomatous portion of the cornea. In the left eye there are slight remnants of uveal pigment on the central portion of the anterior capsule, indicating that a slight iritis had formerly existed. The lens and vitreous humour are clear, and the background of the eye quite normal. In the right eye, on account of the dense central leucoma, the optic disc could be only imperfectly seen, but in the left eye it was quite visible."

The motor nerves of the eye were in their normal condition, there being neither ptosis nor strabismus nor double vision, and all movements of the eye, upwards, downwards, and laterally, being easy of execution.

The pupils were rather constricted, and were only very slightly influenced by variations of light and shade.

In describing the condition of the fifth nerve, I shall speak,

1st. Of the skin of the face and scalp;

2nd. Of the mucous membranes of the eye, nose, and mouth; and

3rd. Of the muscles of mastication.

1st. The common sensation of the face and scalp was entirely lost in both sides, the limit of the anæsthesia being vertically a line running one sixth part of an inch inwards from the horizontal and ascending branches of the lower jaw; and horizontally a line drawn from the tragus of one ear, right across the skull, to the tragus of the other ear. All the parts comprised between these lines, including the temples, forehead, nose, cheeks, and chin, had lost their sensibility. As regards the ear, the tragus was anæsthetic, and part of the external meatus benumbed, while the concha was perfectly sensible. In like manner, the skin of the back part of the skull, and the skin of the neck, had preserved their ordinary sensibility. In the anæsthetic parts of the face and scalp just alluded to, neither pricking nor pinching nor any other mechanical irritation was in the least degree perceived by the patient. With regard to electricity it appeared that Faradisation by dry conductors did not produce any sensation, even when a powerful current was used. On applying to the face the continuous current of ten cells of Daniel's battery, which deflected the needle of the galvanometer to an angle of thirty-five degrees, and which, in a healthy person experimented upon at the same time, caused not only a feeling of heat and pricking in those parts of the skin to which the electrodes were applied, but also a sensation of taste on the tongue, and a flash of light, chiefly on breaking the circuit, no physiological effect whatever was produced in the patient. On using a current of twenty cells of the same battery, which deflected the galvanometer to an angle of fifty degrees, and in a healthy person caused contractions of the muscles of the face, both at the entrance and the cessation of the current, together with strong pricking and heat, vivid flashes of light, giddiness, and strong galvanic taste, no sensation whatever was produced in the patient, but the facial muscles responded readily, chiefly on making the circuit. On further increasing the power of the current to thirty cells, which deflected the galvanometer to an angle of seventy-two degrees, and in a healthy person caused the perception of dazzling flashes of light, a hissing noise, a phosphorous smell, and such powerful feelings of heat, giddiness, and sickness as to be unbearable for more than a second, the patient perceived a slight sensation of warmth and pricking, a slight coppery taste, a slight phosphorous smell, and slight giddiness. These sensations had much the same degree of intensity whenever the poles were applied.

The sense of temperature was completely absent, for neither intense cold, as caused by the application of ether spray or ice, nor heat, caused the least sensation. This had been so from the commencement of the affection; and the patient had several times, on lighting a pipe, accidentally scorched his face without being aware of it at the time.

The sense of touch was entirely gone; for neither of the two points of the æsthesiometer was in the least degree perceived by the patient. Nor was the sense of locality preserved, for the patient could not tell where he was touched or pinched.

2nd.—*The Mucous Membranes of the Eye, Nose, and Mouth.*—*a.* The conjunctiva of both eye and eyelid was completely anæsthetic on both sides, and could be touched by the finger, and blunt and sharp instruments, without exciting reflex movements or lachrymation. The patient stated that when he washed his face, he always kept the eyes open, and never felt the contact of either water or soap.

The secretion of the lachrymal gland appeared to have totally ceased; and the application of substances which generally excite a flow of tears, such as ammonia and mustard, had no effect whatever. There was, however, pathological hypersecretion of conjunctival mucus, by means of which the eye was kept moist. Indeed, the cornea appeared covered with streaks and shreds of mucus, which gave a death-like appearance to the eyes. This mucus was most probably secreted by those mucous follicles which were first described by Professor Krause, and which are situated below the conjunctiva, where this membrane is reflected from the eyeball upon the eyelid.

b. The mucous membrane of the nose was quite insensible to the touch of blunt or sharp instruments, and no sneezing followed the application of snuff. There was, however, an abundant secretion of mucus, which had at one time been so excessive that thick scabs were continually forming in the nose. This mucus was of so acrid a nature that on running down to the lip it made the skin of the sulcus naso-labialis, and part of the lip beyond the sulcus on both sides, very sore, and caused the moustache to fall out there. Otherwise, the beard and hair altogether were in perfect condition, from which it appears that the growth of hair is not under the direct influence of the fifth nerve. That part of the upper lip, where the acrid secretion from the nose used to run, appears now quite white, similar to a scar from burning, or from the application of sulphuric acid. At one time the nose used to bleed very readily when slightly touched, but it had not done so lately. The reaction of the nasal mucus was neutral.

c. The mucous membrane of the mouth was also completely anæsthetic, as far as the gums, the tongue, the inner surface of the cheeks, and the hard palate were concerned. The tongue presented a most frightful spectacle, having been severely bitten and lacerated in every direction during the act of taking food, the patient being entirely unconscious of his biting the tongue whenever he did so. Some parts of the inner surface of the cheeks had also been bitten, and were badly ulcerated. The secretion of buccal mucus was so excessive as to oblige the patient to have a pocket-handkerchief constantly applied to the mouth, in order to prevent the liquid from running down the chin. The lips appeared covered with a sort of froth, such as we see in a patient who has just come out of an epileptic attack. Both corners of the mouth were very sore, being macerated by the constant flow of mucus. The reaction of the liquid was slightly alkaline.

The insensibility of the gums was so complete, that on one occasion, when the patient had a tooth drawn, he felt nothing whatever of the operation. The remaining teeth were perfectly healthy.

The sense of taste was not lost, for the patient tasted sugar, quinine, and salt on the front as well as on the back part of the tongue; yet in the anterior portion of the organ, the perception of taste seemed to have lost its quickness, for while, on my applying sapid substances to the posterior part of it, the patient would at once exclaim 'sweet,' 'bitter,' 'salt,' he took about five or six seconds on the front part of the tongue, to describe the taste, but he never made a single mistake there. He also perceived the galvanic taste of five cells of Daniell's battery, if directly applied to the tongue.

3rd. *The Muscles of Mastication.*—The muscles of mastication, which are animated by the minor portion of the fifth nerve, had not escaped the pathological influence. At one time the temporal and masseter muscles, which move the jaw upwards, were completely paralysed, so that it dropped, as in a dead body, and the mouth was always open. Both pterygoid muscles being also completely paralysed, mastication was rendered impossible; the patient never masticated the food he took for sixteen months consecutively. He was therefore obliged when taking solid food to have it cut very small, and then bolt it. Curiously enough, digestion had never suffered in consequence of the want of mastication, which I think must be explained by the circumstance that a thorough moistening and soaking of the food taken, with a slightly alkaline liquid, went on at least as copiously as it could have done before, owing to the pathological hyper-secretion of buccal mucus, of which I have already spoken, and which therefore, in this case, seemed to exercise a kind of compensating influence.

For several months previous to the patient's coming under my care, the voluntary power had gradually returned in the temporal and masseter muscles, so that the mouth could be closed, and the vertical movements of mastication were well carried out. The pterygoid muscles, however, remained paralysed, so that the lateral movements of the jaw were impossible. He had also great difficulty in putting out his tongue.

Other muscles, animated by the minor portion of the fifth nerve, are the mylohyoid, the digastricus anticus, the tensor palati mollis, and the tensor tympani. As regards the three first named, no morbid symptoms could be discovered showing that they were paralysed. The position and function of the soft palate were in no way altered, which is probably due to the circumstance that the tensor palati mollis receives nervous fibres not only from the minor portion of the trifacial, but also from the pneumogastric and the accessory nerve.

The patient complained of a continuous rushing noise in the head, which he compared to that made by the paddle-wheel of a steam-boat. It would, however, be difficult to determine, at present, whether this symptom was due to paralysis of the motor fibres animating the tensor tympani muscle, or to anæsthesia of the sentient petrosus superficialis minor nerve, which proceeds from the ganglion oticum to the tympanic plexus of nerves.

The sense of hearing was perfectly normal.

The speech was rather thick and indistinct, in consequence of the lacerated condition of the tongue, but not from any affection of the hypoglossus nerve.

All the remaining parts of the nervous system were in good condition ; nor was there any disorder of the chest, stomach, liver, bowels, skin, or genito-urinary organs.

There was no history of scrofula or syphilis.

Such being the condition of the patient, no real difficulty could be experienced in determining the nature and exact seat of the pathological lesion. The patient had evidently suffered from rheumatic inflammation of the neurilemma, first of the left, and afterwards of the right, trifacial nerve, where it emerges from between the transverse fibres of the pons Varolii at the base of the brain. This inflammation had resulted in effusion, and subsequent compression and atrophy of nervous matter.

The affection had to be traced to the nerve-trunk at the base of the brain, and not to any more peripheral part, because not a single fibre of the trifacial nerve had escaped the injury; if the lesion had been more peripheral—for instance, if it had been confined to the Gasserian ganglion—the muscles of mastication would not have suffered. At the same time it was evident that the disease could not have spread to the pons Varolii, because there was an entire absence of all symptoms which occur in disease of the pons. The lesion was therefore confined to the course of the fifth nerve between the pons and the Gasserian ganglion. As the case did not end fatally it was impossible to verify the diagnosis by actual inspection, which however could have added but little to the pathology of the case.

Without entering at present into all the points of interest in physiology and pathology upon which the case just related is apt to throw some light, I will only make a few remarks on the curious fact of the absence of cerebral symptoms during the application of a powerful continuous current to the head.

Indeed, it was only by increasing the power of the current to such a degree as to rouse the faint remnant of sensibility of the trifacial nerve that a slight feeling of giddiness was caused. Now, as the physical relations of the skull, brain, and blood-vessels were in no way altered in this case, there ought to have been no alteration as regards the production of cerebral symptoms, if M. Erb's theory were correct; but, as there was a decided diminution of cerebral reaction, it is satisfactorily proved that the transmission of the continuous galvanic current to the brain is effected not physically, but physiologically, by nervous action.

II.—ACTION OF THE ELECTRIC CURRENT UPON THE SPINAL CORD.

Professor Weber has observed that, if an induced current is applied to the spinal cord, one electrode being directed to the upper, and the other one to the lower extremity of the cord, all the muscles of the trunk and of the extremities are thrown into tetanic convulsions. The same occurs if one electrode is placed to the anterior, and the other one to the posterior, surface of the upper portion of the cord; and likewise when both electrodes are applied to its lower portion, provided that the integrity of the organ has not been destroyed. Hence it would result that the cord is the nervous centre for all the muscles of the trunk and the extremities; for if the cord were only the common trunk of all the motor nerves emerging from the vertebral canal, the application of the induced current to the lower portion of the cord would only produce a convulsion of the hind-legs, but not of all four extremities. If, however, the spinal cord is divided in the middle, and the lower half is then submitted to the electric stimulus, only the muscles of the hind-legs enter into contraction; and even if both parts of the cord are made to touch one another closely at those points where the section has been made, so that there is no impediment to the passage of the electric current to the upper portion of the cord, the muscles of the upper extremities nevertheless remain perfectly quiet. From this Professor Weber has inferred that the convulsions described are not produced because the electric current is transmitted from the cord to the motor nerves, but because the passage of the electric current excites the action proper of the cord, which in its turn excites the property of the motor nerves to produce commotions of the muscles. He also observed that the tetanic convulsions produced in the extremities by the same means continued for a certain time, say half a minute, after the cessation of the current; while, if the anterior roots, or the mixed nerves were excited, the commotions disappeared immediately after the circuit had been broken.

If the spinal cord be subjected to the action of a continuous current, convulsions of the extremities are produced on making the circuit, but if the current continues to traverse the cord, an inhibitory effect is caused, whatever may be the point to which the poles are directed. As long as the cord is traversed by the continuous current, it remains insensible to a stimulus which may be applied to it. Thus we may prick the cord by a pin or excite it by an induced current, and the extremities will nevertheless remain perfectly quiet; but at the cessation of the continuous current, mechanical or electrical excitation of the cord will again give rise to tetanic convulsions of the limbs. It was first pointed out by Baierlacher * that this diminution of excitability is confined to the spinal cord, and does not extend to the motor nerves and muscles; for if an induced current is applied to the motor nerves of the hind legs, while at the same time the cord is being traversed by a continuous current, commotions are produced in the muscles the nerves of which are submitted to the action of the induced current. The inverse continuous current appears to have a more powerful inhibitory action on the spinal cord than the direct current.

Weber's experiments, although carefully performed, have not been entirely confirmed by other observers. Thus Van Deen, Schiff, and other physiologists contend that the substance of the cord itself does not respond at all to the electric stimulus, and that if convulsions are observed in consequence of such an application, this is due to the propagation of the electricity to the roots of the spinal nerves. En-

* Die Inductions-Elektricität. Nürnberg, 1857, p. 102.

gelken and Fick, however, support Weber's assertions. Wislocky found that, if the induced current was applied to the upper portion of the cord, it caused tetanic contractions of the lower extremities only if part of the current was diverted to the roots of the lower spinal nerves.

S. Mayer,* who has made the latest experiments on this subject, has shown that, if a gentle induced current was cautiously applied to the cervical portion of the cord in frogs, which were highly excitable at the time, 'orderly movements' of the lower extremities took place; and these movements were more easily produced by electrisation of the posterior than of the anterior columns. The difference appeared most striking in the upper intumescence of the cord. After the posterior columns had been carefully removed, no further movements took place; but if the cord was divided into an anterior and posterior half, both of which were connected just above the origin of the sciatic nerve, electrisation of the posterior half was effective, and of the anterior half ineffective. The same power of current which caused movements if applied to the cord itself, produced them if applied to the posterior roots on the trunk of the brachial nerve. These observations seem to point to the conclusion that the movements which have been observed after electrisation of the cord, are only reflectory, and caused by the stimulation being transferred to the posterior roots; but further investiga-

* Pflüger's Archiv. für Physiologie, 1869, Heft i. p. 166.

tions of this subject are necessary before exact notions of the mode of action of electricity on the cord can be formed.

Professors Budge and Waller have observed, that the pupil becomes dilated, if the induced current is applied to that portion of the cord which is situated between the seventh cervical and the sixth dorsal vertebræ; and this has, therefore, been termed by them the *cilio-spinal region.* From this part of the cord the excitation is transmitted to the cervical sympathetic nerve, which takes its rise from it, and which animates the radiar fibres of the iris (musculus dilatator). These fibres contract energetically, if the cervical sympathetic nerve is excited, and counterbalance the action of the circular fibres of the iris (musculus constrictor); thus dilatation of the pupil must ensue. After the section of the sympathetic nerve the pupil becomes constricted, as by such an operation the radiar fibres of the iris are paralysed, while the circular fibres remain in their normal connection with the nerves.

Professor Budge * has discovered a similar centre for the lumbar portions of the sympathetic, in that portion of the spinal cord which corresponds to the fourth lumbar vertebra. By the application of the induced current to the same, powerful contractions of the vasa deferentia, the bladder, and the lower portion of the rectum are caused. The same effects are produced by stimulating a small ganglion situated

* Virchow's Archiv., 1859, p. 115.

in the neighbourhood of the fifth cervical vertebra, and which receives branches from the third and fourth lumbar vertebræ. This ganglion Budge has called the *genito-spinal ganglion.* The section of the sympathetic on one side does not quite prevent the effects of the application of electricity to the ganglion of the same side, although it considerably diminishes them. That any effect at all is produced under these circumstances, is due to a propagation of the electric stimulus being effected by means of the connecting branches between the nerves of both sides.

Whether any form of electricity, applied in moderate power to the spine of the living man, is transmitted to the spinal cord, has until now been a matter of controversy. Judging from therapeutical effects, I am led to believe that static electricity, electro-magnetism, and magneto-electricity only act on the nerves of the skin of the back, and not on the substance of the cord, but that the continuous current has a decided action on the latter. M. Erb* is inclined to think that the bones of the vertebral column offer less resistance to the passage of the current than the skull. They are more spongy, contain more water, and the several bones are separated from one another by large and numerous lacunæ, fitted up with blood-vessels, nerves, and connective tissue, along which the current may easily penetrate into the spinal canal. There is however this difficulty, that we can

* L.c. p. 435.

only apply the current to one surface of the cord, and that it cannot be sent right through it, as it may be through the head; but, on the other hand, a much more powerful current may be safely applied to the cord than to the brain, whereby some compensation is afforded for the disadvantageous anatomical position of the cord.

M. Erb performed the following experiment on a dead body with the view to elucidate these conditions:—He removed the bodies of the seventh cervical vertebra and of the first three dorsal vertebræ, and the dura mater, so as to lay the cord open, the parts being dried as carefully as possible. The nerve of an isolated frog's limb was then placed on the cord, and the positive pole of a constant battery directed to the mastoid process, while the negative pole was applied to the sixth dorsal vertebra. Contractions took place in the frog's leg on opening as well as on closing the circuit, showing that the current actually passed through the cord.

Experiments on the living man have shown that it is possible, by applying the two electrodes of a somewhat powerful constant battery to the spine, to produce contractions of muscles, which are animated by nerves situated far below the points where the electrodes are applied. Thus, for instance, if one large electrode was placed near the first dorsal vertebra, and the other to the spinous process of the second and third lumbar vertebræ, and a current of some power was sent through, contractions were caused not only in the muscles of the back, but also in the hamstring muscles of the thigh, which are animated by the sciatic nerve; care being taken that the direction of the current was occasionally rapidly changed in the metallic circuit. By this latter proceeding *voltaic alternatives* are produced, which considerably increase the excitability of the nerves; and after several such alternatives had taken place, contractions of the same muscles could be caused by simply interrupting the current. This shows that the sciatic nerve must have been electrically acted upon within the spinal canal, and that a continuous current, sufficiently powerful to produce decided physiological effects, may be sent through the cord of the living man.

It will be shown in another part of this volume that it is not necessary to cause pain or muscular contractions by such an application if it be intended to affect beneficially the motor or sentient properties of the cord.

III.—ACTION OF THE ELECTRIC CURRENT UPON THE ORGANS OF SPECIAL SENSE.

All the different forms of electricity are capable of exciting the nerves of the organs of special sense; the effect, however, is much more remarkable, if we employ the continuous current than if frictional electricity or the induced current are used. With regard to induction currents, it appears that the magneto-electric current has more effect on the organs of sense, and more especially upon the retina, than the electro-magnetic current; which is probably due to the circumstance, that the variations of the magneto-electric current are not so sudden and considerable as those of the current induced by voltaic electricity.

1. *Organ of Vision.*—If the continuous current of a single galvanic pair is caused to act upon the optic nerve, one of the metals being placed to the conjunctiva or to the well-moistened eyelid, and the other metal to the other eye or eyelid, a faint flash of light is perceived at the commencement of the current; while the circuit is closed, luminous appearances are only seen by persons whose retina is highly sensitive; but there is again a distinct flash when the circuit is broken. This is, of course, no real development of light, but the flash is only seen by one subjected to the experiment, in consequence of the vital energy of the optic nerve being roused by galvanism.

Sparks taken from the common electrical machine and applied to the eyes, produce also luminous appearances, though not very distinct. The electricity of the electrophorus machine, if of somewhat high tension, causes a continuous perception of bluish-white light, together with pain, and spasmodic contractions of the muscles of the jaw.* Electro-magnetism has much less effect on the retina than the continuous current. The extra-current of an

* Schwanda, l.c., p. 199.

induction machine, which circulates in a short and thick wire, and has therefore a low tension, has no such effect at all; while the current induced in a long and fine wire has a slight effect on the retina. Magneto-electricity affects the optic nerve more than electro-magnetism, but not nearly as much as the continuous current.

The flash of light perceived in consequence of the galvanic stimulation of the retina appears coloured; it is bluish when the positive pole is applied nearest to the eye; and Ruete observed that, in this case, the sensation of light is strongest at a point which corresponds to the macula lutea, becoming gradually darker as it approaches the periphery of the field, while if the negative pole is directed to the eye, a yellow-reddish or orange-coloured light is perceived, which appears strongest in the periphery of the field and gradually darkens towards the centre.

Purkinje has made an extensive series of observation on this subject; but no other observer has been able to confirm his results; and it is therefore probable that the extraordinary appearances he has described were due to a hyperæsthetic condition of the retina brought on in him by over-stimulation of that organ.

The luminous appearances just described are produced by reflex action from the sentient fibres of the trifacial nerve to the retina; and they may be perceived, whatever be the position of the poles, provided that one of them touches a point of the skin or of a mucous membrane animated by a filament of the fifth pair. It is, therefore, unnecessary to touch one or both eyeballs or eyelids; we may perceive the flash, for instance, if one pole be directed to the Schneiderian membrane, and the other to the mucous membrane of the cavity of the mouth. Mr. George Hunter observed, that by placing one of the metals as high up as possible between the gums and the upper lip, and the other in a similar situation with respect to the lower lip, a flash was produced as vivid as that occasioned by passing one of the metals up the nose and placing the other upon the tongue.* It differs, however, from the flash produced in any other way by the singular circumstance of not being confined to the eye alone, but appearing diffused over the whole of the face. The flash may also be perceived, if one pole is placed in the mouth and the other in the rectum; this experiment was first made by M. Achard, of Berlin.†

The flash becomes more distinct and of a stronger colour on darkening the room, and Humboldt relates that, during storms, the effect of galvanism upon the eyes is most remarkable. Fowler made the experiment on himself at a time when one of his eyes was inflamed, and noticed that the flash produced in the inflamed eye was much more considerable than in the uninflamed one. On the other hand, Humboldt

* Experiments and Observations relative to the Influence lately discovered by M. Galvani, and commonly called Animal Electricity. By Richard Fowler. Edinburgh, 1793, p. 64.

† Versuche über die gereizte Muskel und Nervenfaser. Von Alexander von Humboldt. Posen und Berlin, 1797, vol. i. p. 334.

states that when he was affected by a bad cold he was not able to perceive the flash at all, even if he made use of an otherwise most efficacious arrangement of the metals.

The intensity of the flash is directly proportional to the intensity of the current employed, and inversely proportional to the resistance offered to the passage of the current. A flash is produced by a very feeble current, such as is excited by a half-crown piece and a penny; it is more distinct if, instead of copper and silver, tinfoil and silver, or zinc and gold, are used. The excitation of the retina produced by a pile consisting of a number of pairs, is very violent, and instantaneous blindness may ensue from it. Duchenne, who was unacquainted with the power of the continuous current to excite the retina in this remarkable manner, relates a case which fully proves the practical importance of the knowledge of the physiological effects which electricity will invariably produce. He galvanised a patient suffering from paralysis of the portio dura, at first by the induced current, and afterwards by the continuous current of a pile. Immediately after the electrodes of the pile had been applied to the face, the patient exclaimed that he saw the whole room in a blaze; he afterwards complained of having lost his sight on that side where the electrodes had been applied: and he never regained it. Duchenne claims for himself the discovery of the special action of galvanism on the retina; but this was already known to Volta, before the commencement of the present century.

If the resistance to the passage of the current be great, the flash perceived in consequence of the galvanic excitation of the retina is very feeble. Thus, if the two metals are applied to the face at two points where the skin is quite dry, the flash is much less vivid than if the skin be previously moistened. Besides, the flash is stronger if the electrodes are directed to the conjunctiva, or to the Schneiderian membrane, or to the mucous membrane of the cavity of the mouth, than if they are applied to the skin of the face; since the delicate epithelium of the mucous membranes offers much less resistance to the passage of the current than the epidermis.

2. *Organ of Smell.*—We have already seen that near the electrical machine when in action a peculiar smell is perceived which is half sulphurous and half phosphoric. It was formerly believed that this odour was due to a peculiar state of the olfactory nerve excited by electricity; but it is now well known that it is due to the development of ozone (p. 4).

Neither the common electric sparks, nor the electricity of the electrophorus machine, nor electro-magnetism, nor magneto-electricity have any effect in exciting a peculiar smell when applied to the mucous membrane of the nose. By applying these forms of electricity to the Schneiderian membrane a more or less disagreeable scratching and tickling is caused, owing to the irritation of the sentient nerves, with which this membrane is richly endowed; and, by reflex action, sneezing is often produced.

The continuous current is the only kind of electricity which is capable of rousing the vital energy of the olfactory nerve. But in order to effect this, a current of high tension is required, such as is hardly possible to bear for more than a second, on account of the concomitant symptoms of dazzling flashes of light, giddiness, and faintness which it induces. The case which has been related above (p. 141) shows that when the function of the fifth pair is in abeyance, the peculiar smell due to the galvanic stimulation of the olfactory nerve, is perceived without being accompanied by any further inconvenience.

Ritter * has experimented upon his own Schneiderian membrane with the current of a voltaic pile of twenty pairs, and says that the inconvenience caused to him by the experiment was 'awful.'

He gives as the result of his researches, that a peculiar smell was perceived at the commencement of the current, while the circuit remained closed, on opening the circuit and some time afterwards. The effects were different according to the direction of the current. If it was inverse, he observed at the commencement of the current, and while the circuit was closed, an acid smell and loss of the capability of sneezing; at the cessation of the inverse current, and a short time after the circuit had been broken,

* Beiträge zur näheren Kenntniss des Galvanismus. Weimar, 1805.

he perceived an ammoniacal smell and disposition to sneezing. If, on the other hand, the direct current was used instead of the inverse, the contrary occurred, viz. ammoniacal smell and disposition to sneezing on establishing the circuit, and while the current continued to pass; and an acid smell and loss of the capability of sneezing, on breaking the circuit, and a short time after it had been broken.

I regret that I have not been able to verify Ritter's observations in any single particular. The condition of the brain during the passage of such a powerful current as is necessary for affecting the olfactory nerve, is not favourable to accurate observations; but I certainly never felt during that time either disposition to sneezing, or that peculiar sensation which is constituted by 'loss of the capability of sneezing.' The smell was neither ammoniacal nor acid, but phosphorous, and, as far as I have been able to judge, there was no difference whether the current was direct or inverse. The patient whose case is described on p. 137 never sneezed during the application of the current to the nose, nor did he feel any inclination to, or aversion from, sneezing; and his statement on the nature of the smell was that it was something like sulphur or phosphorus.

3. *Organ of Hearing.*—Static electricity appears to have no special effect on the organ of hearing; but both the continuous and the induced current are able to rouse the vital energy of the auditory nerve, which

responds to the stimulus by sounds. The best way to make the experiment is, to fill the external opening of the ear with water, the person experimented upon lying on the side; an insulated sound with a metallic top, and connected with one of the poles of the battery, or induction apparatus, is then held in the liquid, and the circuit is closed by placing another moistened conductor on the nape of the neck.

If the continuous current is used, sounds may be produced, not only at the commencement of it, but also while the circuit remains closed, and on opening the same. Volta* relates, in a letter to Sir Joseph Banks, that when he introduced the poles of a pile of from thirty to forty pairs into the external opening of the ear, he felt a shock to his head, and some moments afterwards he heard a sound, or rather a noise, like scratching and bubbling, or like that of a viscid substance boiling. This noise continued without interruption, and became even stronger, until the circuit was opened. But sounds may be produced by means of a much feebler current, such as is produced by a battery of from three to four pairs. The effect is generally stronger if the negative pole be applied to the ear.

The action of the induced current upon the drum of the ear presents some differences according to the tension of the electricity, and the greater or less velocity with which the shocks succeed each other. A single shock from an induction apparatus produces

* Philosophical Transactions, 1800, p. 423.

a noise like a scratch; if the currents succeed each other rapidly, the noises do so likewise, and then resemble the buzzing of a fly on a window, or the blow of a distant trumpet. At the same time a sensation of pricking, and even pain, is perceived, if the current be of high tension.

Ritter was the first who endeavoured to distinguish the pitch of the tone produced by the galvanic excitation of the drum of the ear. He states that, when both his ears were enclosed in the circuit, he felt at the commencement of the direct current a strong shock, and heard the sound ḡ. This persisted as long as the direct current continued to circulate; if the intensity of the current was augmented, the sound became higher than ḡ. On the contrary, when the inverse current was used, the sound was lower than ḡ, and continued to become lower in proportion as the intensity of the current was increased. Both sound and shock were weak on breaking the circuit, whether the current was direct or inverse.

I have made a number of experiments with all sorts and directions of currents, and compared the sound produced by the galvanic excitation of the auditory nerve with that given by a tuning fork of the present philharmonic pitch; and I have always found the sound produced by electricity as near as possible to ā. I have never observed that by changing the direction of the current, or by increasing its intensity, the *pitch* of the sound was changed; the only difference I have perceived was in the *intensity* of the tone. It was louder if the negative pole was directed to the ear, and the positive to the nape of the neck, than if the position of the poles was reversed. The tone was hardly perceptible if a current of low tension was used, and very loud if it was of high tension; but the pitch invariably remained the same.

If a somewhat powerful continuous current be used, it is not necessary, for the response of the auditory nerve to take place, that one of the poles of the battery should be in the external meatus; but it is quite sufficient to touch with the electrodes any portion of the skin of the face or head animated by the fifth pair of cerebral nerves. Thus, on applying a current of forty cells of Daniell's battery, by means of moistened conductors, to both cheeks, I not only perceive sensations of giddiness, pricking, heat, taste, smell, and flashes of light, but I also hear a distinct hissing sound, resembling the gushing of the wind through the rigging of a ship. It is therefore evident that the effect of the continuous current on the organ of hearing takes place by reflex action from the peripheral branches of the trifacial to the auditory nerve, at the base of the brain.

Dr. Brenner,* of St. Petersburg, has made the latest researches on the action of electricity upon the auditory nerve. According to him the induced current is almost useless for experiments of this kind,

* Untersuchungen und Beobachtungen über die Wirkung elektrischer Ströme auf das Gehörorgan im gesunden und kranken Zustande. Leipzig, 1868. And a number of papers in different periodicals from 1863 to 1869.

because the rapidity with which induction currents succeed each other, produce highly unpleasant effects on the nerves of common sensation, without acting upon the nerve of special sense. A specific response of the auditory nerve may nevertheless be obtained, but only by single closing or opening shocks from an induction apparatus, the opening shocks being the more effective ones. The most convenient form of electricity for acting on the auditory nerve is, however, the continuous current, not only because it is more certain in its effects, but also because the different responses of the nerve on closing the circuit, during the closed circuit, and on opening it, may be separately studied; while the induced current, which has only an instantaneous duration, offers insuperable obstacles to the true appreciation of the phenomena separately. The best mode of experimentation is, to direct one electrode to the external meatus, while the other one is placed to any part of the body. It matters not to which part this latter is directed, for the phenomena observed always remain the same, if only the same electrode is in the external meatus.

The following is the normal reaction of the auditory nerve: at the cathode the nerve responds with sounds on closing the circuit, and during part of the closed circuit; while at the anode the nerve answers only on opening the circuit. If a current of such intensity is used as is proper for physiological and therapeutical experiments, there is no response at the anode when the circuit is closed and while the current continues to circulate, nor at the cathode when it is opened. If the power of the current be increased, the response at the cathode on closing appears first, while the nerve answers somewhat later on opening at the anode; on the other hand, if the power of the current be diminished, the effect at the anode on opening disappears sooner than the one at the cathode on closing.

The response at the cathode, on closing, appears at once in its full intensity, and gradually diminishes as the current continues to act; while the response at the anode on opening is only noticed after the current has acted for a certain length of time; and, if the circuit be opened soon after it has been closed, the response at the anode on opening may sometimes be entirely wanting. If the direction of the current is changed so that the anode is replaced by the cathode, sounds may be produced with a much weaker current, which would not produce any sound at the cathode, on simply closing the circuit; the reason for this being, that after the circuit has been opened at the anode the nerve is in a condition of increased excitability. This condition continues for some time after the opening at the cathode, so that, if the circuit be repeatedly closed at the cathode within a certain period, stronger sounds are produced than at first; or, which amounts to the same thing, a less considerable galvanic power is sufficient to produce the specific response of the nerve, on repeatedly closing at the cathode, than was previously required.

It is, however, not only the variations in the density of the current from its maximum to zero which cause sounds, but a response also occurs in consequence of variations during the continuous passage of the current, and this obeys the same law as above, inasmuch as a variation of increase will cause the effect on closing, if the cathode is in the meatus, and a variation of decrease will produce the response on opening, if the anode is in the meatus.

The degree of response of the auditory nerve is not only caused by the absolute amount of the variations of the current, but also by the distance at which they are from zero; and with a current that is at all effective it will be found that the less powerful the original force of the current was, the slighter may be the variations which will cause a response of the nerve.

The sounds which are caused by the galvanic excitation of the auditory nerve vary in kind and intensity according to the peculiarity of the person experimented upon, and according to the intensity of the current. They are variously described as humming, hissing, rolling, whistling, ringing, etc. The last named sensation is the one most frequently experienced, and when in its full development becomes a clear tone, the pitch of which may be musically determined, and which varies in different individuals. There are many persons who, when the power of the current is increased, perceive a regular scale of auditive sensations, which proceed from 'humming' through all the varieties mentioned above to 'ringing,' and who hear 'sounds' with low power, but 'tones' with high power.

An increase of the strength of the current raises the pitch when the auditory nerve is under the influence of the cathode, and lowers it when the nerve is under the influence of the anode.

M. Brenner's publications have given rise to an animated discussion, which was commenced by Dr. Schwartze,* of Halle, who declared every one of Brenner's statements to be erroneous and utterly devoid of value in a diagnostic, prognostic, and therapeutical point of view. He was answered by Dr. Hagen,† of Leipzig, who confirmed Brenner's statements in almost every particular; and by Brenner himself,‡ who justly contended that Schwartze's 'experiments of control' had been made without any regard to the mode of experimentation recommended by himself, and were therefore worthless. As a curiosity it may be mentioned, that Dr. Sycyanco,§ of Charcow, has, by a series of experiments, been led to the conclusion that the continuous current produces no response of the auditory nerve at all, neither on opening nor on closing the circuit, and neither at the anode nor at the cathode; an assertion which is certainly novel, but hardly requires serious notice.

* Archiv der Ohrenheilkunde, 1865, Bd. i. Heft 1.

† Electro-otiatrische Studien. Leipzig, 1866.

‡ Virchow's Archiv. 1867, Bd. xxxi.

§ Deutsches Archiv etc., von Ziemssen und Zeunker, 1867, Bd. iii. Heft 6.

Time has not yet allowed me to fully examine and repeat all of Brenner's experiments in detail; but from the observations I have made on this subject since the publication of Brenner's treatise, I feel compelled to dispute his statements with regard to the physiological inefficacy of the induced current, while I am inclined to corroborate most of his conclusions as far as the action of the continuous current is concerned.

By the application of electricity to the membrana tympani in the living man two other remarkable phenomena are produced, viz. a slight and unpleasant metallic taste, and a more or less abundant flow of saliva. The former of these phenomena has been noticed by Duchenne,* and Baierlacher;† the latter was discovered by myself in 1858.

The production of the peculiar sensation of taste which is caused by the application of the induced current to the drum of the ear, is due to excitation of the trunk of the chorda tympani, which, after having emerged from the cavity of the tympanum through the fissura Glaseri, descends towards the lingual nerve, in the sheath of which it enters, and then proceeds towards the tongue. Thus it is proved by electro-physiology that the chorda tympani essentially contributes to the perception of taste; and clinical experience has confirmed this

* De l'Électrisation localisée et de son application à la physiologie, la pathologie et la thérapeutique. Paris, 1855, p. 809.

† Die Inductions-Elektricität. Nürnberg, 1857, p. 98.

physiological induction; since in certain cases of paralysis of the portio dura, loss of taste has been observed, together with palsy of the muscles of the face; this loss of taste exists only on the affected side, and usually disappears at the same time with the other symptoms of paralysis of the portio dura. Several cases of this kind have been recorded by Dr. Gull * and others.

A not less remarkable phenomenon is the flow of saliva produced by the application of both the continuous and induced currents to the drum of the ear. My attention was directed to this fact in the following way: having often been requested to try the effects of galvanism on patients suffering from nervous deafness, I noticed that the patients during the operation made movements of deglutition; I then experimented on myself with the view of ascertaining the cause of these movements, and found that, if a current of rather high tension was caused to act upon the chorda tympani, the saliva began to flow more or less abundantly; the effect being more marked with the continuous than with the induced current. It is evident that this is due to electric excitation of those fibres of the chorda tympani which do not proceed towards the tongue with the lingual nerve, but are detached from the principal part of the chorda, and penetrate into the submaxillary ganglion. The saliva, therefore, which is ob-

* A further report on the value of electricity as a remedial agent, in Guy's Hospital Reports, 1852, vol. viii. part i. p. 81.

served to flow when the chorda tympani is galvanised, is secreted in the submaxillary gland.

4. *Organ of Taste.*—That a peculiar sensation of taste is perceived when the tongue is touched by two heterogeneous metals, has been known long before the discovery of galvanism. M. Sulzer* seems to have been the first whose attention was directed to this fact. In a paper which was published by him in the Reports of the Berlin Academy of Sciences, in 1754, the following remarks occur: 'If a piece of lead and a rod of silver be connected with one another, and approached to different parts of the tongue, a sensation of taste is experienced, which resembles that produced by vitriol of iron; while, if we employ either of the metals alone, not the slightest taste is perceived. It is probable that by the connection of the two metals a vibration is produced in the smallest particles, either of the lead or of the silver, or of both; and that this vibration, which must necessarily affect the nerves of the tongue, produces the taste described.' This is in so far interesting, as it is in all probability the first observation ever made on the physiological effects of galvanic electricity.

If a single pair of zinc and silver be applied to the tongue, the zinc being directed to the top, and the

* Recherches sur l'origine des sentimens agréables et désagréables, in Histoire de l'Académie des Sciences et Belles-Lettres de Berlin, 1754, p. 356.

silver to the back, of that organ, a decidedly acid taste is produced under the zinc, and a feebly alkaline taste under the silver plate. These sensations are not only perceived at the commencement and at the cessation of the current, but also as long as the circuit remains closed. The effect is most striking when the tongue is at its ordinary temperature, and when the metals have the same temperature as the tongue. When either the metals, or the tongue, or both, are heated or cooled, as far as can be borne without inconvenience, scarcely any sensation is produced; and whatever has a tendency to blunt the sensibility of the tongue, such as acids, pepper, laudanum, spirits, &c., diminishes the effect of galvanism.

M. Tripier * has directed attention to the circumstance that when the tongue is not in direct communication with the electrodes—as for instance, when one moistened conductor is placed to the right, and the other to the left cheek—the taste is neither acid nor alkaline, but metallic. This taste persists longer after the circuit is opened than is the case when the tongue itself is galvanised, and becomes stronger at the moment of breaking the circuit, which is likewise not the case when the tongue itself is galvanised. I have frequently observed that a metallic taste, such as of copper or iron, is produced when the positive pole of the battery is placed to the sacrum, and the negative to the nape of the neck. The sensation of

* Électrolyse et Résolution; Tribune médicale. Paris. Octobre 1868.

taste gradually increases as the current continues to circulate, becomes very powerful at the moment of breaking the circuit, and generally continues in a modified manner from five to fifteen minutes after the current has ceased to act.

A powerful continuous current applied directly to the tongue, produces not only the specific sensation of taste, but also a flash of light, and pain in, and commotions of, the tongue. The induced current produces only the latter phenomena, but no sensation of taste. Frictional electricity, however, has an action on the tongue which resembles that produced on it by galvanism. Fowler has compared the taste produced by common electric sparks to the taste of vinegar, and that produced by galvanism to the taste of diluted sulphuric acid. Volta found that if a chain was formed of several persons, one touching with his finger the tongue of his next neighbour, and so on, while each of the two who formed the first and last link of the chain took hold of one of the poles of the battery, every person in the chain perceived a distinct sensation of taste. I have often observed that persons who are highly sensitive to the application of electricity, feel the galvanic taste distinctly if the continuous current is applied merely to the arms or legs.

This remarkable influence of electricity upon the tongue has been explained in various ways. Some observers consider that the taste arises from a peculiar condition of the gustatory nerve produced by electricity, just as the retina responds to the galvanic stimulus by a flash of light, and the auditory nerve by sounds. On the other hand, the differences in the taste beneath the two poles seem to point to the conclusion that the effect is due to an electrolytic decomposition of the salts of the saliva; as from chloride of sodium, which is contained in that liquid, chlorine or hydrochloric acid would be evolved at the positive pole, whence the acid taste; and soda at the negative pole, whence the alkaline taste. But it must be objected to this explanation that a current which is so feeble that its positive pole does not even redden litmus paper, yet produces a distinct sensation of taste; while highly diluted acids will redden litmus paper visibly, even if they are so weak that they cannot by taste be distinguished from distilled water. Frictional electricity, which has very feeble chemical properties, yet produces a marked sensation of taste; and Volta has observed that an acid taste was perceived under the zinc pole, even when the mucous membrane of the tongue was in contact with an alkaline solution, by which the acid, which might have been formed, would immediately become neutralised, so as to produce no physiological effect whatever. Another important fact which is opposed to the theory of electrolysis, is one observed by Monro, viz., that the taste is perceived, not only when the metals are directly applied to the tongue, but also when pieces of raw or boiled meat are placed between the electrodes and that organ. Now, if the acids and alkalies deposited by electrolysis on the tongue were really the cause of the taste, this latter ought only to be perceived when the tongue is in direct contact with the electrodes; since it is a well-known fact, that the electrolytic deposition of acids and alkalies does not take place within the electrolyte itself, but merely at the extremities of the metallic electrodes.

Rosenthal,* who has recently investigated this subject, has observed that, if the positive electrode of a galvanic battery is surrounded with a piece of blue litmus paper, which in order to make it conduct has been moistened with distilled water, and placed on the tip of the tongue, the acid appears at first only on that side of the litmus paper which is turned towards the metal, and not on that which touches the tongue; for if the current acts for a short time, a red spot will appear on that side which is turned towards the metal, while there is no change of colour on the opposite side. Nevertheless, the acid taste is perceived immediately on closing the circuit, that is, before the surface of the tongue is in contact with an acid solution.

Rosenthal also made the following experiment:—The poles of a Daniell's battery of from one to four pairs were connected with zinc plates immersed in two small vessels filled with a solution of sulphate of zinc. These vessels were connected by means of syphon-tubes, with two other vessels, one of which

* Ueber den elektrischen Geschmack. Du Bois-Reymond's and Reichert's Archiv. 1860, p. 217.

was filled with a solution of table-salt, and the other with distilled water. A cushion of blotting paper moistened with distilled water, was made to emerge from the latter vessel; and a contrivance was interpolated into the circuit which allowed the experimenter rapidly to change the direction of the current. If now one hand was immersed into the solution of table-salt, and the paper cushion touched with the tip of the tongue, the current could be made to travel either from the tongue to the cushion, or in the opposite direction. A piece of blue and one of red litmus paper were now placed on the cushion, so that both touched the tongue; and it was found that the blue paper remained unchanged, while the red one was rendered slightly blue by the alkaline buccal mucus. This was observed whether the current was direct or inverse, and it was therefore proved that no perceptible quantity, either of acid or alkali, is set free between the tongue and the cushion.

Nevertheless, the sensation of taste was eminently acid when the current moved from the cushion to the tongue, and feebly alkaline when it travelled in the opposite direction.

Rosenthal found that the acid taste is not only more intense, but also more immediately perceived on closing the circuit, while the alkaline taste is more gradually developed as the current continues to act. The acid taste persists a short time after the circuit is broken, while the alkaline taste disappears immediately afterwards. If the direction of the current is suddenly reversed, the alkaline taste yields at once to the acid, while the acid only gradually merges into the alkaline taste.

It appears from these researches that the deposition of free acid or alkali on the surface of the tongue is not a necessary condition for the perception of the sensation of taste. The only objection that might still be raised against this conclusion would be, that Du Bois-Reymond has shown polarisation to take place on the point of contact of two electrolytes; and that therefore acid or alkali might be set free at the end of the tongue or the cushion. But this objection is overruled by Volta's experiment, already mentioned, which shows that the chemical composition of the liquid which is in contact with the tongue has no influence on the perception of taste, since an alkaline liquid has an acid taste when an electric current is made to pass from that liquid to the tongue. Rosenthal has, however, made an experiment to prove that polarisation has nothing to do with the production of the galvanic taste:—One of two persons takes hold of the positive and the other one of the negative pole of the battery, after which they touch each other by the tips of their tongues; the one who holds the negative pole, then perceives the acid, and the other one, who holds the positive pole, perceives the alkaline taste. In this experiment both persons are under similar conditions, except as far as the direction of the current in their tongues is concerned. This is the reverse in each, and both perceive the opposite taste, although one tongue touches the other, and therefore the same capillary layer of liquid covers either tongue. It is therefore evident that the electrolytic theory of the galvanic taste is untenable. The long persistence of the taste after the galvanism has been applied in a peculiar manner (p. 171) is likewise opposed to the electrolytic theory.

Professor Schönbein has suggested another explanation.* He supposes that by the galvanic current air becomes decomposed, and that, at the positive pole, the oxygen and nitrogen combine to form nitric acid, which would produce the acid taste. But Schönbein does not explain the cause of the alkaline taste which is perceived under the negative pole, and it seems almost impossible that the action of a single galvanic pair, or of a few and small electric sparks on air, should form a sufficient quantity of nitric acid to produce a decidedly acid taste. We are therefore led to the conclusion that the galvanic taste is due to a peculiar condition of the gustatory nerves caused by electricity.

IV. ACTION OF THE ELECTRIC CURRENT UPON THE MOTOR NERVES AND MUSCLES.

Experiments in Animals.—If a motor nerve of an animal recently killed be subjected to the action of a continuous galvanic current, contractions of all the

* Ueber einige mittelbare physiologische Wirkungen der atmosphärischen Elektricität. Henle und Pfeufer's Zeitschrift, 1851, Heft iii. p. 385.

muscles animated by this nerve are produced, on closing as well as on opening the circuit, whether the current be direct or inverse. Care must be taken, however, that the electrodes connected with the poles of the battery be placed at two points of the nerve which, although they may be near each other, are at a different height, so that the electric current may traverse the nerve in an oblique direction. If the current were to pass transversely through the nerve, one electrode being applied to the right and the other to the left side of it, at the same point of its transverse section, no contractions would take place.

It was Luigi Galvani,* of Bologna, who first observed, in 1786, that when the nerves and muscles of a frog were connected by means of an arc composed of two different metals, powerful contractions of the muscles took place. Soon after Galvani's discovery had been made known, Volta † found that these contractions also took place if the nerves alone were enclosed in the circuit. In their first experiments, Galvani and Volta noticed only the contraction produced on establishing the circuit; it was another Italian philosopher, Valli,‡ who soon afterwards observed another contraction caused by breaking the circuit. It has lately been asserted by M. Du-

* De viribus electricitatis in motu musculari commentarius. Bologna, 1791. This essay was published five years after Galvani had first made his discovery.

† Collezione dell' opere del Cavaliere Conte Alessandro Volta. Florence, 1816, vol. iv. p. 134.

‡ Reinhold, Geschichte des Galvanismus etc., 1792, p. 25.

méril,* that these observations had been made a long time ago by the Dutch philosopher, Swammerdam, who had shown the experiment to the Grand Duke of Tuscany in 1668. Duméril's assertion has been repeated by Matteucci and Dr. Golding Bird; but a close examination of Swammerdam's experiments shows that the contractions he observed were produced by a mechanical irritation of the nerve, and not by galvanism.

Before we enter more fully into the interesting phenomena brought about by the application of galvanism to the motor nerves and muscles, it is necessary to state that the contractions produced by the entrance and the cessation of the current do not take place in consequence of the motor nerve simply conducting the electric fluid to the muscles; although the nerve is, as we have already seen, a conductor of electricity. But the mere conductivity of the nerves does not explain the physiological effect produced by their electric excitation; for if a wet thread be tightly applied to a nerve so that it becomes thin and reduced to its neurilemma, no contractions can be caused in the muscles animated by it, if the electrodes be applied to the nerve above the point where it has been tied; although by such a proceeding the propagation of electricity is not arrested, since the wet thread conducts equally well as the nerve. Another still more remarkable proof is, that

* Annales des Sciences naturelles, 2e série. Zoologie. Paris, 1840, vol. xiii. p. 65.

a few drops of ether applied to any point of the nerve will suspend the contractions of the muscles, if the electrodes be placed above or at the point where the ether has been applied; the contractions, however, will re-appear as soon as the effects of the ether have passed off. Finally, if the nerves of a frog are galvanised which has been previously poisoned by woorara, not the least contraction occurs in the muscles animated by these nerves; although woorara does in no way affect the electric conductivity of the nerves, which remains perfectly intact; nor the contractile power of the muscles, for they are seen to suffer commotions if the electric current is directly applied to their substance without the intervention of the nerves; it is only because woorara destroys that peculiar force by which the nerves are enabled to produce the play of the muscles. *Hence it results that contractions of the muscles cannot be produced by the galvanic excitation of the motor nerves, unless the nerves be in a state of integrity.* The electric current excites the nerve and rouses its power of producing muscular contractions; it causes a disturbance in the molecular equilibrium of the nerve, whereby this is enabled to cause a shortening of the muscular fibres, attended by an increase in their diameter.

Volta,* whose genius unfolded so many phenomena relating to galvanic electricity, thought the contrac-

* On the electricity excited by the mere contact of conducting substances of different kinds. In a letter to the Right Honourable Sir Joseph Banks. Philosoph. Transactions, 1800, p. 421.

tion produced at the commencement of the current easy to explain, but could not well understand why a similar contraction should take place on breaking the circuit; he erroneously supposed that this second shock was due to a sort of counter-current, produced at the moment when the circuit is broken ('causées par une espèce de reflux du fluide électrique'). Another view was taken by Lehot,* who stated that during the passage of an electric current through a nerve, part of the electricity accumulated in it, and on the interruption of the current discharged itself, traversing the nerve in an opposite direction, and thus giving rise to contraction. Nearly thirty years later Lehot's theory was again taken up by Marianini;† but neither Volta, nor Lehot, nor Marianini have been able to furnish any conclusive proofs in support of their opinions, and we are now able to explain the phenomenon described in a satisfactory way without having recourse to hypotheses unsupported by facts.

We have seen that during the time that a continuous galvanic current traverses a motor nerve, no visible effect takes place in the muscles, providing the current of the battery is constant. It appears, therefore, strange that Matteucci,‡ in a paper on the measurement of the nervous force developed by the

* Gilbert's Annalen der Physik, 1801, vol. ix. p. 188.

† Sur la secousse qu'éprouvent les animaux, etc., in Annales de Chimie et de Physique, par Guy-Lussac et Arago. Paris, 1829, vol. xl. p. 225.

‡ Annales de Chimie et de Physique, 1844, 3e série, vol. xi. p. 403.

electric current, should have asserted that a constant relation existed between the consumption of zinc in the production of electricity, and the mechanical effect produced by the contraction of a frog's leg, the nerve of which was traversed by the current; as it is obvious that we may with the same quantity of zinc in a galvanic circuit obtain *ad libitum* few or an immense number of contractions, in proportion as we make and break the circuit more or less rapidly. Indeed, the visible physiological effect occurs at the moment when the density of the current suddenly rises from zero to a certain height, as is the case on establishing the circuit; and, on the other hand, when the density of the current descends again from a certain height to zero, as is the case on breaking the circuit. Proceeding from these facts, Du Bois-Reymond* has established an electro-physiological law for the motor nerves, which he has proposed in the following terms:—'The motor nerve is not excited by the absolute amount of the density of the current, but merely by the variations which occur in the density of the current from one instant to the other; and the physiological effect is the greater, the more considerable are the variations of the density of the current; that is, in proportion as they take place more rapidly, or as they are more considerable in a given space of time.' This affords a striking analogy to the development of induction currents in coils of

* Untersuchungen über thierische Elektricität. Berlin, 1848, vol. i. p. 258.

wires connected with the poles of a battery; since induction currents are only produced on making and breaking the circuit of the battery, but not while the circuit remains closed.

By Du Bois-Reymond's law it is easy to explain a number of phenomena which had been observed a long time ago. Thus, it is not absolutely necessary for producing contractions, that the current traversing a nerve should be closed or opened, as thereby only the *maximum* of variation is produced. Physiological effects may likewise be caused by minor variations in the density of the current; for instance, if the power of the current traversing a motor nerve be suddenly increased; or if another current be suddenly brought to bear upon a nerve traversed by a continuous current; or if a portion of the current passing through a nerve be suddenly diverted, as may be done in the following way:—the legs of a frog which has been skinned and prepared as usual, are immersed in two separate vessels filled with water, and connected with the poles of the battery; the two vessels are then suddenly connected by means of an arc of copper or silver wire; by this wire a portion of the current is withdrawn, and a contraction is immediately produced. Variations of this kind are however not so considerable, and the physiological effect therefore is not so striking, as that observed on closing or opening the circuit.

It also easy to understand from Du Bois-Reymond's law the action of an induced current upon the motor nerves and muscles. Induction currents are instantaneous, they consist only of great and sudden variations, which succeed each other more or less rapidly, in consequence of the commencement and the cessation of the current of the battery, and the magnetisation and demagnetisation of the soft iron. A single induction shock has the same effect as the opening or closing of the circuit of the battery; contractions appear in consequence of the disturbance of the molecular equilibrium of the nerve; but the muscles relax immediately afterwards. But when the induction currents succeed each other rapidly, the contractions caused by them likewise occur in rapid succession, and the muscles relax less and less the more rapidly the shocks be given. With a certain rapidity of the shocks, the contraction appears continuous, as if produced by the will; but this apparently continuous contraction consists only of a very rapid succession of single contractions, the intervals between which are too short to be distinguished. The induction apparatus which I usually employ can furnish 120 currents in a second; so that if it be applied to a muscle, 120 single contractions may be produced in a second, and 7200 in a minute.

Du Bois-Reymond's law was for some time believed to be the absolutely correct expression of these conditions, but more recent researches of Pflüger, Von Bezold, and others, have caused certain modifications of the same to be adopted.

Pflüger * has shown that, although excitation depends chiefly on the variations of the density of the current traversing a nerve, yet even a feeble and perfectly constant current may, under certain circumstances, prove an excitant. The nerve is, according to him, excited as soon as any external force changes, with a certain rapidity, the molecular condition of the nerve, whereas a stationary condition of the same is incompatible with excitation.

Von Bezold † has followed up Pflüger's investigations, and arrived at the following conclusions: A constant continuous current which traverses a nerve may, as long as it flows in the same direction, cause the molecular process of excitation. Where the variations in the density of the current are *positive,* and the current is perfectly constant, excitation is produced only in the neighbourhood of the *negative* electrode; but the nerve or muscle in the neighbourhood of the positive pole is only excited, if at all, by the propagation of the excitation produced at the negative pole. Again, when the variations in the density of the current are *negative,* or on closing the galvanic current traversing the nerves or muscles, excitation only takes place proximately in the neighbourhood of the *positive* electrode; and those transverse sections of muscles and nerves which are in the neighbourhood of the negative electrode are only

* Untersuchungen über die Physiologie des Electrotonus. Berlin, 1859.

† Untersuchungen über die electrische Erregung der Nerven und Muskeln. Leipzig, 1861.

excited, if at all, by the propagation of the excitation produced near the positive pole.

Finally, if the power of the continuous current, the closing or opening of which serves as stimulant, is below a certain standard, the molecular process of excitation in nervous and muscular fibres does not follow immediately upon the positive or negative variation in the density of the current, corresponding to its closing or opening; but a certain space of time elapses before the process of excitation commences, the length of time thus intervening being inversely proportional to the intensity of the current employed. The motor nerve is therefore, according to Von Bezold, not excited by variations which occur in the density of the current from one instant to another; but on closing the circuit the effect is produced by the continuous current traversing the organs in a perfectly constant manner; and on opening the circuit, the same takes place in consequence of the disturbances of molecular equilibrium in these organs, which persist for some time after the circuit has been opened.

Von Bezold is, by these results of his investigations, led to the conclusion that, as far as the continuous galvanic current is concerned, its exciting effect is in reality due to its chemical action upon the nerves and muscles, and that galvanisation of the nerves and muscles acts by inducing chemical changes in the same. The induced current stands, according to the same observer, in a totally different position, and has more complicated effects. Each single shock from an induction machine is composed of at least three different acts which have to be separately considered; viz. the rise, the constant flow, and the fall of the density of the current.

A. Fick* has made some ingenious experiments on the effects of the continuous current upon the sphincter of the fresh-water mussel. He found that, generally speaking, variations in the density of the current stimulate the sphincter of the mussel in the same manner as the frog's muscles; it is, however, in this case necessary that the rapidity of the variation should not fall below a certain standard. If the sphincter of the fresh-water mussel is very gradually subjected to, or withdrawn from, the influence of the current, no contractions are perceived. Moreover the electric condition must have a certain duration, the length of which should be inversely proportional to the intensity of the current used; that is, where the current is very weak it must act longer, while with a strong current less time is required.

Influence of intensity and direction.—If a feeble continuous current be applied to a nerve, the nerve may retain its excitability very long, and will not be destroyed, as is done by mechanical and chemical stimuli. But if the current be of some power; if, instead of a single pair, a pile be applied; the nerve

* Beiträge zur vergleichenden Physiologie der irritabeln Substanzen. Braunschweig, 1863.

is cauterised by the chemical action of the pile, especially at the point where the negative pole has touched the nerve, for by the electrolysis of the saline solution contained in the nerve, caustic alkali is set free at the negative pole.

No physiological effect whatever is produced if a nerve to which a powerful continuous current has been applied, be afterwards again subjected to the action of a feeble continuous current or an induced current, above or at the point to which the negative pole has been directed; but if the same nerve be excited at a point nearer to the muscle and beneath the negative pole, the muscles animated by it may again be caused to contract. A wire rendered incandescent by voltaic electricity will destroy the nerve by heat. Induction currents of ordinary power have no such destructive effects; but an induced current of very high tension, or powerful shocks of static electricity, may annihilate the vitality of the nerve by the mere force of the concussion.

The phenomena produced by the electric excitation of motor nerves also present certain differences according to the *direction* of the current. This was first pointed out by Pfaff.* For observing these differences, however, it is necessary to employ a feeble current, as furnished by a single galvanic pair. It is then noticed that when the nerves are in the highest degree of excitability, as is the case immediately after death, and when they have not yet been

* Ueber thierische Electricität und Reizbarkeit. Leipzig, 1795, p. 74.

subjected to the action of the galvanic current, the contractions are equally powerful on using the direct or the inverse current, and on closing and opening the circuit. But if the nerves have lost some of their excitability, as is the case a certain time after death, and when they have been somewhat exhausted by the application of electricity, a difference may be noticed in the physiological effect. It is then seen that, if a direct or downward current be applied to a nerve, the contraction is produced only at the moment when the circuit is established, but not while the current continues to traverse the nerve, nor at the moment when it ceases to pass; and, on the other hand, if an inverse or upward current be sent through the nerve, there are no contractions at the commencement of the current, nor while the circuit remains closed, but only at the moment when it is broken. If a frog prepared in Galvani's fashion is used, and the two legs are immersed in two vessels filled with water and connected separately with the poles of the battery, contractions will no longer take place in both limbs at the same time, as was the case immediately after the death of the animal; but a contraction is observed on *making* the circuit in that leg in which the current is direct or downwards, and on *breaking* the circuit in the other leg in which the current is inverse or upwards. If the period elapsed after the death of the animal be still greater, or if the nerves have for a considerable time been subjected to the action of the galvanic current, only one contraction will occur, viz. that produced by making the direct circuit; and finally, all contractility will disappear. These differences in the contractile power of the muscles were first investigated by M. Nobili,* of Reggio, who has distinguished five different periods of the excitability of the muscles, the first of which is, where, by the direct as well as by the inverse current, contractions are produced both at the commencement and at the cessation of the current; the last, where neither by the direct nor by the inverse current contractions are to be perceived, whether the circuit may be opened or broken.

The following table may serve to illustrate

Nobili's Law of Contractions.

	Direct Current		Inverse Current	
	Making	Breaking	Making	Breaking
I.	Contraction	Contraction	Contraction	Contraction
II.	Strong contract.	Feeble contract.	...	Strong contract.
III.	Strong contract.	...	...	Strong contract.
IV.	Contraction	...	...	...
V.	...	...	...	...

It is very probable that these differences depend upon certain changes which occur in the current proper of the nerves after their separation from the animal body. But Nobili's law is not invariable;

* Memorie ed Osservazioni edite ed inedite del cavaliere Leopoldo Nobili, Florence, 1834, vol. i. p. 135; and Annales de Chimie et de Physique, mai 1830, vol. xliv. p. 60.

for in some instances just the contrary will happen, viz. a strong contraction on breaking the direct and on making the inverse current. These exceptions, which, it is true, are of rare occurrence, are probably to be accounted for by certain differences which exist in the nutrition of the nerves and muscles, and by the different way in which these parts have been treated after death. It is a curious fact that two and even three of these different periods of excitability of the muscles may exist in the same nerve at the same time, provided that the nerve be excited at different points of its length. This depends upon the circumstance that the nerves, when they have been separated from their centres, die in a direction from the centre to the periphery, as was first pointed out by Valli and Ritter. The vital energy will, therefore, continue longest in the terminal branches of a nerve. Thus contractions may occur both at the commencement and at the cessation of the current, whatever may be its direction, if the intra-muscular branches of the nerve be excited; but if the nerve be galvanised nearer to the centre, only two contractions may appear, viz. on making the direct and on breaking the inverse; while if the nerve current is applied close to the spinal cord, a contraction is caused only on making the direct current. From this it may be inferred that the manifold differences noticed in the electro-muscular contractions have not that important physiological bearing which had been attributed to them by previous observers. It is quite true that there are different periods of excitability in the nerves after they have been separated from the animal body. But these do never occur in the living nerves, so long as they are connected with the nervous centres; they are merely the result of the fatigue of the nerves which necessarily occurs a certain time after their separation from the animal body; and after they have been repeatedly subjected to the action of the galvanic current.

Pflüger was led by his researches to the establishment of a different law of contractions, which has superseded Nobili's law. It is as follows:—

Strength of Current	Direct Current	Inverse Current
Feeble	Making: contraction	Making: contraction
	Breaking: rest	Breaking: rest
Medium	Making: contraction	Making: contraction
	Breaking: contraction	Breaking: contraction
Strong	Making: contraction	Making: rest
	Breaking: rest	Breaking: contraction

Before we leave this subject, it is necessary to mention the experiments which have been made by Messrs. Longet and Matteucci,* in order to determine if different physiological effects would be brought about by the application of galvanism to the motor and the mixed nerves; that is, the pure motor nerves,

* Annales de Chimie et de Physique, 3e série. Paris, 1844, vol. xii. p. 574.

before they have received sensitive fibres from the posterior roots, or the motor nerves after sensitive fibres have been associated with them. They say that if the anterior roots were galvanised, contractions were produced on making the inverse current and on breaking the direct, while the contrary was observed if the mixed nerves were subjected to the action of the current; viz. contractions on making the direct, and on breaking the inverse current. Hence they concluded that it might be possible to tell the nature of nerves, whether mixed or purely motor, by merely applying to them a continuous current, and noticing the physiological effect produced by it. These results have, however, not been confirmed by the recent and more exact researches of Claude Bernard and Rousseau,* so that the assertions of Messrs. Longet and Matteucci deserve a place only in the history of physiological science.

Effects on Living Nerves.—When the motor nerves are in their normal connection with the nervous centres, the application of galvanism produces somewhat different effects from those which are observed in nerves separated from the body of the animal. It was first pointed out by Valentin and Bernard, that if a nerve was galvanised while still connected with the spinal cord of the living animal—that is to say, in its normal physiological condition—

* Leçons sur la Physiologie et la Pathologie du Système nerveux, par M. Claude Bernard. Paris, 1858, vol. i. p. 167.

a contraction was produced *only on establishing the circuit*, whatever might be the direction of the current. But if the nerve was fatigued by any cause, as for instance, by the prolonged and energetic action of the galvanic current, or by the action of heat during summer, or if the nerve was ligatured or divided above the point touched by the electrodes, two contractions were produced, one at the commencement and another at the cessation of the current. These two contractions are, therefore, an indication of a fatigued state of the nerve. If the fatigue becomes greater, contractions are only produced on making the direct and breaking the inverse current; finally, only a single contraction is obtained on making the direct current. These four different periods succeed each other much more rapidly in summer than in winter, as cold weather is favourable to the continuance of the excitability of the nerve.

Effects on the Living Nerves of Man.—If in a healthy man a feeble or moderately powerful continuous current is made to act on a motor nerve, *there is only a contraction on establishing the circuit*, whatever may be the direction of the current, and whether the closing and opening is effected with the positive or the negative pole. *At the cessation of the current there is no contraction at all.* The negative pole is, however, in so far more effective than the positive, that, if the negative is applied to the nerve, and the positive to the muscle, a contraction on closing will be produced by less galvanic power than if the position of the poles is reversed.

Galvano-tonic Contractions.—If the power of the current used is very high, tonic contractions may be observed during the whole time the circuit is closed, and also on opening it. These contractions have by Remak* been described as *galvano-tonic contractions.* He observed that if a very powerful current was sent through certain nerve-trunks, tonic contractions were apt to occur in the antagonistic muscles. Thus, for instance, when he acted upon his own median nerve, he felt tingling in all the parts animated by branches of the median nerve, and observed a contraction, which gradually increased, in the extensors of the wrist and of the fingers. The hand was raised to an angle of about 45°, and the fingers were extended. This contraction continued as long as the current of the battery circulated in the median nerve, but the hand immediately dropped on breaking the circuit. He states that he was able to resist the involuntary extension of the hand while the circuit was closed, since he preserved the full force of volition over the muscles animated by the median nerve; but as soon as he ceased to resist, the extension of the wrist and the fingers was again produced. The same took place if he sent a continuous current through the trunk of the radial nerve, by placing one electrode to

* Galvanotherapie der Nerven- und Muskelkrankheiten. Berlin, 1858, p. 56.

the point between biceps and triceps, where the radial nerve is accessible, and the other electrode on the back of the fore-arm, where the inter-osseous nerve is superficial. He then perceived tonic contractions of the muscles animated by the median and ulnar nerves, that is to say, flexion of the hand and the fingers. He termed these contractions galvano-tonic contractions in order to distinguish them from the clonic contractions which are caused in the muscles by the induced current or a rapidly interrupted continuous current; and he believes them to be due to variations in the density of the current, inasmuch as the resistance in the circuit varies as the current continues to circulate. In order to produce galvano-tonic contractions, a current of great power is necessary. Usually this current causes much pain, and in some instances the pain may be severe even if no galvano-tonic contractions take place; while in other instances less pain may be experienced, and the contractions be well marked. If a somewhat considerable length of the nervous trunk be traversed by the current, the contractions are more easily produced than if only a small portion of the nerve is acted upon. In some cases it is sufficient to employ from twenty to thirty plates of Daniell's battery charged with acid; in other instances, however, fifty are necessary. Besides, in the same individual the phenomena may be different on different days; so that at first contractions occur in the muscles animated by branches of the nerve which is traversed by the current, while at another time the antagonistic muscles are affected; sometimes even a struggle may be observed between the different groups of muscles, so that at first there is flexion, and some time afterwards extension, while the current continues to traverse the same nerve. In Remak's opinion these contractions are not produced by direct excitation of the nerves, but are reflex movements, caused by the propagation of the galvanic current to the nervous centres. It is however most probable that these incongruous phenomena observed by Remak are due to galvanic ill-usage of the nerves and muscles.

The circumstance whether the circuit is closed in the battery after the electrodes have been placed in contact with the nerves and muscles, or whether it is closed by directing electrodes already traversed by the current to the nerves and muscles, does not appear to cause any differences in the physiological effects of the current.

A phenomenon which is invariably observed when the continuous current is applied to the nerves and muscles of the living man, is that the power of the contraction produced on closing the circuit gradually increases, while if the induced current be used, the extent of the contractions remains the same. Benedict,* who alludes to this increase of galvano-muscular contractions during the application of the continuous current, ascribes it to an increase of nervous excitability in consequence of the applica-

* Electrotherapie. Wien, 1868, p. 32.

tion of the galvanism. But this only partially explains the circumstances of the case, the chief cause of the phenomenon being, in my opinion, that by the application of the current the resistance of the skin is considerably diminished.

Soon after the current has been made to act, the skin is seen to assume a pinkish hue, in consequence of the dilatation of the blood-vessels of the corium; and as the blood is the chief conducting medium of the human body, an increased quantity of it in any organ must of course improve the electric conductivity of that organ. The induced current, which, if applied in moderate power and by moistened conductors, has no influence on the blood-vessels of the skin, produces therefore generally the same effects at the commencement and at the end of the operation; but a continuous current, which at first may produce hardly any contractions at all, generally causes extensive contractions after the circuit has been made and broken ten or twenty times, or after the electrodes have remained fixed for half-a-minute or a minute on those points of the skin which correspond to the motor nerves.

The galvano-muscular contractions are much more marked if a portion of the nervous centres is included in the circuit, than if merely the motor nerve and muscle be acted upon. Thus, for instance, a current which, if applied from the peronæal nerve down to the foot, will not produce any contractions, does so if one pole is placed to the lumbar portion of the spine;

and even more so if one pole is placed to the cervical portion of the spine, or to the head. If an inverse current is directed from the nerve to the spine, contractions are only observed on opening the circuit.

Effects of the Closed Circuit.—The first who directed his attention to the question whether any physiological effects are produced during the time that a closed continuous current traverses a nerve was Ritter,* who observed that if a frog's leg be traversed for a certain time, say half an hour, by a direct continuous current, it did no longer exhibit any contractions, if the current was interrupted and afterwards established and broken again; but that it suffered a commotion if an inverse current was applied to the nerve; this commotion being feeble on making the circuit and strong on breaking it. If now an inverse current was made to act upon a leg, its excitability appeared to be increased. Hence Ritter concluded that the direct current exercised a paralysing action on the nerve, while the inverse current was apt to augment its irritability.

Ritter also discovered that, when a nerve has for some time been traversed by a continuous galvanic current, the muscles animated by this nerve pass at once into strong tetanic contractions when the circuit

* Beweis dass ein selbstständiger Galvanismus etc. Weimar, 1798, p. 119.

is opened.* A direct current does not give rise to this tetanus, nor does the inverse current do so unless it has acted for a sufficient length of time. This phenomenon is called 'Ritter's tetanus.'

Three years afterwards Volta made some experiments to determine the effect of the closed circuit upon the motor nerves.† While Ritter had operated with a single galvanic pair, Volta employed the stronger current of the pile, and therefore obtained different results, which may be described as follows: Both the direct and inverse current exercise a paralysing action when they have traversed the nerve for a certain length of time. When the nerve has for some time been subjected to the action of a direct current, the frog's limb no longer responds to the same; but it may be convulsed anew if an inverse current be substituted for the direct, and *vice versâ.* This may be repeated several times, and we may thus annihilate and revive *ad libitum* the readiness of the muscles to respond to the galvanic current. The succession of phenomena just described has been designated by the name of *Voltaic alternatives*; but to Ritter the merit is due of having first proved that the closed circuit has a distinct action upon the motor nerve.

In 1834, Volta's researches upon the action of the closed circuit were repeated by Marianini,‡ who

* Beiträge etc. 1800, vol. x. p. 142.

† Collezione dell' opere, etc., vol. ii. p. 219, *note* (a).

‡ Annales de Chimie et de Physique, vol. lvi. p. 387. Paris, 1834.

operated with a pile consisting of sixty pairs of plates, and confirmed Volta's results. Nobili * endeavoured to explain these phenomena in the following way:—He assumed three different states in the nerve—*a.* the natural state; *b.* the state of direct alteration, brought about by a prolonged action of a direct continuous current; and *c.* the state of inverse alteration produced by the passage of the inverse current. He thought it necessary for the production of contractions, that there should be a sudden transition in the nerve from one state to the other; and believed that by the prolonged action of a continuous current, whatever might be its direction, the nerve was rendered incapable of transmitting the action of a current moving in the same direction: but that it would regain this property if it were allowed to rest for some time, or if it were acted upon by a current guided in a contrary direction.

Rosenthal,† who has investigated this subject very carefully, has come to the conclusion that if the continuous current traverses a motor nerve for a certain length of time, it causes a peculiar condition in the same in which its excitability is *increased* to the opening of the acting current, and the closing of one flowing in an opposite direction; and *diminished* to the closing of the acting and the opening of the opposite current.

* Ibid., vol. xliv. p. 60.

† Monatsberichte der Berliner Akademie. December 1857, p. 640.

Inhibitory effects.—That a continuous current may under certain circumstances soothe an irritated condition of a nerve, had already been observed by Nobili,* who remarked now and then in the course of his experiments, that prepared frogs were affected by violent tetanus without any apparent cause, and again became quiet if a continuous current was sent through their limbs in a certain direction, while the tetanus continued if the current moved in the contrary direction. (Nobili does not state in which direction.) Matteucci † afterwards observed that when frogs, tetanised by strychnia, were subjected to the action of a continuous galvanic current, the tetanus disappeared rapidly, and did not return ; the frogs died from the effects of the poison, but without the convulsions which are otherwise the consequence of the absorption of strychnia. With regard to the direction of the current, he stated that tetanus was arrested by the passage of the inverse and increased by that of the direct current. Together with M. Farina he endeavoured to utilise this effect of the continuous current in a patient who suffered from traumatic tetanus in consequence of having been shot through the leg. He caused a current of from thirty to forty pairs of plates to pass along the spinal cord in the direction from the sacrum to the nape of the neck, and introduced the patient gradually into the circuit in order to avoid muscular commotions.

* Memorie etc., p. 91.

† Comptes rendus etc., mai 1838, vol. vi. p. 680.

The lockjaw was relieved for a time, circulation and respiration were re-established, and the patient appeared generally comforted, but died nevertheless afterwards, the irritation having been kept up by foreign bodies in the wounded limb.

Another instance of this has been mentioned by Du Bois-Reymond,* who remarked that in a tetanised frog's limb the gastrocnemius muscle became quiet as soon as the sciatic nerve was laid upon the tendon of the muscle; that is, if the *inverse* current proper of the muscle was made to pass through the nerve; but that the tetanus continued unchanged if the nerve touched the flesh of the muscle, that is, if the *direct* current proper of the muscle traversed the nerve.

Further researches bearing upon this question were undertaken by Professor Eckhard,† of Giessen, who was led to the conclusion that if a continuous current of a certain intensity and direction was made to pass through a nerve, the excitability of this nerve was so much diminished that any mechanical, chemical, or electrical stimuli which would otherwise cause contractions of the muscle, no longer induced any when the galvanic current continued to traverse the nerve; but that as soon as the circuit had been opened contractions again appeared if the nerve was excited.

In order to ascertain the differences in the action

* Untersuchungen etc., vol. i. p. 384.

† Beiträge etc., p. 25.

of a direct and of an inverse current, M. Eckhard made three series of experiments.

a. He placed the positive electrode at a certain point of the nerve, and the negative lower down; he then tetanised the muscles by applying salt water to the nerve, at a point *between* the two electrodes. As soon as the electrodes had been connected with the poles of the battery, that is, when a direct continuous current traversed the nerve, the tetanus was arrested; but when the circuit was opened, the tetanic convulsions re-appeared. This inhibitory effect was more striking if, instead of the direct, the inverse current traversed the nerve.

b. The continuous current was made to pass through a motor nerve, as above, and afterwards a stimulus applied, not between, but *above* the electrodes. The result was the same as in *a*; both the direct and the inverse current exercised an inhibitory influence, but that of the inverse was stronger than that of the direct. If, instead of a mechanical or chemical stimulus, an induced current was used for exciting the nerve, the inhibitory effect was strongest, if both the continuous and the induced current were inverse.

c. An inverse continuous current was sent through a nerve, and the stimulus no longer applied between or above, but *beneath* the electrodes; the inhibitory effect was again observed, whether a salt solution or the induced current were used as excitants. A direct continuous current was then made to pass through the nerve, and the curious fact elicited that in this instance the continuous current did not only exercise no inhibitory effect at all, but that, on the contrary, the excitability of the nerve was increased by its passage. Tetanus, caused by the application of a salt solution to a nerve, became much stronger as soon as the electrodes of a direct continuous current were placed above the excited point; and if a nerve had been immersed in salt water, and the tetanus had not yet made its appearance, it came on immediately after the circuit had been established in the way described. If two shocks of an induction apparatus were applied to the nerve, one before making the circuit, and another one after it had been established, the contraction produced by the second shock was stronger than that by the first. Hence Eckhard concluded that an inverse continuous current of a certain intensity, when traversing a motor nerve, would enfeeble its excitability altogether, whatever might be the point of the nerve to which the stimulus was applied, and whatever might be the nature of the stimulus itself; while a direct continuous current, when passing through a motor nerve would diminish its excitability only at those points to which the electrodes themselves were applied, and at all points beyond the positive pole; but that it tended to increase the excitability of the nerve on all those points which were beneath the negative pole.

Pflüger * has shown that Eckhard's method of

* Ueber das Hemmungs-Nervensystem etc., p. 3.

experimentation is liable to give rise to errors, inasmuch as he quite omitted to take into consideration the intensity of the continuous current used, which is of great influence in these conditions. Pflüger's more careful experiments have led to the following results:—

a. If a motor nerve be excited above an *inverse* continuous current which is not very powerful, the contraction is not in the least diminished, as Eckhard has asserted; but a diminution takes place by the influence of a *direct* current of the same strength. If the power of the current goes beyond a certain degree, the contrary is observed.

b. Eckhard's assertion that the excitability of a nerve subjected to the influence of an inverse continuous current is everywhere diminished, is incorrect; for if the power of the current does not go beyond a certain degree, the contraction obtained by exciting a portion of a nerve situated above the electrodes is not in the least enfeebled, but on the contrary increased. If, however, the current is one of very high power, the reverse occurs, viz. enfeebled contraction.

Restorative Effects.—Heidenhain has discovered that if the muscles of a frog had lost their excitability in consequence of fatigue or ill-usage, but were not quite dead yet, their excitability could be restored by directing to their substance a somewhat powerful continuous current for half-a-minute or more; and that the inverse current was more effective than the direct. Remak first noticed that in the living man the continuous current may increase the excitability of both sentient and motor nerves. Thus, for instance, if a feeble induced current is applied to a nerve, and a feeble muscular contraction is caused, the same induced current applied to the same nerve will cause a strong contraction, after a continuous current of twenty or twenty-five cells of Daniell's battery has passed for half-a-minute or more through the nerve and muscle.

On the other hand, the excitability of the nerves and muscles may be diminished, if the stimulation is too powerful or too long repeated. If a muscle has been caused to contract for a short time and in a moderate manner, the intensity of the current proper of the muscle does not appear to be diminished; but if powerful contractions have taken place for a considerable time, the deflection of the magnetised needle appears less than it was before, showing a weakening of the muscular current. M. Brown-Séquard * has shown that if a powerful induced current was applied for half-an-hour consecutively to the hind leg of a rabbit, and the animal was then killed, rigor mortis and putrefaction appeared much more rapidly in the limb which had been galvanised than in the others.

Electrotonus.—Pflüger † has shown that a con-

* Gazette médicale de Paris, 1849, p. 881.

† Untersuchungen etc., p. 95.

tinuous galvanic current which traverses a certain length of the nerve, divides this latter into two physiologically different sections or zones, which pass into one another at a point where the condition of the nerve is unchanged (*point of indifference*), and which is situated at an equal distance from either of the poles. One of these sections or zones is placed into a condition of increased excitability (*catelectrotonus*), while the other section is in a condition of diminished excitability (*anelectrotonus*). The zone of increased excitability is in the neighbourhood of the cathode or negative pole, while the zone of diminished excitability is in the neighbourhood of the anode, or positive pole. The condition of increased excitability is propagated from the negative pole towards either side, and the condition of diminished excitability is propagated from the positive pole towards either side. This alteration of excitability in the extra-polar portions of the nerve diminishes in the same ratio as the distance at which they are from the electrodes increases, and at a certain distance it completely disappears. As a rule the positive zone of the nerve diminishes in extent proportionately to the intensity of the current; and if the latter be very feeble, almost the whole portion of the nerve included between the two electrodes may be in a state of increased excitability.

M. Eulenburg,* of Berlin, has investigated these conditions in the living man, and has come to the

* Deutsches Archiv von Ziemssen und Zencker, 1867, Bd. iii. p. 117.

following conclusions :—Certain motor nerves which are easily accessible to the galvanic current, such as the spinal accessory, the median, ulnar, and peronæal nerves, and certain muscles which are easily accessible, such as the deltoid and the opponens pollicis, may be made to assume the electrotonic state during life. He placed the negative electrode of an induction apparatus on the nerve, and the positive electrode on the sternum; after which he sent a direct or inverse continuous current through the nerve above the negative electrode. It was then seen that if the inverse current was used, a negative, and if the direct current was used, a positive modification of excitability took place in that portion of the nerve which was behind the electrodes; and that the extent of the positive and negative modification, and the duration of the subsequent effects, increased in proportion to the power of the current, and the length of time during which the circuit remained closed. As regards the muscles, Eulenburg found that there was a distinct positive modification with catelectrotonus, while the negative modification with anelectrotonus was less perceptible.

M. Samt * has likewise made a series of experiments on this subject, the results of which do not quite agree with those obtained by Eulenburg. According to Samt, this is due to the circumstance that in Eulenburg's experiments the excitability of the nerves is modified, not only by the pressure of

* Centralblatt für die med. Wiss. November 1868.

the electrodes upon the same, but also by the effect of the induced current which is used as a stimulant.

Von Bezold has shown that during electrotonus the power of conduction is diminished, in the an-electrotonic as well as in the catelectrotonic portion of the nerve; and that if the nerve be excited by closing the circuit, more time is required for making the contraction appear than if it be excited by opening the circuit. This is more especially the case if the inverse current be used, and not so much with the direct current. Von Bezold believes that whenever a continuous current enters a nerve, a certain space of time is necessary for preparing the nerve to respond to the current, and that this time of preparation is the shorter the greater is the power of the current. According to the same observer, the conduction is also retarded in the *muscular* fibre during the electrotonic state; but this is exactly limited to the place where the electrodes are applied, and does not extend beyond them, as it does in the nerve.

Electrotonus is only produced by the continuous current, and not by induction currents. It appears probable that this is to some extent the cause of the therapeutical superiority of the continuous over the induced current.

Remak has observed in some cases that if a direct current of from twenty to thirty pairs of Daniell's battery was applied to a motor nerve in the living man there was only pain, while if the inverse current was used there was only contraction. If forty pairs or more were used there were contractions on closing the circuit, both with the direct and the inverse current; and if the so-called 'uni-polar' application was used, that is, if one conductor was placed on the nerve and the other on any other part of the body, the positive electrode corresponded in almost all respects to the direct current, while the negative electrode answered to the inverse current.

Inherent Muscular Irritability.—So much for the remarkable phenomena brought about by the electric excitation of the motor nerves: we now proceed to consider the question whether or not the electric current has any direct and immediate action upon the muscular fibre without the intervention of nervous filaments. Is there a *vis musculosa insita*, a property inherent to the muscular fibre, which is capable of being excited to action independently of the immediate instrumentality of the nerves; or are the nerves the only excitors of muscular motion, and is it always necessary, in order to cause muscular contractions, that the vital energy of the motor nerve animating the muscle should have been previously roused?

It is obvious that it would not be difficult to settle this question, if it were as easy to prepare muscular fibres without nervous matter, as it is to prepare nerves without muscular substance. But even if the greatest care be taken to remove every nervous fibre from the muscular tissue, generally, by means of the microscope, small nervous filaments may be discovered still adhering to the muscular fasciculi. Many physiologists have therefore been of opinion that the question could never be decided, and that irritability belonged in all probability to the compound structure.

Glisson seems to have been the first who used the word irritability. He says: * 'Motiva fibrarum facultas, nisi irritabilis foret, vel perpetuo quiesceret vel perpetuo idem ageret. Actionum igitur earum varietates et differentiæ earundem irritabilitatem clare demonstrant.' But Glisson ascribed an irritability proper to all the tissues, even to the bones and liquids of the human body, while Haller † was the first to point it out as a property inherent to the muscular fibre. He termed irritable part of the human body or muscular fibre that which is shortened if touched by any foreign body; and sensitive or nervous fibre that which, if touched, transmits to the mind the impression of contact, and the irritation of which in animals occasions evident signs of pain and discomfort. According to Haller, sensibility and irritability are properties totally independent of each other. Most tissues are sensitive, and this property is possessed by them in a direct proportion to the quantity of nervous fibres they contain; a part, the nerves of which have been ligatured or divided, has lost its sensibility; parts which are devoid of nervous fibres, such as the dura-mater, the cornea, the tendons,

* Francisci Glissonii Tractatus de Ventriculo et Intestinis. Lugdun. Batavor. 1691, p. 168.

† Elementa Physiologiæ, vol. iv. lib. xi. Lausannæ, 1762.

are not sensitive. But the nerves do not possess the slightest amount of irritability, since they are never put in motion themselves, whatever stimulus may be applied to them. Sensibility is a property which ceases with life. Irritability, on the contrary, is to be observed a certain time after life has become extinct, or after the nerves of a part have been divided; it is by no means so generally diffused in the system as sensibility, as it is possessed merely by the muscles, the intestines, the chylifera, and the arteries. These parts are not sensitive, or, if they are, the property is not inherent to their structure, but merely due to the few nervous fibres which are mixed up with them; and if motion be caused by the instrumentality of the nerves, it is only by their conducting the orders of volition to the muscles, and by strengthening their inherent force. Haller was therefore the first to make a distinction between the *functions* of motion and sensation; he is, in this respect, the precursor of Sir Charles Bell, who pointed out that there are also different *organs* for motion and sensation, viz. the motor and sentient nerves.

Haller supported his opinion especially by reference to the disproportion that exists between the bulk of the nerves and the contractile power of the organs in which they are ramified; thus, for instance, the heart, which has the greatest contractile power of all the muscles of the animal body, has very few and small nerves only. Haller's chief opponent in the last century was a distinguished German physician, Dr. Unzer,* who proved that there are nerves in all muscular organs, and maintained that the nerves are the only excitors of muscular motion; when motion occurs in muscles, the nerves of which have been divided or ligatured, the motion is, according to Unzer, solely due to the fine intra-muscular nervous filaments. Unzer's view, however, was contested by Felice Fontana,† who supported his opinion by an important experiment. He divided the crural nerves of frogs, and observed that, after a certain time, the muscles of the thigh still contracted when a stimulus was applied directly to the muscular substance; but that the muscles remained perfectly quiescent if the nervous trunks were irritated.

After the discovery of galvanism the question was again taken up with much interest. Galvani, Volta, and Valli maintained that muscular contractions were caused by the 'metallic stimulus,' if the muscles alone were touched by the galvanic pair; but others, like Fowler,‡ thought that we should never arrive at a solution of this question, since it would always be impossible to satisfy ourselves whether nerves had not been present in a muscle contracted by electricity.

The same view was taken by Baron Humboldt,§ who maintained that, if a piece of muscular flesh was

* Erste Gründe einer Physiologie. Leipzig, 1771.

† Ricerche filosophiche sopra la Fisica Animale, 1775, vol. i. p. 123.

‡ Experiments and Observations relative to the Influence lately discovered by M. Galvani, and commonly called Animal Electricity. Edinburgh, 1793, p. 64.

§ Versuche über die gereizte Muskel- und Nervenfaser. Posen und Berlin, 1797, vol. i. p. 105.

so prepared that no nervous fibre was visible in it (as may best be done, he says, in the upper part of a frog's thigh, or in the fins of a fish), no contraction was caused by galvanism. If there was a contraction, however, it was easy to distinguish by means of a magnifying glass, traces of nervous filaments, which, in spite of careful dissection, had been left in the muscular substance. He was therefore led to the conclusion that irritability is a property of the compound structure, the nerves receiving the stimulus, and the muscles undergoing contraction.

Fifty years later, the same opinion was given by Marshall Hall,* who thought the question, whether the property of irritability belonged to the pure and isolated muscular fibre, or to the muscular fibre combined with the nerves, could not be determined by direct experiment, and that irritability belonged, probably, to the compound structure.

In 1834, Fontana's experiment, to which I have alluded above, was repeated by M. Sticker under the superintendence of J. Müller, of Berlin.† Sticker found that some weeks after the section of the nerves had been made, neither the nerves nor the muscles responded to the galvanic stimulus. But Longet rightly objected to this, that Sticker had allowed too much time to elapse before he compared the excitability of nerves and muscles. Another objection

* Article 'Irritability,' in Cyclopædia of Anatomy and Physiology, 1847, vol. iii. p. 29.

† Ueber die Veränderungen der Kräfte durchschnittener Nerven. Müller's Archiv. etc., 1834, p. 202.

which, in my opinion, should be made to Sticker, is that in his researches he used only a single galvanic pair to excite the muscles, and that perhaps he might have succeeded in obtaining muscular contractions, if he had used a powerful battery instead.

The experiments of Fontana and Sticker were repeated by Longet,* who took care to examine the nerve during the first few days after the operation. He found that a motor nerve, which has been separated from the nervous centres, loses every trace of excitability on the fourth day after it has been divided; any mechanical, chemical, or electrical stimuli will then fail to produce muscular contractions, if they be applied to the free extremity, or the branches of the nerve; but a muscle, the motor nerve of which has lost its excitability, may still visibly vibrate under the influence of a stimulus, even twelve weeks after the section of the nerve has been made. From this Longet inferred that the motor nerves are not the only excitors of muscular motion, and that muscular irritability is independent of the motor nerves, but depends essentially upon the supply of arterial blood, a condition necessary, not to impart or communicate to the muscles the property in question, but only to maintain in the muscular fibres the nutrition which keeps up the vital properties of all the tissues of the animal body.

Dr. John Reid was led to the same conclusion as

* De l'irritabilité musculaire. Archives générales de Médecine, 3e série. Paris, 1842, vol. xiii. p. 81.

Longet.* He divided the spinal nerves in the lower part of the spinal canal of frogs, so that both hinder extremities were insulated from their nervous connection with the spinal cord. He then daily exercised the muscles of one of the paralysed limbs by a feeble galvanic current, while the muscles of the other limb were allowed to remain quiescent. This was continued for two months, and at the end of that time the muscles of the galvanized limb retained their original size and firmness, and contracted vigorously, while those of the quiescent limb had shrunk to at least one-half of their former bulk, and presented a marked contrast with those of the galvanised limb. But even at the end of two months the muscles of the quiescent limb had not lost their contractility.

Stannius † repeated these experiments, and found that the muscles retained their irritability six months after the nerves had been divided, while the nerves had lost their excitability much earlier. The muscles which did not contract on irritation of the nerves, responded readily to the electric current applied directly to their tissue. But Stannius himself suggested that this was no conclusive proof for the existence of Hallerian irritability, since the nerves die in a direction from the centre to the periphery (law of Valli and Ritter), and that therefore, while the trunks of the nerves had lost their excitability, yet the fine

* Edinburgh Monthly Journal of Medical Science. May 1842, p. 327.

† Untersuchungen über Muskelreizbarkeit. Müller's Archiv., 1847, p. 443.

nervous fibres contained in the muscular tissue might have retained their integrity.

Marianini concluded from his experiments that the muscles may be directly acted upon by the electric current without the intervention of the nerves, and that when a continuous current acts upon the muscles alone, contractions take place only at the moment the circuit is closed. He distinguished two sorts of contractions; viz. *idiopathic* contractions, such as are produced by the direct excitation of the muscles; and *sympathetic* contractions, such as follow the application of the electric current to the motor nerves. But Marianini did not furnish any proofs in support of his opinion.

Matteucci also adopted the view of an irritability proper of the muscles, which he thought was proved by his experiments on the different conductivity of the nerves and muscles. As muscles conduct electricity better than nerves, he believed that no portion of the current could ever traverse the nerves which are mixed up with the muscles, if an electric current is caused to act upon the latter. He incised a muscle of the leg of a rabbit which had been dead so long that every trace of muscular irritability had disappeared, and introduced into it the nerve of a very sensitive galvanoscopic frog. The current of a powerful pile was then sent through the substance of the muscle, by applying the electrodes to different points of it; nevertheless the galvanoscopic frog did not undergo any contractions, in spite of its nerve being enclosed in the muscle, and forming almost an integral part of it. Matteucci's reasoning is no doubt ingenious; but I cannot admit its being conclusive, as the conductivity of a muscle which has lost every trace of excitability is greater than that of a living muscle, and the differences between the conducting power of nerves and muscles are not nearly so considerable as Matteucci imagined.

Thus, after numerous and careful researches, the question still remained *in suspenso*, since the supporters of Hallerian irritability had never attempted to prove a contraction of muscles which had been entirely isolated from all connection with nervous fibres. The first step in this direction was taken by Mr. Bowman,* who adduced the evidence of direct microscopical observations made on living fragments of the elementary fibres of voluntary muscle, which he had entirely insulated from every extraneous substance, whether nerve or vessel. He observed that if by design or accident a particle of foreign matter was included in the field, so as to touch the side of the fibre at a single point, the fibre exhibited a contraction limited to the point touched, and not involving the whole of the muscular substance. Hence he concluded that the muscles possessed an irritability proper, capable of being roused into action by a stimulus topically applied. Dr. Wundt,† of Heidel-

* Article 'Muscular Motion,' in Cyclopædia of Anatomy and Physiology, vol. iii. p. 519.

† Die Lehre von der Muskelbewegung. Braunschweig, 1858, p. 122.

berg, has likewise made some microscopic observations, which are in favour of an irritability proper of the muscles. He observed that when the circuit of a galvanic battery was closed in the muscular tissue, the fibres were shortened, and that, after the contraction produced by the commencement of the current had passed off, the fibres did not immediately regain their previous appearance, but remained for several minutes somewhat shorter than they had been before. If the circuit was opened, there was a difference, according to whether a contraction was produced or not. If there was no contraction at the cessation of the current, the muscular fibres suddenly regained their previous length, and if there was a contraction, the fibre appeared to be even longer than before, after the contraction had passed off. None of these phenomena, however, were observed, if instead of the muscular fibres the nerves were enclosed in the circuit.

Another way by which it is possible to arrive at a satisfactory conclusion, was first pointed out by Harless.* He supposed sulphuric ether to be a substance which would paralyse the nerves by dissolving the fat contained in them, but would not interfere with the muscular tissue. For proving this he made the following experiments:—He produced anæsthesia in rabbits; laid bare the brain and the spinal cord, and applied to them the electrodes of an induction apparatus. The muscles remained tranquil, under

* Müller's Archiv., 1847, p. 228.

these circumstances, but contracted powerfully as soon as the electric current was applied directly to their substance. Similar experiments, however, which were undertaken by Stannius,* did not yield the same results, and it remained doubtful if the terminal branches of the nerves had been really paralysed by the ether.

Such was the state of the question when Claude Bernard first undertook his experimental researches on the physiological action of the woorara poison.† He took two frogs, and poisoned one of them by inserting under its skin a small piece of woorara. When, at the end of five or six minutes, the frog had ceased to show signs of life, the poison was withdrawn. A galvanic current was then caused to traverse a portion of the lumbar nerve of each of the frogs successively. The muscles of the frog which had *not* been poisoned were immediately seen to suffer a powerful contraction, but not the slightest twitching occurred in the other frog which had been poisoned. On the other hand, when the poles of the battery were directly applied to the muscles, both frogs suffered commotions, and it even appeared that the poisoned frog preserved the property of suffering contractions for a longer time than the one which had not been poisoned.

Thus the existence of an irritability proper of the muscles appeared to be proved; but the old objec-

* Müller's Archiv., 1847, p. 443.

† Comptes rendus, 1850, vol. xxxi. p. 533.

tion was once more raised by Eckhard,* that paralysis of the intra-muscular nerves had not been proved. Eckhard concluded from his own experiments on the influence of a closed circuit upon the excitability of the motor nerves, that the muscles are devoid of an irritability proper; and maintained that, if there was such irritability a continuous current which inhibits the action of a motor nerve, would not be able to prevent the contraction of a muscle animated by this nerve, if a stimulus were applied to the muscular substance. But when he applied a stimulus to a muscle, the nerve of which was under the inhibitory influence of the continuous current, he perceived that the contraction was diminished, or that there was no contraction at all. Hence he concluded that the only excitors of muscular motion are the nerves.

But it is obvious that Eckhard's reasoning is not conclusive. If an electric current applied to a muscle produces contractions, this is due to the excitation of both the muscles and the intra-muscular nerves; and if by a continuous current the action of the nervous fibres is inhibited, one element causing the contraction will be lost, and therefore, of course, the contraction will be diminished. Bernard† has, however, recently completely refuted the fundamental objection against Hallerian irritability, which has been raised over and over again tince the time of Unzer. He observed that the motor nerves lose their excitability

* Beiträge etc., p. 47.

† Leçons sur la Physiologie, etc. Paris, 1858, vol. i. p. 193.

from the centre to the periphery (law of Valli and Ritter), only in case they have been previously separated from the nervous centres. Thus, when the sciatic nerve has been cut off from its connection with the spinal cord, galvanisation of the trunk of the nerve will, after a certain time, no longer cause contractions of the muscles; but if the branches of the nerve are galvanised nearer to the periphery, contractions will still appear. If, however, the nerve be kept in its normal physiological connection with the cord, it loses its properties in the inverse ratio, namely, from the periphery to the centre. Thus, if the crural nerve of a frog be laid bare, and contractions are no longer produced by galvanisation of the nerve near the muscles, such may still be caused, if the nerve be galvanised near the cord; and if the whole nervous trunk has lost its excitability, the muscle may be made to contract by galvanisation of the anterior root of the nerve. This is the way in which the nerves lose their excitability if animals die from hæmorrhage or from woorara; and the different modes of death of the nerves may be demonstrated in one and the same animal. If the lumbar nerves of the right side of a frog are divided, and the animal be afterwards poisoned by woorara, the nerves lose their excitability in the direction from the centre to the periphery on the *right* side, where there is no longer any connection between the nerves and the spinal cord; and they die in the direction from the periphery to the centre on the *left* side, where that connection is still kept up. Therefore, the terminal branches are the first, and not the last, which are destroyed by woorara: and as, in spite of the destruction of the properties of these nervous fibres, the muscles nevertheless readily respond to the galvanic stimulus, the existence of Hallerian irritability is clearly proved.

Bernard's researches have been confirmed by a series of experiments undertaken by Kölliker* with woorara and coniine: he found the action of coniine nearly equal to that of woorara. I have myself been able to experiment with woorara, a quantity of which I obtained from my friend, Dr. Stamm, on his return from the Brazils, and I can therefore fully corroborate the accuracy of Bernard's and Kölliker's statements. The following experiment shows best that the motor nerves and not the muscles are killed by the poison: the crural artery and veins are closely tied up on one side, so that the circulation of the blood in the limb is arrested; and the animal is then poisoned by inserting a small quantity of woorara under the skin. If the motor nerves are a short time afterwards galvanised, it appears that all the nerves have lost their energy, with the only exception of the crural nerve of that side where the vessels were ligatured; this nerve, when galvanised, produces the play of the muscles as usual. But if the electric stimulus be then directed to the muscular substance itself,

* Physiologische Untersuchungen etc. Virchow's Archiv., vol x. 1856.

contractions may be obtained in *all* the muscles; and the contractile power will last even longer in those muscles from which the nervous influence has been removed than in those where it has been preserved through the stoppage of the circulation of the blood in the nerves.

Von Bezold* found in his experiments with woorara that the contractions of the muscles caused by direct excitation of their fibres, after the nervous influence had been removed from them, commenced as rapidly after the application of the stimulus, and showed the same progress as regards time, as the contractions induced by the same excitants in muscles which had not been poisoned. According to this observer, woorara acts on the intra-muscular nerves, by retarding the propagation and transmission of the excitation from the nerve to the muscle; this retardation increases continually, and at last merges into complete annihilation of the vital properties of the nerve. The same takes place in the nerve-trunks, although there the effect is not so rapidly produced as in the intra-muscular nerves, and larger doses of the poison are necessary for producing it. The maximum diminution of the velocity of propagation in the trunk of the sciatic nerve of the frog was from 26 mètres to 5·5 mètres in the second.

It is therefore evident that the molecular equilibrium of the muscles may be directly disturbed by the electric

* Untersuchungen über die Einwirkung des Pfeilgiftes. Reichert's und Dubois' Archiv. 1860, p. 168.

current, just as well as the molecular equilibrium of the nerves. As soon as the equilibrium of either motor nerves or muscles is disturbed, contractions take place. The contractions produced by applying the electric current directly to the muscular substance, present, however, certain peculiarities which are worth mentioning.

If the current be directed to a motor nerve, the whole substance of all the muscles animated by the nerve enters into contraction; but if the current be directly applied to a muscle, only those fibres are seen to contract which are traversed by the current; and if it is intended to produce a contraction of the whole substance of a muscle, one of the electrodes must be placed on its upper, and the other one on its lower end. Besides, a current of greater intensity is required for producing muscular contractions without the intervention of nervous filaments, than is necessary if contractions are caused by excitation of the motor nerves. *Hence we may conclude that the molecular equilibrium of the nerves is more easily disturbed by the electric current than the molecular equilibrium of the muscles.*

If a muscle is caused to contract by the application of an induced current, the contraction is composed of two elements; viz. of direct excitation of the muscles, and of excitation of the intra-muscular nerves. Muscular contractions will therefore be most easily produced if those points are touched by the electrodes where the motor filaments are easily accessible; but if a sufficiently strong current be employed, contractions will be induced, even if the electrodes are placed on points of the surface of the muscle where dissection does not show the existence of motor fibres.

It was formerly believed that if a continuous current was directly applied to a muscle, a contraction was only produced on closing and opening the circuit; but Wundt, Von Bezold, and Fick have observed that if a continuous current traverses a muscle, contractions take place not only on making and breaking the circuit, but also while the circuit remains closed, and that these contractions increase in proportion to the intensity of the current.

Many interesting facts have been elicited by the application of electricity to the study of the functions of the muscles of the living body; and no observer has been more diligent or happy in his researches on this subject than M. Duchenne (de Boulogne).*

It is true that the deep strata of the muscles, covered by the superficial ones, will not clearly exhibit their contraction. But here pathology has seconded physiology. In progressive muscular atrophy the superficial muscles are destroyed and the impediments to the passage of the electric current cleared away, so that in such cases the function of

* De l'Électrisation localisée, et de son application à la physiologie, la pathologie et la thérapeutique. 1st edition, Paris, 1855; 2nd edition, Paris, 1862.

nearly every muscle in the living body may be ascertained. Many of the theories on the functions of the muscles formerly adopted have thereby fallen to the ground. One of the most interesting facts now established is that the extensor communis digitorum muscle has no influence whatever on the extension of the second and third phalanges of the fingers, but only on the first; that the interossei and lumbricals extend the second and third phalanges, and bend the first; and that the flexor sublimis and profundus muscles bend the second and third phalanges, but not the first. This is proved by many pathological facts which have been observed in cases of lead-palsy and muscular atrophy. In lead-palsy the extensor digitorum is paralysed, but not the lumbricals and interossei. Therefore, in this affection, the power of extension of the second and third phalanges is not interfered with, while the first phalanges cannot be extended. On the other hand, cases occur where the extensor digitorum is quite healthy, yet the hand has assumed the form of a claw, the interosseous spaces are deeply hollowed, the parts are very thin, the first phalanges are extended, but the second and third are bent. This condition of the hand is due to paralysis and atrophy of the lumbricals and interossei, and may generally be cured by the local application of the electric current to the suffering muscles.

M. Duchenne has given special study to the function of the muscles of the face, in order to arrive at a knowledge of the mechanism of physiognomical expressions; for it is only the muscles which are put in action by thoughts, passions, and character; they preserve during rest the predominance of tonic force, and stamp on every physiognomy its peculiar impression. If there were not in every face this tonic predominance of certain muscles, all physiognomies would be nearly alike, as the muscles have the same direction, insertion, and strength, and the bones only differ in bulk. Although the facial muscles have only a very small surface, electricity may be localised in each one singly, so as to produce isolated contractions. A good way to show the part which every muscle plays in the different physiognomical expressions, is to electrify the muscles of the face of a man who has died a short time previously, and whose muscles still retain their excitability; for the living man, when electrified, always mixes involuntary movements with the contraction of the stimulated muscle; which constitutes, of course, an impediment to the observation of the individual action of the muscles. The action of the facial muscles is however shown with the greatest distinctness in patients suffering from anæsthesia of the fifth nerve, where the muscles may be faradised without inflicting the least sensation of pain, and therefore without the production of reflex movements. Cases of this kind are, however, unfortunately for clinical demonstration, very rare.

The following account is given by M. Duchenne of the action of the muscles of the face, as shown by the local application of the induced current:—

The frontal muscle, when slightly contracted, cheers up the face; when more contracted, it expresses doubt or surprise; and when in the highest degree of contraction and united with other muscles, it gives the expression of an agreeable surprise or of terror. It also produces horizontal wrinkles in the forehead, and when it is paralysed, the wrinkles disappear.

The pyramidales nasi, which are in intimate connexion with the frontal muscle, and are therefore considered by many anatomists as identical with it, are nevertheless antagonists of the same; they give a sad expression, and, when more contracted, a threatening one. It forms a striking contrast to see these two opposite movements produced in so small a space as the level of the eyebrows.

Isolated contraction of the orbicularis palpebrarum expresses contempt; that of the corrugator supercilii reflection, and when united to the pyramidalis, malice. The platysma myoides gives an expression of pain; united with the frontal muscle, it expresses terror; and, with the pyramidalis, rage. Contraction of the triangularis nasi gives the expression of lust. The zygomaticus major always expresses mirth, from simple smiling to the most boisterous hilarity; united with the frontalis, it gives the expression of an agreeable surprise; with the platysma myoides, the sardonic laugh: while the zygomaticus minor, on the contrary, gives a melancholy air. The levator alæ nasi, and labii superioris, is the crying muscle of children, and produces an ugly grimace. By the contraction of the external fibres of the orbicularis oris, the lips are protruded, as for kissing and whistling: the internal fibres press the lips against the teeth, as is done by players of the clarionet, for pinching the reed of their instrument between the lips. The levator menti is the only muscle in action in persons who repeat their prayers inaudibly, as is often seen in Catholic churches. The triangularis oris expresses sadness; in children it is the precursor of tears; in the maximum of its contraction it expresses disgust.

The deltoid muscle, when galvanised, abducts the humerus, but does not raise it above the horizontal line. If the anterior fibres only are galvanised, the arm is at once raised, and moved forwards and inwards; if the middle fibres are galvanised, the arm is directed outwards; while, by galvanisation of its posterior fibres, the arm is carried backwards, and the hand raised behind the back. The deltoid muscle is very frequently attacked by wasting palsy.

If the inferior portion of the trapezius be galvanised, the base of the scapula is approached to the spinous processes, and its inferior angle drawn downwards; this portion of the muscle tends by its tonic contractility to keep the base of the shoulder-blade at a distance of about two and a half inches from the median line. If the middle portion of the trapezius be stimulated, the scapula is raised, and its inferior angle removed from the median line. Finally, if the current be applied to the clavicular portion of the trapezius, the head is drawn towards the side acted upon, and a little backwards, so that the chin is turned towards the opposite side; at the same time the clavicle is raised. If the clavicular portions of both trapezii receive the electric stimulus, the head is drawn backwards. The clavicular portion of the trapezius is very excitable, as it receives nervous influence from two sources, viz. from the spinal accessory nerve, and from the cervical plexus.

The latissimus dorsi, when galvanised, draws the arm downwards and backwards; the scapula is at the same time approached to the median line, but it is not raised.

The rhomboid muscle is only accessible to the electric current if the trapezius is destroyed. If it then be galvanised, the scapula is raised; at the same time it is so turned that its inferior angle is placed nearly in the same line with its external angle. The rhomboid, by its tonic contractility, fixes the base of the shoulder-blade against the thorax. If it be destroyed, the base of the scapula is removed from the thorax, and becomes prominent under the skin, so that a cavity is formed between the base of the shoulder-blade and the spine.

The serratus magnus is chiefly inspiratory muscle; it raises the ribs from which it arises; and contributes to lift the humerus. The arm is lifted above the horizontal line by the joint action of the deltoid, the serratus magnus, and the middle fibres of the trapezius. The serratus magnus also contributes to the external angle of the scapula being kept in its normal position; for the weight of the upper extremity tends continually to depress the external angle of the shoulder-blade. Both the trapezius and the serratus are opposed to this depression being effected. If the trapezius be atrophied, the external angle of the scapula is depressed, while at the same time its inferior angle is raised and approached to the spinous processes; if the serratus be also attacked by wasting palsy, the external angle is still more depressed; the inferior angle is raised to the level of the external angle, and it is placed at a considerable distance from the thorax.

Generally the most striking result of electro-muscular contractions is an *increase of heat and bulk* in the parts acted upon.

It had already been noticed by Becquerel and Breschet* that an increase of temperature took place in muscles which had been made to work for some time consecutively. They found that the heat in the biceps of a man who had been sawing wood for five minutes at a time, was 1° C. above the heat noticed previous to it. Helmholtz,† who experimented on frogs, found that the circulation and the heat of the blood had nothing to do with this increase of heat,

* Annales des Sciences naturelles. Zoologie. 2e série, vol. iii. p. 275.
† Müller's Archiv. für Anatomie etc., 1848, p. 144.

but that it was owing solely to the muscular contraction. Dr. Ziemssen,* of Greifswald, however, was the first to make systematic researches on this point, on healthy as well as on paralysed muscles, in the human subject. He used a thermometer on which the twentieth part of 1° C. could be easily read off. The bulb of this thermometer was placed into the sulcus between the extensor digitorum communis and the extensor carpi radialis brevis muscles, and remained in this position twenty minutes before, during the passage of the current, and some time after the current had ceased to act. In some of these experiments the skin was left bare, while in others the skin and the bulb were covered with three layers of thick flannel. It is obvious that certain sources of error are unavoidable in both modes of experimentation; since in the former the bulb will cool more rapidly by being in contact with the atmosphere, while in the latter the normal loss of heat from the skin is to some degree prevented; nevertheless the results of the two series of observations agree on the whole so well, that the results which Dr. Ziemssen has obtained may be accepted without reserve. He caused the extensor muscles of the fore-arm to contract by applying the positive electrode of an induction machine to the radial nerve, between the external condyle of the humerus and the insertion of the deltoid muscle; the negative electrode being fixed on the sternum. By acting in this way, the

* Die Elektricität in der Medicin, p. 29.

fore-arm, and more especially the surface of skin over the extensors, was not touched by the electrodes, so that there was no direct action of the current on the blood-vessels of the corium. It then appeared that muscular contractions caused by the application of the induced current to the motor nerves augment the temperature in the muscles acted upon, and indirectly in the skin covering the same, without altering the colour of the latter or the lumen of its blood-vessels. The increase of heat is proportional in its extent to the energy and duration of the contractions. The person experimented upon perceives, during and after the experiment, a sensation of intense heat in the electrified muscles. The bulk of the latter is considerably increased, so that the fore-arm gains one-fourth to one-half inch, and the thigh one-half and even a whole inch in circumference. As regards the increase of heat, it appeared that during the first minute of the contraction the mercury fell by 0°·1 to 0°·5 C., but rose in the third minute and continued to rise afterwards. In one experiment the increase of heat amounted to 4°·4 C. (7°·9 F.). If the contractions are not continued very long, the mercury rises most rapidly in the first minute after they have ceased, and reaches its acme between the fourth and the sixth minute; if the contractions are then continued, and the temperature is already high, it does not rise further after the first minute. If the skin and the mercury be covered with a bad conductor of heat, the heat rises more quickly and to a higher degree than when the skin is bare. In both cases, however, the heat produced is the same, and the apparent difference in the latter instance is merely due to the exclusion of air from the galvanised part, whereby the heat generated is longer preserved.

After the cessation of the excessive development of heat in the muscles, there is a tendency towards equalisation of temperature within the body, so that the heat of the rectum and of the other colder organs rises at the expense of the heat of the muscles.

The decrease of temperature, after the electric excitation has ceased, is slow and regular; but it is more rapid when the skin is exposed to the atmosphere than when it is covered.

In 1858, I made a number of experiments on the heat developed by electro-muscular contractions, especially on paralytic patients, which have led to the following conclusions:—

1. The heat observed after the application of induction currents to the muscles is in no way due to the action of the current upon the skin. This we might theoretically infer from the fact that, although the electrodes are in direct contact with the skin, the induced current, if applied by well-moistened electrodes, does not act on the skin, but traverses it, and penetrates to the muscles; but the proposition is also affirmed by pathological experience. Some time ago a patient suffering from lead-palsy was under my care. In that case the contractility of the extensor

muscles of the *right* fore-arm was quite gone, while a certain amount of contractile power still remained in the extensor muscles of the *left* fore-arm. On applying induction currents for five minutes to the extensors of the left fore-arm, the temperature was increased from 89° F. to 91°·5 F., while the same operation made on the extensors of the right fore-arm did not produce any increase of heat; but, on the contrary, the heat, which had been 87°·5 in the right fore-arm before the application of electricity, was only 86° F. afterwards; which was no doubt due to the contact of the skin of the fore-arm with the atmosphere.

2. The increase of heat observed after the application of induction currents to the muscles is not due to a greater afflux of blood to the arteries and veins, for these are not expanded, but constricted by direct faradisation, and consequently contain less blood after having been acted upon by induction currents, than they do in their normal physiological condition.

3. But the increase of heat observed after the application of induction currents to the muscles, is due to an augmentation of those chemical changes which are continually going on in the tissue of a muscle, and which constitute its nutrition. The solid structure of a muscle is imbibed by a fluid, the composition of which is variable. Muscular fluid taken from a muscle which has been at rest is neutral or feebly alkaline; but when induction currents have been applied to a muscle, the fluid becomes acid, in conse-

quence of an augmented absorption of oxygen and the formation of lactic acid. It is probable that this acid is afterwards neutralised in the system by the alkaline carbonates contained in the blood; lactate of soda being formed, and carbonic acid being set free.

On examining the quantity of oxygen absorbed, and carbonic acid exhaled, by the muscular substance of frogs' thighs which have been skinned and suspended in vessels filled with air or oxygen, it is found that if some of the muscles are galvanised, and the others not, the quantity of the gases absorbed and exhaled by the galvanised muscles is more than double that absorbed and exhaled during the same time by the quiescent muscles. The same differences occur in the living muscles of man; since by the augmentation of the chemical changes, the heat is increased, and more blood is attracted to the capillary vessels of the muscular substance, whereby the bulk of the muscles is considerably augmented.

4. With regard to the influence of the direction of the current upon the increase of heat, I have generally remarked a slight difference in favour of the *direct* current—moving from the centre to the periphery—in healthy muscles; and an equally slight difference in favour of the *inverse* current—moving from the periphery to the centre—in paralysed muscles. In such comparative experiments the current used was always of the same intensity, equally rapidly interrupted, and directed to the same muscles for the same length of time.

5. Respecting the more or less considerable rapidity of the shocks used, I observed that the heat was increased more quickly and to a higher degree, if a rapidly-interrupted current was employed, than if the intermittences were slow.

The relations between heat and muscular work have been further investigated by Béclard,* Solger,† Meyerstein and Thiry,‡ Heidenhain,§ and others; but space prevents me from giving a complete account of their researches. I will therefore only mention the results arrived at by Heidenhain, as being the most important amongst them. He found that a single contraction of a muscle of a frog, even after being separated from the body of the animal, gives rise to a slight increase of heat, and that, as the muscle becomes gradually exhausted, the development of heat is diminished. At a certain period, the muscle may still be able to contract, but is unable to cause an increase of temperature. If the muscle is stimulated, but prevented from contracting, more heat is developed than if a muscle is similarly stimulated but allowed to contract; from which it appears that the heat developed is not due to friction; for if it were owing to that, the heat would be greater in the second case, while it is actually less. At first the temperature rises rapidly, then the rise becomes more gradual until a maximum is reached, after

* Archives générales, etc., 1861, vol. xvii. p. 21.

† Studien des physiol. Instituts zu Breslau, 1862, p. 125.

‡ Zeitschrift für rationelle Medicin, vol. xx. p. 54,

§ Mechanische Leistung, Wärmeentwicklung etc. Leipzig, 1864.

which a gradual decrease of temperature takes place. If the intensity of stimulation is augmented beyond that degree which causes the maximum of contraction, the heat developed is not greater than before.

Leyden * found that, on applying induction currents to the cord of dogs, tetanic contractions of the muscles took place, by which the heat of the blood was increased by 5·2° C., as shown by the thermometer in the rectum. Billroth and Fick † have shown that, when the cord is thus faradised, the temperature of the tetanised muscles rises more rapidly than the temperature of the rectum, which under ordinary conditions is higher than that of the muscles; and that the muscles then actually become hotter than the rectum and all the other organs of the body.

V.—ACTION OF THE ELECTRIC CURRENT UPON THE SENTIENT NERVES.

Sparks taken from the common electrical machine while in action, produce a sharp pungent sensation in the skin. The discharge of a Leyden jar through the body causes a peculiar stunning sensation, known as the electric shock. If such a shock is very powerful, it may destroy sensation and consciousness altogether, especially if directed to the head or neck; but, unless the electricity is of very high ten-

* Virchow's Archiv. 1863, vol. xxvi. p. 538.

† Vierteljahrsschrift der naturforschenden Gesellschaft in Zürich, 1863, p. 427.

sion, it does not cause a diminution of sensibility. Dr. Richardson * has shown that if shocks of slight or medium power from the jar are sent in rapid succession through the fingers, the last is felt as severely as the first, and the fingers are afterwards as sensitive to the prick from the point of a lancet as they had been before.

The continuous galvanic current, when applied to a sentient nerve, causes a sensation of pricking and heat, not only at its commencement and cessation, but the whole time that the circuit remains closed. If the power of the current is not very great, the sensation produced is slight and not unpleasant, like a mustard poultice in the commencement of its action; while with a pile of high tension severe pain may be caused. The sensations produced differ likewise, according to the condition of the electrodes used; if these be dry, the feeling of heat predominates over that of pricking, and is extremely disagreeable when the current is strong, resembling, as it does, the sensation produced by the application of a hot iron to the skin. If, however, moistened conductors are employed, the effect is much less unpleasant; and wherever there is a morbid increase of excitability in a nerve, the galvanic sensation is actually relished by the patient. As a rule, the effect on the sentient nerves increases proportionately to the length of time during which the current is made to act, owing to its improving the conduc-

* Medical Times and Gazette, September 11, 1858.

tivity of the skin and subjacent tissues (p. 198); but if the current is applied for a considerable length of time, viz. from twenty to thirty minutes, the sensations of pricking and heat gradually give way to a feeling of numbness.

Marianini* was the first to investigate the influence which the direction of the current, when applied to sentient nerves, has in the production of the physiological effects; and he arrived at the conclusion that the sensation caused by the application of the continuous current was strongest on making the inverse and on breaking the direct current; that is just the reverse of what takes place when the motor nerves are acted upon, as muscular contractions are more easily produced on making the direct and on breaking the inverse current. Therefore, if mixed nerves are excited, the phenomena would be as follows:

Direct Current		Inverse Current	
Making	Breaking	Making	Breaking
Contraction	Sensation	Sensation	Contraction

The sensations produced by the application of the induced current to the sentient nerves vary according to the tension of the electricity used, the rapidity with which the shocks succeed each other, and the condition of the conductors which are used for the transmission of the electric current. A cur-

* Mémoire sur la secousse qu'éprouvent les animaux, etc., in Annales de Chimie et de Physique. Paris, 1829, vol. xl. p. 225.

rent of low tension causes slight feelings of pricking and heat; while one of high tension causes intolerable pain. A rapidly-interrupted electro-magnetic current has more effect on the sentient nerves than a slowly interrupted current; because sentient nerves have the property of perceiving the effects of impressions some time after they have been acted upon. Thus, if a sentient nerve in its normal condition is subjected to the action of a single induced current of low tension, the sensation caused by it is trifling; but if a second shock rapidly succeeds the first, the sensation is more marked; because the nerve is no longer in its normal physiological condition when it receives the second shock from an induction apparatus, but in an excited state; a third shock has more effect than the second, and so on. If the velocity of the intermittences is very great, and the current sent for a certain length of time through the trunk of a nerve, a maximum of excitation is reached; after which the sensibility of the nerve is diminished, and even falls below its normal standard.

Electrical anæsthesia.—The question whether surgical anæsthesia might be caused by electricity has, at various times, occupied the professional mind. It has been often alleged that teeth might be extracted without pain by the aid of galvanism, and that, in severe surgical operations, electricity might be substituted for chloroform. Experience, however, has shown that no form of electricity can be used as a direct anæsthetic; and that if surgical operations are performed with the aid of electricity, the patient feels not only the pain of the operation, but also in addition to it the electric shock.

Dr. Richardson's researches on voltaic narcotism will be mentioned in a subsequent chapter; but I may say at once that electricity has no share in the production of that form of anæsthesia.

Although, therefore, electricity is no anæsthetic in the ordinary sense of the word, yet a considerable reduction of sensibility in a nerve may be accomplished by it. Thus, if a continuous, or a rapidly-interrupted induced current of medium intensity is sent through the trunk of a nerve—say the ulnar, or the sciatic, by placing a moistened conductor connected with the positive pole to a point of the skin where the trunk of such nerve is accessible, and another moistened conductor connected with the negative pole to the terminal branches of the nerve, and the action of the current be kept up for a quarter of an hour or more, the pain which is caused by this proceeding becomes much less after a certain time, than it was at the beginning of the operation, and a feeling of numbness is produced in the limb. The tension of the current may then be gradually increased to an enormous extent, without causing much, if any, inconvenience to the person subjected to the experiment; while such electric power would have been perfectly unendurable at the commencement of the operation. If the tension of the current is then again diminished, the person experimented upon appears to be quite insensible to shocks which had caused him much inconvenience previously.

Independently of the direction of the current, the negative pole of a voltaic pile and of induction machines has a stronger effect on the sentient nerves of the skin than the positive pole. This circumstance may enable us to tell the direction of the current in an electrical apparatus, provided that certain precautions be taken. It is necessary, in the first place, that similar or nearly similar parts of the skin should be acted upon; since the epidermis is not of the same thickness in all parts of the body, and electricity is less strongly felt where the epidermis offers much resistance to the passage of the current; moreover, the distribution of sentient nerves is not equal in all parts of the skin, and electricity is always felt more on those parts which are richly endowed with nervous filaments, such as the face, than on parts which possess a less abundant network. It is also essential that the size and condition (moist or dry) of the conductors should be equal, since a current of the same power possesses more density if conveyed by a small electrode, than if transmitted by a conductor with large surface; and a moist conductor will act less on the skin and more on the muscles, while a dry conductor will act more on the skin and less on the muscles. If, however, the precautions just described be taken, it is easy to distinguish the negative pole from the positive pole, by the stronger sensation caused by the former. It frequently happens that no sensation whatever is produced by the application of the positive pole, and the negative pole is the only one felt. I have verified this fact on many patients, who have almost invariably been able to tell the direction of the current, after they had been informed that the strongest sensation is excited at the negative pole.

The difference alluded to is especially remarkable if the feet of the patient are immersed in two basins filled with water, and connected with the poles of the apparatus; in this instance the current is always felt more strongly in that limb in which it is upward. If the hands are plunged into the basins this effect is not quite so evident, as the epidermis of the right hand is generally thicker than that of the left, in consequence of the greater use made of the right hand. Thus, if the current is upward in the left arm, the sensation is much stronger in the left than in the right hand; but if the current be upward in the right, the sensations are nearly the same in both hands, as the more powerful stimulus conveyed to the right hand is compensated by the greater resistance offered by the epidermis to the passage of the current.

There are sentient nerves, not only in the skin, but also in the muscular tissue; and by applying the continuous or induced current to the latter, a peculiar sensation is produced which varies in strength according to the power of the current that is used. Duchenne has called this kind of sensibility 'electro-muscular sensibility.' Remak has denied that there is any such kind of sensibility; and it is quite certain that Duchenne has in some instances confounded it with the sensibility of the skin. Yet there is no doubt whatever that every electro-muscular contraction is accompanied by a special sensation, which exists independently of, and is quite different from, electro-cutaneous sensation.

VI.—ACTION OF THE ELECTRIC CURRENT UPON MIXED NERVES.

The phenomena produced by applying galvanism to mixed nerves are due to the excitation partly of the motor and partly of the sentient fibres, of which the mixed nerves are composed. It appears that, by the application of the direct current, powerful muscular contractions are produced, and comparatively little sensation; while, if the inverse current be used, the contrary takes place, viz. the muscular contractions are not very decided and the sensation is stronger.

VII.—ACTION OF THE ELECTRIC CURRENT UPON THE SYMPATHETIC NERVE.

Experiments on animals.—The first experimental researches on the function of the sympathetic nerve were undertaken in 1727, by M. Pourfour du Petit, who found that after the section of the cervical sympathetic in animals the pupil became constricted, the cornea flattened, the conjunctiva hyperæmic;

the secretion of the palpebral mucus was increased, the eyelids were partially closed, and the third eyelid or nictitant membrane was laid over the eyeball. If the animals continued to live some time after the operation had been performed, the eye appeared smaller, and shrunk, and was drawn backwards into the orbit. The experiments of M. Pourfour du Petit were repeated and confirmed by Dupuy, Breschet, and Dr. John Reid. In 1846, M. Biffi, of Milan, observed that if the pupil had become constricted after the section of the cervical sympathetic, it could again be dilated if the cephalic end of the nerve was galvanised.

In 1852, Professor Claude Bernard* published his important experimental researches on the physiology of the sympathetic, which have enlarged our knowledge of the function of this nerve more than those of any other observer. He pointed out that after the section of the nerve, or after the destruction of the superior cervical ganglion, besides the phenomena noticed by M. Pourfour du Petit, the following took place: a more or less marked constriction of the nostril and of the mouth on the corresponding side and an increase of the circulation of the blood, together with augmentation of heat and sensibility in the head. If the cephalic end of the sympathetic nerve was galvanised, all the phenomena observed

* Sur l'influence du nerf grand sympathique sur la chaleur animale, in Comptes rendus, etc., 29 mars 1852; also Comptes rendus de la Société de Biologie, octobre et novembre 1852; and Leçons sur la Physiologie, etc., 1858, vol. i. p. 469.

after the section of the nerve disappeared, and were even exaggerated in the opposite direction. Not only did the constriction of the pupil produced by the section of the sympathetic disappear by the application of galvanism, but the pupil became even larger than that of the opposite side; the eye, which had been drawn backwards, protruded beyond the orbit; the temperature, which had been notably increased, fell below its average standard, and the conjunctiva, the nostrils, the ears, which had been red and injected, became quite pale. But when the application of electricity was discontinued, all the phenomena previously observed after the section of the nerve, gradually re-appeared. They could, however, be made to disappear a second and even a third time by repeated applications of galvanism to the cephalic end of the nerve. If a drop of ammonia was applied to the conjunctiva of a dog, in which a section of the nerve had been made, the pain felt by the animal obliged it to keep its eyelids firmly closed; but if the upper end of the sympathetic was galvanised, the dog, notwithstanding the pain he felt, was no longer able to keep them shut, but opened them wide, while at the same time the redness of the conjunctiva, produced by the caustic, was diminished, and soon entirely disappeared.

Experiments of the same kind have afterwards been made by Drs. Augustus Waller, Budge, Schiff, Brown-Séquard, and many other physiologists, who have added some new facts to those already known about the physiology of the sympathetic, and which may be resumed as follows :—

After the section of the nerve, almost all the muscles of the eye, of the angle of the mouth, and of the nostril, are contracted; the ear is kept erect, which is partly owing to contraction of its muscles; the quantity of blood in the ear and in the whole corresponding side of the head is notably increased; the arteries are fuller, and seem to beat with more power; the temperature is augmented, in some instances to 11° or 12° F.; sensibility is increased; after the death of the animal sensibility and reflex function last longer than on the other side; perspiration, lachrymation, and the secretion of cerumen are increased; the colour of the venous blood is changed; poisonous and other substances, which are deposited in equal quantities on both sides, in the subcutaneous cellular tissue of the face or at the base of the ear, are more rapidly absorbed on that side where the section has been made; chloroform destroys sensibility later there than on the opposite side; rigor mortis appears later and lasts longer; putrefaction commences later, and the current proper of the muscles is strong, when compared to the current proper of the muscles on the other side.

By applying the induced current to the cervical sympathetic nerve the following phenomena are produced: the pupil is dilated; the eyelids open; the eyeball protrudes; the blood-vessels contract; the quantity of blood is diminished; temperature and sensibility sink below the average ; the conjunctiva and cornea are dry ; the current proper of the muscles is very weak ; the excitability of the motor and sentient nerves of the iris, and of the muscles, and the contractility of the arteries disappear sooner after death than on the other side ; and cadaveric rigidity and putrefaction commence also sooner.

All the phenomena observed after section of the sympathetic are due to a paralytic condition of the blood-vessels, which is the direct consequence of the operation, and owing to which more blood passes through these vessels in a given space of time than before ; hence an increase of the vital properties of the contractile tissues and the nerves. Almost all the phenomena observed after the section of the sympathetic may be observed, if the quantity of blood circulating in the blood-vessels of the head in a given time, is increased by any other means ; thus the hanging down of an animal, by holding it by its hind-legs, produces congestion in the head, and almost all the effects of the section of the sympathetic. It is seen that the effects of electricity are just opposite to those produced by the section of the nerve ; viz. contraction of blood-vessels, diminution of the quantity of blood, and corresponding diminution of the vital properties of the tissues.

The phenomena observed by applying electricity directly to the ears of animals, differ according as a section of the sympathetic has been made or not. After the section of that nerve the ear becomes hot. If one pole of an induction apparatus is then applied to the base of the ear and the other to the top, so that the longitudinal diameter of the ear is traversed by the current, the temperature is not lowered, as is the case if the cephalic end of the sympathetic nerve be galvanised; but the heat in the ear is thereby further increased. On the contrary, if no section of the sympathetic has been made, and the ear is galvanised, the temperature of the part is lowered. Thus Bernard galvanised the ear of a rabbit, in which he had divided the left sympathetic, while at the right side no such operation had been made; and found that if the left ear was galvanised, a rapid and considerable increase of heat took place; but that if the right ear was galvanised, heat was just as rapidly diminished. Bernard has explained this in the following manner:—on that side where the sympathetic has been divided, the elevation of temperature results from the circumstance that, under the influence of the pain, the heart acts more vigorously upon the arteries of the ear, which are relaxed in consequence of the section of the sympathetic; while, on the other side, where the nerve is in a state of integrity, electricity produces an excitation of the sentient nerves, which is transmitted to the spinal cord and by reflex action to the sympathetic; hence the vessels of the ear are constricted, and the action of the heart cannot produce the same results as on the other side, where no reflex action from the spinal cord to the sympathetic is possible. This is proved by the following experiment:—if the auricular nerve, which takes its rise from the cervical plexus, and which transmits reflex action from the ear to the spinal cord, be divided, the temperature of the ear can no longer be diminished by the direct application of galvanism to the ear; but a decrease of temperature in the ear may again be caused if, after the section of the auricular nerve, its central end is galvanised; whereby the reflex action to the cord and thence to the sympathetic is re-established.

If the inferior cervical ganglion of the sympathetic nerve be galvanised, the pulse is accelerated; the same is observed if the cardiac branches are subjected to an electric current; while, if the pneumogastric is galvanised, the action of the heart is arrested.

Claude Bernard has further shown that the same effects which are produced by dividing and galvanising the cervical sympathetic, may be brought about by division and galvanisation of the vaso-motor nerves of the limbs.

Prussak * has made some observations on the effects of the application of the induced current to the sympathetic on the blood-vessels of the tympanum; and found that the arteries were at first constricted, but became dilated after the stimulation had ceased; the veins were dilated during the stimulation, probably because the arteries were emptied; and they became constricted afterwards. In these experiments he rendered the tympanum of the dog

* Sächs acad. Ber., 1868, p. 101.

visible by trephining the mastoid portion of the temporal bone, and illuminating the interior by means of a reflector.

Such are the effects of the application of the induced current to the cervical sympathetic in animals, which have been subjected to more or less severe operations. It now remains to describe the effects of the continuous current on the sympathetic in healthy men.

Experiments on man.—Frictional electricity, electro-magnetism, and magneto-electricity appear to have no effect whatever on the vital energy of the sympathetic unless great power be used, while a gentle continuous galvanic current has a direct influence on the same. Eulenburg and Schmidt * have observed that, if the positive pole of a Daniell's battery of from twenty to forty cells is applied to the manubrium sterni, the negative pole being placed immediately behind and below the angle of the lower jaw, to a point corresponding to the ganglion cervicale superius; and if the circuit is closed in the metallic closing arch, the electrodes being fixed at the time, there is, as soon as the current begins to act, a slight dilation of the pupil of the same side, after which the pupil is gradually constricted. Sometimes these phenomena do not appear on first closing the circuit, but only after the current has been closed for half a minute or a minute, and is then broken and

* Centralblatt für die medicinischen Wissenschaften, 1868. Nos. 21 and 23.

closed again; they also occur afterwards, each time the circuit is again closed. In most cases this initial instantaneous dilatation of the pupil is so slight that it cannot be observed with the unassisted eye, but can only be shown to occur with the aid of the pupilloscope lately invented by Giraud-Teulon. This instrument allows us to notice any modifications of the size and distance of the dispersing circles in the retina by minimal alterations in the diameter of the pupil, such galvanic power being used as is applicable for therapeutical purposes.

With the aid of the pupilloscope it is seen that at the instant of closing the circuit the dispersing circles are suddenly enlarged; and if the circuit remains closed, they undergo a gradually increasing diminution. When the circuit is opened the effect differs, there being sometimes an enlargement and sometimes a diminution of the same; or there may be no perceptible alteration whatever in the dispersing circles. In rare cases, or where a very powerful current is used, the pupil becomes dilated after the application has lasted for a certain length of time; and this dilatation may then be observed with the naked eye. These phenomena are more uncertain if the direction of the current be reversed; they completely disappear if the negative electrode is removed from the place corresponding to the ganglion cervicale superius to the cervical vertebræ; and if both electrodes are symmetrically applied behind and below the angle of the lower jaw, the phenomena occur in a more marked manner, and more strongly in that eye which corresponds to the negative pole.

If a somewhat powerful current is uninterruptedly applied in the same direction for a certain length of time, the rate of pulsation appears to diminish. Where the action of the heart is normal, the pulse falls from four to sixteen beats in the minute; but in pathological conditions, where the pulse is accelerated, as in certain forms of heart disease, exophthalmic goître, etc., the fall may be much more considerable. This diminished rate of pulsation is accompanied by a decrease of tension and pressure in the carotids of both sides, and even in the radial arteries, which is quite perceptible to the finger. An examination by means of the sphygmograph, however, gives much more distinct results, showing that the typical relation of the curves of the carotid as they appear in healthy persons, are considerably altered during the time that galvanism is applied in this manner. The line of ascension becomes more slanting, and deviates more strongly to the right side; the pointed summit disappears completely, or almost completely, and instead of it a broad level is traced, which either proceeds in a horizontal plane or shows another more or less steep ascension. The end of this part of the curve which forms the commencement of the line of descension, is formed by the summit of the secondary elevation; this is, therefore, at the same level as, or even higher than, the summit of the primary wave, which otherwise corresponds to the geometrical summit of the curve. The line of descension falls rather flatly, and the last great incision, with its corresponding ascension, is also flat and rounded. Some of these phenomena may also be observed in the curve of the radial artery.

Eulenburg and Schmidt consider it probable that by applying the current in the way first described, both general and local effects are produced. The general effect is retardation and enfeebling of the heart's action, as shown by diminished rate of pulsation and tension; while the local effect would be due to a direct galvanic action on the vasomotor nerve-fibres of the head, which are contained in the cervical sympathetic, whereby the arterial tone in the sphere of the carotid artery and the pressure of blood in the same is reduced. This supposition would appear to be supported by the following experiment:—

If a powerful direct current is sent from the spine to the brachial plexus, the positive pole being applied to the spinous processes of the lower cervical vertebræ, while the negative pole is in the supra-clavicular fossa, we observe after a time a diminution of the rate of pulsation, but which is generally less marked than in the previous experiment; viz. from four to ten beats in a minute only. At the same time, or even before the tension of the radial artery of the corresponding side is much diminished, and on examining the same by means of the sphygmograph, similar drawings are produced as were noticed on the carotid, the summit of the curve is enlarged, and the first summit of the secondary wave is higher. These phenomena, however, are only temporary effects of the galvanic application: for, if the circuit remains closed for some time longer, the curves of the radial artery gradually return to their normal condition, and the rate of pulsation is again increased, although it does not quite reach its previous standard. After the circuit is opened, both the curve of the radial artery and the rate of pulsation return to their normal condition.

The rate of pulsation is further diminished by symmetrical application of both poles to each superior cervical ganglion and by galvanisation of the spine with a strong direct current of from forty to sixty cells, even in the lower dorsal zone. If a powerful induced current is applied to the skin, there is at first acceleration and afterwards retardation of the heart's action with corresponding graphic alterations of the radial pulse. There can, therefore, be no doubt, that by applying galvanism in a certain manner, peculiar effects on the action of the heart and the current of the arterial blood may be obtained. It is not improbable that some of these effects are due to reflex excitation of the pneumogastric nerve.

Splanchnic nerves.—In 1856 Pflüger * discovered, that the splanchnic nerves have an inhibitory influence upon the movements of the intestines. He has shown that if these nerves, which take their

* Ueber das Hemmungs-Nervensystem für die peristaltischen Bewegungen der Gedärme. Berlin, 1856.

rise from the six lower dorsal ganglia of the sympathetic are galvanised, the peristaltic movements of the small intestines are almost immediately arrested. Hence he concluded that there is a peculiar set of nerves which has the function of diminishing or arresting the peristaltic movements; this set of nerves he called the inhibitory system. Mr. Lister,* who has experimented upon the same subject, inclines to the opinion that the inhibiting influence is only produced if a strong electric current is applied to the splanchnic nerves; but that there is an increase of function in them if they are excited by a gentle current.

VIII. ACTION OF THE ELECTRIC CURRENT UPON THE CONTRACTILE FIBRE-CELLS.

All forms of electricity have a marked action upon the muscular fibre-cells, but more especially so the induced current.

If an electric shock is applied to a voluntary muscle, it immediately contracts, and then as quickly relaxes; while the movements induced by the application of electricity to the contractile fibre-cells are not observed simultaneously with the application of the electric current, but only a certain time after it has acted upon the tissue. The only exception from this rule is made by the iris, which is, in this respect, similar to the voluntary muscles. Moreover,

* Preliminary account, etc., in Proceedings of the Royal Society, Vol. i. No. 32.

the motion once excited in the fibre-cells, continues for a certain time after the cessation of the current; and is not confined to those parts to which the electricity has been directly applied, as is the case with the voluntary muscles, but is propagated to other parts of the same tract. It has, however, been shown by Helmholtz and Fick, that both the striped and the unstriped fibres pass actually through the same periods of contraction; and that there is only a difference as regards the rapidity with which these latter succeed each other.

If the continuous current is used contractions are observed, not only at its commencement, as is the case with the voluntary muscles, but also while the circuit remains closed. The power of the current employed, and the length of time during which its action is kept up, determine the intensity and duration of the movements brought about in the organic fibre-cells by the application of electricity.

These contractions always take place in an order which corresponds to the physiological purpose; thus, by the electric excitation of the intestines, peristaltic movements only are induced, but never anti-peristaltic contractions; if the uretheres are acted upon, the contraction proceeds from the kidneys to the bladder, but never in the opposite direction, whatever may be the intensity and the direction of the current, and whatever may be the point of the tract to which the electrodes are applied.

The effects of electricity on the unstriped fibres have been investigated, not only in living and dead animals, but also in recently-killed bodies of criminals. Researches of the latter kind were undertaken especially by M. Nysten,* during the wholesale slaughter which accompanied the first French Revolution, and more recently by Professors Henle, Kölliker, Gerlach, Harless, and others. The results of these experiments are somewhat at variance with each other; which is no doubt due to the circumstance that some have employed the continuous, and others the induced, current; and that those who employed the continuous current have, in some instances, made use of very feeble batteries.

Iris.—If the induced current is applied to the iris, this membrane, like the voluntary muscle, contracts rapidly, and returns to its previous condition as soon as the circuit is broken. By applying electricity to the iris, however, dilatation as well as constriction of the pupil may be produced, according as the current acts upon the dilatator or the constrictor muscle. A constriction of the pupil is observed, if one pole is directed to the centre of the cornea, and the other one to any point of the head or face; by this arrangement the circular fibres of the iris (sphincter pupillæ) are put in action. A constriction of the pupil is also perceived, if one metal of a galvanic pair is placed in the nose and the other one on the tongue; it is, however, necessary for the success of such experiments that they

* Nouvelles expériences galvaniques faites sur les organes musculaires de l'homme et des animaux à sang rouge. Paris, an xi. (1803).

should be made in a room where only so much external light is admitted as is sufficient for discerning the size of the pupil. It is then easy to observe that a constriction of the pupil takes place each time the metals are brought in contact with each other.

If the poles of an induction apparatus, or of a single galvanic pair, are directed to the edge of the cornea or to the sclerotica, the radiar fibres of the iris (dilatator pupillæ) are excited, and the pupil is, therefore, dilated. When the electrodes are applied to the upper and the lower part of the cornea, the pupil assumes the shape of a lying oval; and when they are placed to the right and left side of the cornea, the pupil takes the form of a standing oval.

Intestines.—The fibre-cells of the intestines respond readily to the galvanic stimulus. Aldini observed that when a zinc plate was introduced into the mouth of a recently-killed bull, and a piece of silver into the rectum, and both metals were connected by means of a wire, the abdominal muscles of the animal were convulsed and the fæces discharged. This experiment was repeated by M. Achard, of Berlin, on himself, who experienced, almost immediately after the circuit had been established, pain in the pelvis, and soon afterwards the bowels were voided of their contents.

If the *salivary glands* are directly galvanised, no apparent effect is produced; but Professor Ludwig*

* Lehrbuch der Physiologie des Menschen. Heidelberg, 1853. Vol. ii. p. 59.

has shown that if the induced current be applied to the lingual and auriculo-temporal nerves, the chorda tympani, and the posterior parotideal branches of the portio dura, an abundant flow of saliva takes place. M. Claude Bernard* has proved, that if the nerves just named are galvanised, the blood-vessels of the salivary glands become enlarged, and that this dilatation of the blood-vessels is due to a greater attraction of arterial blood developed in the tissues; while, if the sympathetic nerve is galvanised, the salivary secretion is arrested. The amount of saliva which may be collected in a very short time from the salivary glands, if the nerves above named are galvanised, by far surpasses the volume of the glands themselves, so that it cannot be supposed that the saliva is simply squeezed out of the gland; but it is secreted in the gland at the very moment when the galvanism is caused to act on the secretory nerves. The excretion of the saliva is effected by the same forces which attract the blood to the glands, and not by the tissue of the glands, since the elementary substance of the glands has no inherent contractile power. M. Bernard is inclined to assume that the capillaries possess two properties, one of contraction, and the other of dilatation; and that either of these properties is put into play by a peculiar set of nerves.

Galvanisation of the *œsophagus* in man causes contraction of its longitudinal as well as of its circular fibres; and if the action of the current be kept up for

* Journal de la Physiologie de l'Homme. Paris, Oct. 1858, p. 649.

a certain time, the contraction is no longer limited to the part directly operated upon, but proceeds downwards towards the stomach. In man and most of the mammalia, the œsophagus is composed of both striped and unstriped fibres, so that the aspect of its contraction by galvanism resembles neither that of voluntary muscles, nor that of fibre-cells. In birds the œsophagus consists exclusively of unstriped fibres; the motion excited by galvanism in the œsophagus of birds therefore commences slowly and continues for some time after the cessation of the current. In the rodentia or gnawers the œsophagus consists of striped fibres only, and if it be galvanised, a rapid contraction occurs which ceases immediately with the cessation of the current.

The *stomach* responds well to the electric stimulus by a shortening of both its longitudinal and transverse diameter; the direction of the movement being always from the cardia to the pylorus.

The *small intestines* are particularly excitable by galvanism. If the cavity of the abdomen is opened in recently-killed animals, powerful contractions of the intestines take place, which are produced by the contact of these tissues with air. After a time these contractions cease; and if an electric current is then caused to act upon the small intestines, they are again seen to contract strongly, and the contents of the bowels are propelled towards the rectum. If the electrodes be placed very near each other to any point of the intestines, and shortly afterwards rapidly removed, a constriction of the canal occurs on that particular point to which the electrodes have been directed. This constriction reaches its maximum a short time after the electrodes have been removed, and then slowly disappears. It generally extends a little above and below the point where the electrodes have been placed; and it is most striking in the duodenum, while it is not very marked in the cœcum. The *colon* and the *rectum* respond well to the electric stimulus, although not so readily as the small intestines.

If the *gall-bladder* is acted upon by electricity, it is seen to contract and to void the bile into the duodenum. If the electrodes are placed very near each other, a constriction is produced in the gall-bladder which may be so strong as to divide that organ in two distinct parts which do not communicate with each other.

The *spleen* of most mammalia contracts fairly well under the influence of the electric current; but concerning the contractility of the human spleen there is much difference of opinion. Kölliker, Dittrich, and Gerlach* deny its contractility; while Wagner,† Harless,‡ and Claude Bernard affirm it. This discrepancy is probably owing to the circumstance that Kölliker used a feeble continuous current, while Wagner and Bernard employed a powerful induction apparatus.

* Prager Vierteljahrschrift, 1851. Vol. viii. p. 65.

† Jena'sche Annalen, 1849. Heft 1.

‡ Augsburger allg. Zeitung, 1850.

The *uretheres* respond readily to the electric current; they are at the same time shortened and constricted, and the contractions proceed in the direction from the kidneys to the bladder. These contractions continue long after the application of galvanism has ceased.

The *bladder* contracts vigorously when galvanised; and the *vas deferens*, the *epididymis*, and the *tunica vaginalis propria* are likewise not devoid of contractility. The uterus answers to the application of galvanism, whether it be in the gravid state or not. Weber has observed partial contractions of the uterus in bitches and rabbits; and that the human uterus in the gravid state contracts *in toto*, when galvanised, is confirmed by clinical experience.

According to Dr. F. W. Mackenzie,* the uterus contracts more readily when the positive pole is directed to the spine and the negative to the cervix, than when both poles are directly applied to the substance of the uterus; and the electric current, directed longitudinally through the uterus, promotes powerful and general uterine contraction, whereas a current passed transversely through the organ excites partial contractions only in the direction of the current. Dr. Mackenzie has asserted that the contraction of the contractile fibres of the uterus caused by galvanism differs widely, by its slowness, from that of the other involuntary muscles when acted upon by electricity; but such is not the case, as the cœcum, the gall-

* Medico-Chirurgical Transactions for 1859, p. 160.

bladder, and other involuntary muscles respond equally slowly to the galvanic stimulation as the uterus.

The contractility of the *blood-vessels* is proportionate to the number of unstriped fibres they contain. It has been affirmed by Vassalli, Giulio, and Rossi that the aorta of man contracts when galvanised; but neither Nysten nor Kölliker have been able to perceive such contractions. The absence of contractility in the aorta is readily to be understood, if we consider that it consists almost entirely of elastic fibres, and contains only very few contractile elements, which, even when excited by galvanism, are not capable to counterbalance the elastic force which continually tends to keep the aorta open. The unstriped fibres are much more abundant in the smaller arteries of man, and consequently these are seen to contract energetically when galvanised. The aorta of horses, cows, and sheep contains more fibre-cells than the human aorta; and it is therefore probable that, were that vessel galvanised in those animals, contractions would be noticed. The smaller arteries of man are much constricted when galvanised; these constrictions are not observable immediately after the commencement of the current, but only after its action has been kept up for a certain time. When the application of galvanism is discontinued, the constrictions still increase for a short time, and then slowly disappear.

IX. ACTION OF THE ELECTRIC CURRENT UPON THE HEART AND THE PNEUMOGASTRIC NERVE.

The phenomena produced by the application of galvanism to the heart differ according to the parts of the heart acted upon. The heart receives its nervous supply from four sources; viz. 1. The sympathetic ganglia, which are situated in the substance of the heart itself, and which, as Bidder and Rosenberger have shown, are found clustered together in the lines of junction between the auricles and ventricles, and between the auricles and the great veins; these impart to the heart the power of beating rhymically. 2. The nerves, which, from the cervical sympathetic send the motor impulse to the heart. 3. *Bezold's cardiac nervous centre* in the medulla oblongata; and 4. The *depressor nerve*, which, according to Ludwig and Cyon, originates from the superior laryngeal, and which, when its central end is galvanised, causes dilatation of the blood-vessels, and diminished pressure of the blood. If the ventricle and the atrium of a frog's heart, which is still actively pulsating, are galvanised, the heart is constricted, and its movements may cease altogether; but if the electrodes are applied to the bulbus aortæ, the pulsations become more powerful; they disappear entirely if an electric current is caused to act on the vena cava, but begin again after the cessation of the current. These differences are only to be understood by remembering that some of the nerves of the heart impart to it motive power, while others regulate and inhibit it. If the former are galvanised, the action of the heart is augmented, while by galvanisation of the latter the pulsations are arrested. This fact was discovered by Professor Weber, of Leipzig; and seen independently of him by Professor Budge, of Greifswald; while M. Claude Bernard has observed many other interesting phenomena in connexion with it.

If the pneumogastric nerves are galvanised without having been previously divided, the action of the heart as well as the respiratory movements are arrested, and the eyes protrude; from which it appears that those nerves have at the same time a centripetal and a centrifugal action. If a section of the same nerves be made in dogs, and their upper ends be galvanised, the pupils are dilated and the eyes protrude; if galvanism be then discontinued, the eyes are drawn backwards and the pupils constricted. By galvanisation of the upper ends of the vagi no effect whatever is produced upon the action of the heart, and if the current be gentle the respiratory movements also continue undisturbed; but if a strong current be used, the respiratory movements are stopped during inspiration, the blood in the carotid arteries becomes black, and a passive congestion of the mucous membrane of the cavity of the mouth is produced; the tongue appears brownish black, in consequence of the momentary asphyxia produced by galvanisation of the upper ends of the vagi; but the arteries continue to beat. If galvanism be then discontinued, the respiratory movements begin again, and the velocity with which they succeed each other is even greater than before the galvanisation was commenced. Moreover, after galvanisation of the upper ends of the vagi, sugar is found in the blood, in the cerebro-spinal liquid, and in the bile; the secretion of urine appears to be arrested, and a flow of saliva is observed; this saliva, however, is much more viscid than that observed to flow after the galvanisation of the lingual nerve, or of the chorda tympani.

Galvanisation of the *lower ends* of the vagi produces opposite effects; it does not stop the respiratory movements, as is done by galvanisation of the upper ends; but arrests the pulsations of the heart and the arteries, and generally causes vomiting.

If after death the heart of an animal has ceased to act, and an induced current is applied to it, rhythmic contractions of the heart are again observed. These contractions are much more marked in the right than in the left ventricle. After death the left ventricle is generally firmly contracted, and insensible to the electric stimulus; the right ventricle, on the contrary, is almost always loaded with blood, and contracts very powerfully when galvanised. In animals killed by chloroform, sometimes the left ventricle still continues to pulsate feebly, while the action of the right ventricle is entirely stopped, in consequence of excessive distension with black blood. If in such instances the right ventricle is galvanised, its pulsations begin again and the dilatation becomes less. From this we may infer that galvanisation of the right ventricle may be resorted to in cases of chloroform poisoning during surgical operations, after the usual remedies, especially artificial respiration, have failed. But it is indispensable that in such instances a gentle current should be used, as a strong one would, in all probability, totally annihilate the excitability of the heart. Baron Humboldt has performed interesting experiments with electricity on the heart of a carp which had been cut out of the body.* Immediately after that operation had been performed, there were thirty-four pulsations observed in a minute; the heart was then touched with a solution of sulphuret of potassium, after which only nine pulsations took place. Five minutes after the heart had been cut out there were only three pulsations in a minute. Feeble discharges from a jar were now directed to the substance of the heart, when the pulsations again rose to twenty-eight in a minute; a somewhat stronger discharge was then administered, and the pulsations again fell back to eight; a still stronger discharge entirely destroyed its contractility, and no stimulus was capable of inducing further pulsations.

Mr. Lister † has observed that the movements of the heart are not always arrested under these cir-

* Untersuchungen über die gereizte Muskel- und Nervenfaser. Posen und Berlin, 1797. Vol. ii. p. 214.

† Preliminary Enquiry into the Functions of the visceral nerves. Proc. Royal Society. August 13, 1858.

cumstances. He found that a feeble current had a directly opposite action to that of a powerful one; for when a weak current was used, the rhythmical movements of the heart were quickened; when the power of the current was increased, these movements were arrested during diastole; while, when the power of the current was still more augmented, the movements re-appeared.

X. ACTION OF THE ELECTRIC CURRENT UPON THE BLOOD.

The action of electricity on the blood appears to be wholly chemical, and it is, therefore, easy to understand that the continuous current has a different effect upon it than frictional electricity, or the induced current. The latter two forms of electricity seem indeed to have little or no action upon blood at all, while electrolysis by means of the continuous current, causes a profound modification of the same. The effects of the extra-current upon the blood have not yet been investigated; but it appears probable that it would resemble, only in a much more feeble manner, the effects of the continuous current.

The action of electricity on the blood has been studied by Scudamore *, Dutrochet †, Müller ‡, Steinheil §, Fraser ||, and many others. The following is the substance of my own experiments on this subject:—

* Annales des Sciences nouvelles, 1831.

† An Essay on the Blood, etc. London, 1824.

‡ Poggendorff's Annalen, 1832,

§ Zeitschrift Wiener Aerzte, April 1853.

|| Edinburgh Medical Journal, 1868, p. 110.

The immediate effect of the electrolytic decomposition of any animal liquid is, that the positive conductor is oxidised and chlorinated, and from a metal changed into a metallic salt, since no metal whatever can resist the effects of oxygen and chlorine in their nascent condition. On the other hand, metals are not changed by hydrogen or free alkali, and the negative pole therefore always retains its pure and bright metallic aspect, whatever may be the power of the current used, or the length of time during which it is made to act. Thus it appears that, in using merely the negative pole of the battery, we do not introduce any foreign substance into the animal liquid, but only alter its composition; while, if we use the positive pole, we introduce into it salts of iron, copper, silver, gold, or any other metals used as conductors, that is to say, irritant foreign bodies, which in the system may give rise to inflammation, suppuration and other undesirable surgical complications.

The following effects are produced if the albumen of an egg is subjected to electrolysis:—When a steel needle connected with the negative pole and another steel needle connected with the positive pole are immersed into the albumen, a peculiar substance is formed round the negative pole, which at first sight looks like a coagulum or clot, but is in reality no clot, but a sort of lace-like jelly-froth, which consists of the smallest particles of albumen, mechanically driven asunder by the nascent hydrogen, and chemically altered by the evolution of free alkali, viz. soda, potash and lime, the presence of which may be shown by its effects on litmus and turmeric paper. The principal salines found in the egg-albumen are the chlorides, sulphates, and phosphates of soda, potash and lime. These are decomposed by electrolysis, hydrochloric, sulphuric and phosphoric acid appearing at the positive pole, while soda, potash and lime accumulate at the negative pole. An entirely different effect is therefore produced at the positive pole, where the steel needle is oxidised, and by the development of sulphuric and phosphoric acid and chlorine, sulphate, phosphate and chloride of iron are formed, which impart a reddish-brown colour to the albumen, with which they form an organic compound.

If we substitute gold needles for steel needles at both poles, we perceive that the effect at the negative pole is exactly the same as that produced by the steel needle, while at the positive pole the effects are different; for there we have no longer chloride and sulphate of iron, but perchloride of gold, by which a greenish-blue clot is formed. If the nature of the positive pole be once more changed by substituting a brass or copper wire for the steel or gold needle, the effect is again different at the positive pole, where a white clot is produced, which is due to the action of the copper-salt on albumen, while at the negative pole the same substance is formed as before.

The effects of the continuous current on the albumen of an egg are therefore twofold; viz. first, mechanical disintegration of its substance by the nascent hydrogen, and chemical alteration by caustic potash, soda and lime at the negative pole; and, on the other hand, chemical alteration by chlorine and acids at the positive pole. There is in such experiments no visible development of oxygen at all at the positive pole, because the oxygen that is evolved immediately combines with the metals to form oxides. This is the reason why, after such experiments, the gold needle appears black, the steel needle brown, and the brass wire greenish-black; while at the negative pole no alteration of the metals is produced.

The effects of the continuous current on blood resemble those produced on albumen, but are, of course, modified by the presence, in the former liquid, of fibrine, hæmatine and iron. This is the reason why coagulation takes place at both poles, with only this difference, that the negative clot is red, soft, and bulky, while the positive clot is black, hard, and small. Both clots remain unchanged for several days, and are only dissolved when putrefaction of the animal liquid commences. The clots formed in arterial blood are more firm and less dark than the clots formed in venous blood. The effects are otherwise the same, whether the blood has been taken from arteries, veins, or capillary vessels, and is experimented upon in a cup, or whether it is still circulating in the living body.

It is easy to coagulate the blood while circulating in the arteries of living dogs and rabbits. On dissecting the arteries, it is found that the time required for coagulation varies, according to the power of the current used, from five to thirty minutes. Coagulation is produced at both poles, the clot formed at the positive being firmer, smaller, and darker than that formed at the negative. These clots extend a short distance beyond the points of the needles which have been used in the experiment, and adhere well to the coats of the vessel. If the operation is continued for a considerable time, the coats of the vessel itself are destroyed.

The microscopic alterations of the blood-corpuscles produced by the passage of the continuous current, have been minutely described by Rollet and Neumann; but as these phenomena have only little scientific, and no practical importance, the reader interested in the same is referred to the original papers published by those two able observers.* The same applies to the experiments of Dr. Golubew,† who has lately investigated the action of induction currents on the white blood-corpuscles.

XI.—ACTION OF THE ELECTRIC CURRENT UPON THE SKIN.

Sparks taken from the common electrical machine produce a sharp sensation in, and a peculiar eruption

* Sitzungsberichte der Wiener Akademie, vol. xlvi., and Reichert and Dubois' Archiv etc. 1865.

† Ibidem, vol. lvii. p. 552, 1868.

on, the skin, viz. a small circumscribed wheal which resembles lichen urticatus, and is surrounded by a little inflammatory blush. The action of the continuous current upon the skin differs according to the intensity of the current, to the resistance offered to its passage, and to the length of time during which the action of the current is kept up. Thus there is only a trifling action if the skin be dry; it is much stronger if the epidermis be moistened previous to the application of the electrodes, and still more so if the epidermis be totally removed by blisters. This was first pointed out by Baron Humboldt, in 1795. He had two blisters, each of the size of a crown, applied in the region of the two shoulder-blades, above the trapezius and deltoid muscles. By cutting the blisters open, a serous uncoloured liquid was seen to flow out. He then had the excoriated spots covered with a silver plate, and as soon as the zinc was connected with it, a liquid was seen to flow, which no longer appeared uncoloured, but was of a reddish hue, and which produced considerable inflammation on those parts of the skin which were touched by it; at the same time a severe burning pain was perceived. Baron Humboldt relates that for several hours after his experiment he looked like a soldier who had been flogged. If the action of a feeble continuous currrent be kept up for some hours, destruction of the skin and the subjacent structures will be produced; if a powerful pile be used, the destruction will take place very rapidly. This effect is always more striking at the zinc pole of a single pair, as by the action of the current the saline fluids effused on the surfaces of the blisters are decomposed, sodium being liberated at the silver surfaces, and chlorine being evolved at the zinc plate, thus forming chloride of zinc, the escharotic action of which produces ulceration of the tissues. On the silver plate sodium is set free, which by oxidation rapidly becomes soda. Proceeding from these facts, Dr. Golding Bird has recommended the action of the zinc pole for establishing an electric moxa in cases where we may wish to induce a persistent discharge from some part of the body; the opposite action of the silver plate has been used by Mr. Spencer Wells to favour a rapid healing of torpid ulcers.

According to Remak, the two poles of the continuous current applied by moistened conductors differ as follows: the positive pole relaxes the blood-vessels and reddens the skin, while the negative pole, after a continuous application of from five to ten minutes, produces the opposite effect. On the positive pole there is moreover a depression of the skin, while on the negative one, a swelling of the epidermis and corium is produced.

If an induced current of some intensity be applied to the skin, three effects are produced; viz. pain, contraction of the muscular layer of the skin, and changes in the diameter of the blood-vessels. The effect is much greater if the skin be dry than if it be moistened; for, if it be moist, the largest portion of the electricity passes off into the deeper structures;

while, if it be dry, the resistance to the passage of the electricity is very considerable, and the skin itself receives almost the whole of it. If the current, however, be powerful, and the skin delicate, both the skin and the deeper tissues will be equally affected.

The effects of Faradisation on the blood-vessels of the skin have been studied microscopically by Weber,* Max Schultze,† Kölliker,‡ and Pflüger.§ They all agree that, at first, there is contraction, and afterwards dilatation of the smallest vessels of the skin. This fact may be easily shown clinically by applying a fine wire-brush to the skin. We then see, at first, anæmia produced by spasmodic contraction of the capillaries, which is, after a time, succeeded by considerable erythema, owing to enlargement of the vessels; and if the tension of the current is very high, circumscribed wheals are produced, as after the application of frictional electricity. This is especially remarkable if the current be applied by means of fine metallic wires. The erythema is more easily produced in women and in persons whose skin is delicate; it is more marked at the negative than at the positive pole. An increase of temperature in the skin also takes place, as shown by the thermometer; and this increase of heat may continue for a considerable time after the application.

By the action of electricity on the contractile fibre-

* Müller's Archiv, 1847, p. 232.

† De arteriarum structura. Gryphiae, 1849.

‡ Prager Vierteljahrschrift, 1849. Bd. vi. Heft 1.

§ Allgemeine mediz. Centralzeitung, 1855. Vol. xiv. August.

cells of the skin, cutis anserina is produced; and Kölliker has observed this phenomenon on a piece of skin taken from the thigh of a criminal who had been executed a short time before.

The contractions of the fibre-cells are most powerful in the tunica dartos and the nipple; the latter rapidly becomes erect, and remains so for a long time after the cessation of the current. The fibre-cells of the hair-roots can also be excited by Faradisation; and if a current be applied to such parts of the skin as are covered with hair, the latter becomes more or less erect.

XII.—ACTION OF THE ELECTRIC CURRENT UPON THE BONES.

If an induced current is applied, by means of moistened conductors, to bones which lie closely beneath the skin, such as the frontal bone or the tibia, a peculiarly unpleasant sensation is perceived, in consequence of the irritation of the sentient nerves of the periosteum. It is probable that, by applying electricity directly to the periosteum and the bones, a greater quantity of blood may be attracted to these parts; but direct observations on this point are now wanting. The continuous current does not produce this particularly disagreeable sensation when applied to the surface of bones.

CHAPTER III.

MEDICAL ELECTRIC APPARATUS, AND METHODS OF APPLYING ELECTRICITY.

In this chapter I shall describe the electrical machines which may be used for therapeutical purposes, and the methods in which the different forms of electricity have been, and are to be, medically applied. I shall speak at first of *Electrisation*, or the medical application of static electricity: after which I shall consider *Galvanisation*, or the application of the continuous current of galvanic electricity; and at last *Faradisation*, or the method of applying induction currents. The term 'Faradisation' has been proposed by Duchenne in order to honour the name of Faraday, who discovered both the electromagnetic and the magneto-electric current; and Duchenne's proposal has been generally adopted, both in Europe and America.

First principles of Application.—Benedict * has put it down as a general principle that, in using electricity or galvanism, care should be taken to apply it to the seat of disease; and, if this should be im-

* Electrotherapie, Wien, 1868, p. 73.

practicable, to direct it rather to a more central than to a more peripheral part of the body. Although I agree in the main with Benedict's proposition, I think it requires to be so far modified that, in a considerable number of cases, there should be not only an application of electricity to the seat of the disease, and which I term the *radical application*, but that the agent should also be directed to those more remote parts in which the symptoms are manifested, that is, the *symptomatic application*. Thus, for instance, in the treatment of hemiplegia of the left side of the body, the only allowable application, according to Benedict's principle, would be to direct the electricity to the right cerebral hemisphere. Now, I am convinced that this is an effective method of treatment, and I never omit to use it in such cases, unless special circumstances should appear to prohibit the same; but I am equally satisfied that the progress towards recovery is far more rapid, if a peripheral or symptomatic application to the nerves and muscles of the paralysed arm and leg is combined with the central or radical application. What holds good for hemiplegia applies likewise to many forms of anæsthesia, hyperæsthesia, and other affections of the nervous system, which will be considered in the fifth chapter.

(A) Electrisation. I. *History of it.*—The first who applied static or frictional electricity for medical purposes was a German physician, Dr. C. Kratzenstein,* Professor of Medicine at the University of Halle, who cured a patient of a contraction of the little finger, by sparks drawn from the ordinary electrical machine (1744). He also relieved another patient, who had two lame fingers, so far that he could again play on the harpsichord; and observed that the rate of pulsation was increased by the application of electricity. In 1748, M. Jallabert,† of Geneva, published a treatise on the effects of electricity upon the living body, and stated that the phenomena generally observed after the application of electricity were acceleration of the pulse, increase of heat, and involuntary contractions produced in paralysed muscles. He cured a locksmith, aged fifty-two, whose right arm had been paralysed by a blow from a hammer, within three months, by means of sparks and shocks; but it is stated that this patient afterwards relapsed into his previous condition. However, M. Sauvages, of Montpelier, was, by the report of this case, induced to employ electricity in a number of paralytics.

The report of the new remedy brought together such an enormous concourse of patients, that it was impossible to electrify them all sufficiently. The neighbouring populace, indeed, considered the cures which were made due to witchcraft, and the opera-

* Abhandlung von dem Nutzen der Electricität in der Arzney-Wissenschaft. Halle, 1745.

† Expériences sur l'Électricité, avec quelques conjectures. Paris, 1749.

tors were obliged to have recourse to the priests to undeceive them.*

A few years later, Dr. Bohadtch, a Bohemian, communicated a treatise on medical electricity to the Royal Society, in which he contended that, of all diseases, hemiplegia was most successfully treated by electricity. In 1757, Mr. Patrick Brydone cured a hysterical woman in three days of general paralysis. This patient was thirty-three years of age, and had been paralysed for two years. Dr. Watson succeeded in restoring to health a girl, aged seven, who had for some time been in a state of complete muscular rigidity and consequent immobility. Dr. Edward Spry recorded the cure, by the same means, of a girl, aged eighteen, of lockjaw and paralysis. On the other hand, cases were not wanting in which the remedy, being promiscuously and often injudiciously employed, did no good whatever, or even harm. Thus, the Abbé Nollet was honest enough to confess that, during a practice of fifteen or sixteen years, he had in no case produced any permanent good effects. Dr. Hart, of Shrewsbury, completely paralysed a girl who was submitted to the treatment; and the paralysis was only removed by the use of proper medicines. The Abbé Mazeas caused epileptic fits in a person subject to that disorder, by the application of electricity; and Franklin, to whom a great many paralytics resorted from all parts of Pennsylvania,

* On the History and Present State of Electricity, by Joseph Priestly, 3rd edition. Two vols. London, 1775.—See also a paper on this subject by Mr. Donovan, in Dublin Quarterly Journal, 1846–47.

found that, in no case treated by him, any permanent good was effected. He thought, however, that more advantage might have been obtained from the electric treatment, had it been accompanied with proper medicines and regimen, under the direction of a skilful physician.

In 1778, M. Mauduit gave a highly favourable account on the curative effects of electricity before the Société Royale de Médecine, at Paris; and it was chiefly in consequence of this report that the application of electricity to various diseases became for some time fashionable in the medical world. According to Mauduit electricity is an exciting remedy; it increases the vital powers, swells those parts of the body which are touched by it; and excites perspiration and even salivation, which frequently become very abundant if the electricity employed is of high tension. By applying electricity to patients, obstinate pains are relieved, the normal heat is restored to parts which have been cold for years; patients suffering from costiveness experience abundant evacuations; muscular atrophy, œdema, paralysis are cured, and tranquillity and sleep follow the application of electricity. The pulse at the wrist is strengthened by positive electricity, and retarded by negative electricity.

A few years later Cavallo collected a number of observations in his essay on the theory and practice of medical electricity. He recommended the use of the electrical machine in paralysis, deficiency of vision, deafness, chorea, epilepsy, and for rescuing persons from apparent death. In 1802, M. Sigaud de la Fond published a treatise on the same subject, in which he elaborately described the different methods to be employed in the use of electricity, and which are, the electric bath, drawing sparks, irroration, friction, insufflation, exhaustion, and commotion. If we were to believe M. Sigaud de la Fond, there is scarcely a disease known in pathology that would resist the use of electricity.

After the discovery of the voltaic pile (1800), and especially after that of induction currents (1831), the medical use of frictional electricity has been more or less abandoned; and it is only in the electricity room of Guy's Hospital, under the superintendence of Drs. Golding Bird and Gull, that therapeutical experiments on a large scale have been undertaken with it. More recently static electricity again found a staunch advocate in Dr. Clemens, of Frankfort, who has undertaken the irksome task of curing nearly all diseases which exist by means of it; but, generally speaking, the ordinary frictional electricity may be said to have disappeared from medical practice. This is especially due to the circumstance that a clumsy apparatus is required for its use; that the weather has a very considerable influence on the activity of the machine; that the dose of electricity to be administered cannot be exactly regulated, and that by frictional electricity we are obliged to act indiscriminately upon the different tissues, without being able to localise the stimulus in those parts which require it.

II.—METHODS OF APPLYING STATIC ELECTRICITY.

The principal methods of applying static electricity, which are even at the present time now and then used, are the electric bath, electrisation by sparks, and shocks from the Leyden jar.

As to the form of the machine, it matters little whether a glass cylinder or a glass plate be employed. As a curiosity it may be mentioned that, in the last century Signor Pivati,* of Venice, used in his machines glass cylinders filled with Peruvian balsam and various other medicines; and Dr. Giuseppe Bruni has even recorded a case, in which he employed a cylinder filled with purgative substances, and the patient, after having been electrified, is said to have experienced the same effects as if he had swallowed the drug.

1. *The Electric Bath.*—The electro-positive bath is said to increase the vital forces, the electro-negative bath to diminish them. If an *electro-positive* bath is to be given, the electricity accumulated upon the glass plate is collected, care being taken that the negative electricity, which the cushions or rubbers acquire by friction, be lost in proportion as it is liberated. Therefore the cushions, between which the plate or cylinder is turned, must communicate with the ground by means of a metallic chain connected with the cushions. The machine being in action, the

* Lettere dell' Elettricità medica. Venice, 1747.

patient is placed upon an insulating stool and takes hold of the prime conductor of the machine. The whole surface of the body of the patient thus becomes charged with positive electricity, while the air surrounding it is rendered negative. If the electric bath be given in a dark room, luminous appearances are produced by the escape of electricity into the air, especially about the hair and the eyelashes. It is said that during the discharge, heat is evolved, circulation is quickened, and the secretions, especially perspiration, become more active; but it is very doubtful if these be constant physiological effects produced by the electric bath; probably they are merely caused by the excited imagination of the patient. The electric bath has been much recommended in certain affections in which the functions of the skin and of the mucous membranes are deficient; and the patient ought to sit in it for about three hours a day.

If an *Electro-negative* bath is to be given, the negative electricity acquired by the cushions is collected, and the positive electricity accumulated upon the glass plate dispersed in proportion as it is liberated. The cushions must therefore be insulated by means of glass supports, and the conductor upon which positive electricity is liberated must be made to communicate with the ground by means of a chain. The electro-negative bath is said to have a weakening effect, viz. to reduce the natural electricity of the patient, so that the body is left without its natural stimulus; it, therefore, is said to act like blood-letting, and the pulse at the wrist is thereby retarded. It has been recommended for erysipelas and chronic inflammations of every kind; more especially for headache and different forms of neuralgia; but it appears extremely doubtful if any constant physiological or therapeutical effects follow the use of the electro-negative bath.

2. *Electrisation by Sparks.*—If a patient is sitting in an electric bath, and the hand of the operator is brought sufficiently near the patient's body, it becomes negative; and the negative electricity combines with the positive electricity of the patient's body, whereby a vivid flash of light is produced, together with a peculiar snapping noise, which forms the electric spark. Sparks may also be drawn from the body by approaching metallic conductors to any part of it. These sparks produce a sharp pricking, or pungent sensation, at the points touched; and if the proceeding be continued for a certain time, the skin becomes reddened, and white circumscribed wheals are produced. This eruption is more perceptible in persons with a delicate skin; the time necessary for its production varies in different people from five to ten minutes; it generally disappears within an hour from its production. In the electricity room of Guy's Hospital sparks are usually taken from the spine in the following way: a brass ball, attached to a wire or chain, in connection with the ground, is passed up and down in the direction of the spine at a distance

of about an inch from the surface. The machine being put in action and the patient placed on an insulating stool, he becomes charged with electricity; sparks therefore pass to the brass ball, and thence escape through the wire or chain to the ground. In this manner a rapid succession of sparks can be obtained which act like instantaneous electric currents. Cavallo has recommended the drawing of electric sparks through flannel; the patient sits on the insulating stool, as usual, and takes hold of the prime conductor of the machine; a piece of flannel is placed over the part which is to be electrified, and the knob of an insulated conductor placed in close contact with the flannel, and moved steadily down the part affected, so as to draw a large number of small sparks in the direction of the ramifications of the nerves. If sparks succeed each other rapidly, they may produce slight vibrations in such muscles as are close under the skin. Electrisation by sparks has been much used for paralysis, chorea, and other affections of the nervous system; and its effects in certain spasmodic disorders and some forms of amenorrhœa are decidedly useful.

3. *The Leyden Jar.*—This instrument yields a rather large quantity of electricity accumulated under a small surface. To charge the jar, it is held in the hand by its outer coating, and the knob which communicates with the inner coating is presented to the conductor of the electrical machine while in action. Thus, the inner coating of the jar receives positive

electricity from the machine, while negative electricity is accumulated on the outer coating; and if a communication be established between the two coatings, neutralisation takes place between the two contrary electricities. If the jar be discharged through the human body, a violent, sudden, and painful sensation, the *electric shock*, is perceived, the force of which is proportional to the area of the metallic coating and to the intensity of the charge. Such a shock may be transmitted through a number of persons forming a chain; the first taking hold of the jar by its outer coating, the last touching it by the knob. If several jars are combined to form batteries and discharged through the body, the concussion may be so strong that the whole body is affected by it as if struck by lightning. If the discharge takes place through the arms, the shock is felt chiefly in the wrists, elbows, and across the chest.

If it is intended to apply the Leyden jar to any particular part of the body, a conductor with two branches is generally used, which communicates by one of its branches with the inner coating of the jar, while the other branch is approached to the surface of the part which is to be operated upon. The outer coating of the jar is then held to the opposite surface of the part, whereby a spark is produced, and the neutralisation of the two contrary electricities takes place through the part of the body interposed between the conductor and the outer coating of the jar. In Guy's Hospital shocks from the Leyden jar are especially employed in the treatment of amenorrhœa; in such cases it is discharged through the pelvis.

M. Beckensteiner* has recommended to 'animalise' static electricity through the interposition of the body of the operator, before applying it to a patient; and is of opinion that the Pacinian corpuscles play a considerable part in this animalisation of electricity! The operator touches the conductor of the machine with one hand, and rubs or shampoos the patient with the other; in some cases it is even found sufficient to make simple passes, without touching the patient at all; which must produce extraordinary effects on the imagination of persons willing to believe in animalised electricity. M. Beckensteiner has likewise a theory of his own on the influence of different conducting bodies upon the curative effects of the electricity, viz. that the metals become 'etherealised' by the electricity which passes through them. He believes that conductors of gold, silver, iron, antimony, zinc, tin and lead, have all a special action of their own on the body, independently of the electricity they convey; but that conductors of gold are, on the whole, the best. He also thinks that he is able, by means of static electricity, to introduce iodine, valerian, moschus, and assafœtida into the human system. Electrical mysticism has at all times found devoted adherents, and it is said that M. Beckensteiner's theories are acted upon at Paris,

* Études sur l'Électricité. Paris, 1859.

London, and Rome; if so, they will not do much harm.

A more important attempt to re-introduce static electricity into medical practice has been made by Professor Schwanda, of Vienna.* He does not use the old-fashioned friction apparatus, but Holtz's electrophorus machine (p. 14), and has found that the electricity yielded by it has the same effects in paralytic conditions as the induced current; that in anæsthesia of the skin it acts much more powerfully than either the continuous or the induced current; and that in passive hyperæmia and swelling of the skin the best results are obtained. Moreover the air is rapidly ozonised by means of it, and this alone may possibly be of use in certain pathological conditions. General effects of the application are increased heat and perspiration, and improved appetite. Professor Schwanda has recorded several cases of nervous affections which were improved or cured by the use of the electrophorus machine, which would, therefore, appear to be an important addition to the electrical instrumentarium.

(B) GALVANISATION. I. *History of it.*—Galvanism was discovered in 1786, and made known in 1791. Its medical application was soon afterwards (1792) recommended by Drs. Behrend and Creve for distinguishing real death from apparent death or trance.

* Medicinische Jahrbücher, 1868, Heft 3; and Poggendorff Annalen, vol. cxxxiii. p. 126.

Soemmering proposed that, in such instances, the galvanic current should be applied to the neighbourhood of the phrenic nerve. Valli succeeded in reviving, by the galvanic shock, frogs which had been all but suffocated in vessels filled with hydrogen, and fowls which had been nearly drowned. Hufeland, Pfaff, Reil, Baron Humboldt, and other German philosophers and physicians strongly recommended the use of galvanism for the cure of disease, without, however, having employed it themselves in medical practice.

The first therapeutical experiments on patients were made at the University Hospital of Jena, with the current of a single jar, under the supervision of Professor Loder, without any appreciable result. But, after the discovery of the voltaic pile (1800), experiments of this kind were again commenced by Drs. Bischoff and Liechtenstein, who have recorded the cure of two cases of amaurosis and the amelioration of a case of hemiplegia. The first systematical treatise published on the remedial powers of galvanism is from the pen of Dr. Grapengiesser, of Berlin (1801). He recommended the use of it in deficiency of vision and amaurosis, in deafness, certain paralytic conditions, aphonia, tumor albus, rheumatism, and sciatica. In palsies he applied the direct current, and placed the positive pole on the trunk of the nerve, and the negative pole lower down ; or he used basins filled with water, in which the poles, and the feet or hands of the patient, were immersed. In all other diseases he applied galvanism after having vesicated the skin by means of blisters, in order to diminish the resistance to the passage of the current. A few years later, Drs. Jacobi and Augustin published treatises on galvanism as a remedial agent, and recommended to moisten those parts of the skin to which the electrodes were to be applied, in order to diminish the resistance to the passage of the current. The most celebrated of the early treatises on medical galvanism is, however, by Galvani's pupil, Aldini, of Bologna,* who recommended the new remedy for diseases of the organs of special sense and for disorders of the mind. Indeed, the physical, chemical, and physiological properties of galvanism, as they became successively known in the course of time, excited the imagination of physicians and laymen in an equally powerful manner; and it was concluded that so marvellous an agent must needs possess wonderful curative effects. It is difficult, at the present time, to imagine the enthusiasm, bordering on intoxication, for the newly-discovered remedial agent, which reigned in the commencement of the present century, and the unbounded expectations which were entertained as to its therapeutical value. It was not only recommended and used for almost all diseases which exist, but was also believed to be able to rescue from death persons who had just been hanged or drowned.

Of the physiological action of the galvanic current

* Essai théorique et expérimental sur le Galvanisme. Paris, 1804.

upon the different tissues of the human body very little was known. The voltaic pile was indiscriminately and injudiciously applied, even for such diseases in which it must have done harm; moreover, the power of this apparatus is, for reasons which have already been given (p. 31), very variable, and after a certain time entirely disappears, so that there was sometimes no current at all, while at others there was either a weak or a very strong current, and, by the use of the latter, accidents of a serious character, such as fainting fits, blindness, etc., were produced. Moreover, it was found very troublesome and expensive to maintain the pile in any state of efficiency; and it is therefore no matter of surprise that the confidence in the curative powers of galvanism was soon thoroughly shaken, and the voltaic pile ranged together with talismans, amulets, animal magnetism, and mesmerism, amongst the curative treasures of charlatans.

Further physical and physiological discoveries on the nature and properties of galvanism were evidently necessary before it could be employed with a fair chance of success in the treatment of disease. It was in Italy that thirty years afterwards the physiological part of the subject was more thoroughly investigated, especially by Nobili, Marianini, and Matteucci; while Becquerel in France, Daniell and Grove in England, and Bunsen in Germany, invented galvanic batteries which furnished a much more constant current, and one, therefore, more applicable for medical purposes than that yielded by the original voltaic pile.

In 1825, Sarlandière,* who had much experience of the beneficial effects of acupuncture in certain diseases, recommended to combine the application of electricity with acupuncture (electro-puncture). Sarlandière is generally mentioned as the inventor of *galvano-puncture,* but it appears from his work that he used only frictional electricity, and not galvanism. Galvano-puncture was probably first used by Fabré-Palaprat,† who translated La Beaume's‡ unreliable treatise, and added to it fantastic dogmas of his own. A more scientific use of galvanism was made by Magendie, who from 1830 to 1840 used this agent in many cases with considerable success, chiefly by means of galvano-puncture. During the next twenty years it was more the surgical than the medical application of galvanism which was studied and practised. Thus Gérard and Pravaz, seeing that the blood could be coagulated by the galvanic current, proposed to utilise this discovery for the cure of aneurisms; Mr. Liston was the first to use galvano-puncture in a case of this kind, and M. Ciniselli the first who did so successfully. It having been shown that wires should be readily rendered incandescent by voltaic electricity, Steinheil, Mr. Marshall, Prof.

* Mémoires sur l'électro-puncture considérée comme moyen nouveau de traiter efficacement la goutte, les rhumatismes et les affections nerveuses, et sur l'emploi du moxa japonais en France. Paris, 1825.

† Du Galvanisme appliqué à la Médecine. Paris, 1828.

‡ On Galvanism, with observations on its chymical properties and medical efficacity in chronic diseases. London, 1826.

Middeldorff and M. Amussat used the galvanic cautery in a number of surgical diseases. Prévost and Dumas, M. Bonnet, and Dr. Bence Jones, succeeded in decomposing urinary calculi by means of galvanism, and Mr. Spencer Wells applied the same agent for promoting the growth of healthy granulations and the cicatrisation of ulcers.

To Professor Remak,* of Berlin, the merit is due of having again directed the attention of the profession to the use of the continuous current in nervous and muscular affections, and having shown that, if properly applied, it may produce beneficial effects in diseases of the nervous centres and of the sympathetic system of nerves. The singularly objectionable manner in which Remak brought forward his discoveries did much to discredit his writings and damage his reputation; but, within the last few years, a great reaction in favour of Remak has set in, and many of his apparently most reckless assertions have, by accumulated experience, been shown to be correct. This better appreciation of Remak's discoveries, and the re-introduction of the continuous galvanic current into medical practice, has been chiefly due to the labours of M. Benedict,† of Vienna, M. Moritz Meyer,‡ of Berlin, and the author of the present

* Galvanotherapie der Nerven- und Muskelkrankheiten. Berlin, 1858. And Application du courant constant au traitement des Névroses. Paris, 1865.

† Electrotherapie. Vienna, 1868. And many papers in Austrian and German journals.

‡ Die Electricität in ihrer Anwendung auf practische Medicin. 3rd edition. Berlin, 1868.

treatise.* The author has likewise endeavoured to introduce the scientific use of the electrolytic effects of the continuous galvanic current into surgical practice.†

II.—MEDICAL APPLICATION OF THE CONTINUOUS GALVANIC CURRENT.

Under this head I shall describe both the apparatus and the methods of applying galvanism in those diseases which fall within the province of the physician; while the galvanic cautery and the electrolytic treatment of surgical diseases will be subsequently considered.

1. *Batteries furnishing a Continuous Galvanic Current.*—I consider the following requisites indispensable for machines of this kind. (1.) They should furnish a large quantity of electricity. (2.) The current should not be subjected to any considerable variations within a certain time (say one or two months). (3.) The apparatus should be handy and fit for use in the consulting and sick room (acid vapours being particularly objectionable). (4.) The number of cells should be considerable, so as to allow the dose of electricity to be given in an individual case to be exactly adapted to the nature of the malady and the constitution of the patient.

* On the value of Galvanism and Electro-Magnetism in Medicine and Surgery. London, 1868; and many papers in the Lancet, Medical Times and Gazette, and other journals.

† On the Electrolytic Treatment of Tumours and other Surgical diseases. London, 1867.

a. *Inconstant Batteries.*—The original voltaic pile has entirely disappeared from medical practice, as it is not only very troublesome to keep in order, but also extremely unreliable.

A new modification of the old voltaic pile has lately been recommended by Professor Hammond,* of New York. In this instrument the copper and zinc plates are perforated, and soldered together. At the bottom of the pile is a plate of hard india-rubber, upon which is placed a pair of copper and zinc with a copper wire soldered to the copper plate; upon this pair is laid a piece of flannel or woollen cloth, equal in size to the pair; then follows another pair, another piece of flannel and so on. The pairs are so placed that the copper is always below. Another copper wire is soldered to the zinc plate of the last pair. For putting the machine into action strong vinegar is poured upon the top; this passes through the pairs and moistens the flannel; a saucer underneath receives the excess of the vinegar. On the top of the instrument are two other plates of india-rubber, having each a large hole in the centre, and four holes for an equal number of hard india-rubber rods, by which the instrument is hung to an iron or brass support. Insulated wires are used to connect the poles with the electrodes. This instrument is certainly better than the original voltaic pile, but far inferior to the constant batteries of Daniell, Grove, Smee, Bunsen, and Stöhrer.

* Quarterly Journal of Psychological Medicine, etc. July, 1867. Vol. i. p. 62.

Another modification of the voltaic pile, which was much used some time ago, is *Cruikshank's battery.* It has the advantage of being easily manipulated, but its current is as inconstant as that of the voltaic pile. It consists of plates of copper and zinc, which are arranged in wooden troughs. One trough generally contains fifty pairs, so that two troughs furnish a rather strong current. To excite the battery, water, salt water, or acidulated water, is used: if distilled water be employed, the chemical action is very feeble; but with acidulated water the current often attains a considerable degree of power.

Cruikshank's battery was a decided improvement on the original pile, but has now been completely superseded by more convenient and reliable instruments.

Wollaston's battery has the advantage that the

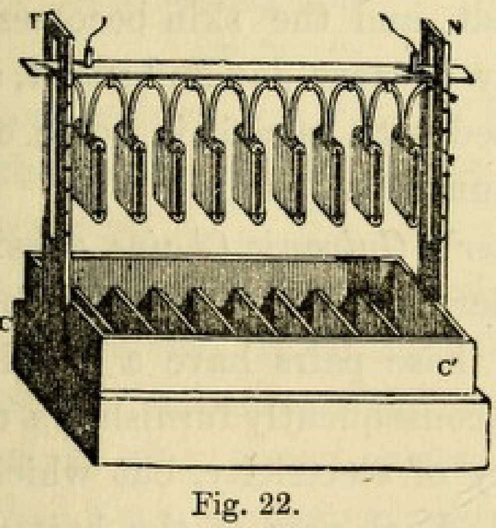


Fig. 22.

pairs of copper and zinc can be easily immersed in, and withdrawn from, the exciting liquid; but the current furnished by it is likewise in constant.

Amongst the portable modifications of the original voltaic pile, the instruments of Récamier, Pulvermacher, Breton, and Prudhomme deserve special mention.

The *Galvanic Poultice* of M. Récamier consists of pieces of cotton-wool, which contain minute particles of zinc and copper, each pair being separated by a piece of flannel. The wool is placed in a bag, one surface of which is made of an air-tight and impermeable substance (gutta-percha), the other of cotton. The permeable surface of the bag is applied to the skin and fixed by a binder; the impermeable side retains the perspiration, which soon accumulates in a liquid state and causes the pile to act. The effect is more powerful if the flannel is wetted with vinegar. One of these poultices, bound tightly to the skin, produces a sensation of warmth; if two of them are applied, pricking is felt, and the skin becomes red. This apparatus may be worn day and night, and is said to have been used with benefit in some cases of amenorrhœa, rheumatism, etc.

Pulvermacher's Galvanic Chains consist of a more or less considerable number of pairs, forming a little voltaic pile; these pairs have a small surface, and the apparatus consequently furnishes a comparatively small quantity of electricity, but which possesses a high tension. Each pair of the battery consists of a piece of wood, round which are coiled a zinc wire and a brass wire: each wire terminates in a ring, by which it is connected with the heterogeneous wire of the next link, that is, the zinc with the brass, and the brass with the zinc. At one end of the chain the zinc wire is free, forming the positive pole ; at the other end the brass wire is free, forming the negative pole. If these chains are immersed in

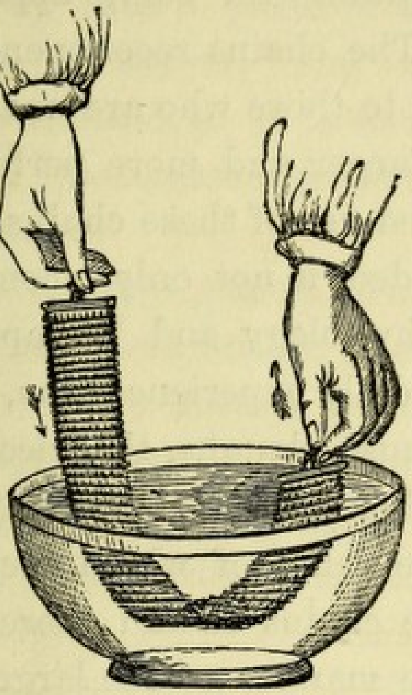


Fig. 23.

vinegar, the wood is impregnated with fluid, whereby the action of the battery is excited, the wood serving as a moist conductor.

The inventor has frequently modified the construction of these chains, and in the last form given to them has done away with the wood, using merely a hollow cylinder of zinc, round which the brass is coiled. This has the advantage of allowing the zinc to be replaced when it has been destroyed by the chemical action of the battery. Pulvermacher's chains are portable, handy, and easily put in action ;

but they have the drawback inherent to all modifications of the original voltaic pile, viz. that the current generated by them is liable to great and sudden variations within a very short time. Moreover, in consequence of their small surface, and high tension, they are not suitable for being applied to the nervous centres. The chains recommend themselves by their cheapness to those who are unable or unwilling to procure the larger and more perfect instruments. A very prolonged use of these chains, which is generally recommended, is not only inconsistent with all principles of physiology and therapeutics, but also condemned by daily experience; as, when thus employed, they cause sloughs, the cicatrices of which remain throughout life, and often aggravate the disorder for the relief of which they were brought into play. The chains should therefore be used in nearly the same manner as the larger batteries, and which will be presently described.

Messrs. Breton Frères, of Paris, have constructed a *Galvanic Belt*, consisting of zinc and copper plates, which are separated from each other by a moist mastic; it furnishes very little electricity. *Breton's Electric Mixture* consists of two pastes, one of which contains zinc, and the other copper in a pulverised state, mixed with sawdust and chloride of calcium, in order to keep it moist.

Innumerable varieties of galvanic belts and similar portable machines have since then been constructed, but which it is not necessary to describe. The only one which appears to give a somewhat constant current is Prudhomme's modification of Marié-Davy's sulphate of lead battery (p.40).

This consists of a disc of zinc of the size of a two-shilling piece, a ring of pasteboard the interior of which is filled up with a paste of sulphate of lead, and a thin disc of copper. Any number of such pairs may be connected so as to form a belt, which, according to M. Prudhomme, preserves its efficacity for four or five days.

b. *Constant Batteries.*—Almost all constant batteries now in use are modifications of Daniell's, Bunsen's, and Smee's pair, while Grove's arrangement has, on account of its high price, the difficulty of managing it, and the necessity of using nitric acid for its charge, completely disappeared from medical practice.

Remak's apparatus (Fig. 24) consists essentially of four parts, viz. the battery, B, the dial for regulating the power of the current, S, a contrivance for changing the direction of the same, C, and a galvanometer, for showing the condition of the battery, G. The battery consists of sixty pairs of Siemens and Halske's modification of Daniell's pair, viz. zinc and copper, with water and a concentrated solution of sulphate of copper. Each of these pairs is, by means of telegraph wires, connected with the dial, the commutator, and the galvanometer. The dial is furnished with two sets of five knobs each, standing in a semicircle. One of these is marked 2, 4, 6, 8, 10, and

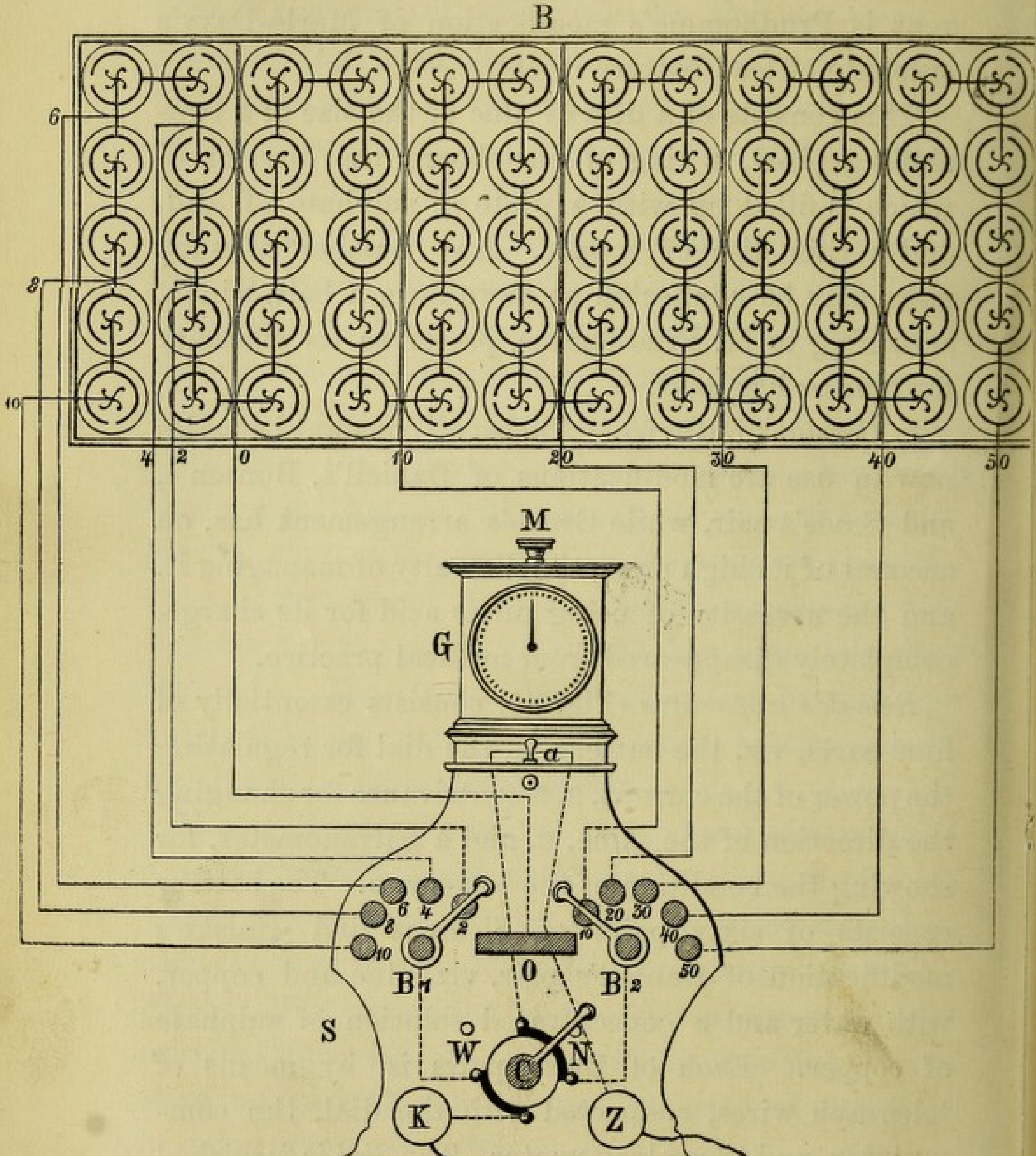


Fig. 24.

the other 10, 20, 30, 40, 50. In the middle of each semicircle is fixed a hand-plate, B_1, B_2, which may be turned so as to touch any of the metallic knobs connected with the wires. B_1 gives a current of from two to ten pairs, while B_2 yields the same of from ten to fifty. If, for instance, a current of eight cells is desired, the hand-plate B_1 is placed to the knob 8, while B_2 is made to touch the board marked 0. If it is intended to use 26 cells, B_1 is made to touch 6, and B_2 put on 20, and so on. If both B_1 and B_2 touch 0, there is no current at all.

The conducting wires are connected with the binding-screws, K, copper, and Z, zinc. If the hand-plate of the commutator, C, marks N, the positive current travels through K into the human body, and through Z to the negative pole of the battery; but if the hand-plate marks W, the direction of the current is reversed. The galvanometer, G, shows the intensity of the current as soon as the stopper *a* is removed, so as to allow the transmission of the current to the instrument. M is a brass knob furnished with a small magnetic rod, by means of which the position of the needle may be rectified, in case it should have become faulty, and show a deflection when no current passes through it. This apparatus may be procured from Messrs Krüger and Hirschmann, of Berlin, the successors of Siemens and Halske.

Apparatus used by the Author.—The apparatus which I generally use for the consulting-room consists of 100 cells of that modification of Daniell's which is known as Muirhead's battery. Ten pairs of copper and zinc are immersed, the zinc in water contained in a porcelain vase, and the copper in a cell of porous earthenware, filled with a solution of sulphate of copper; the whole of this is contained in a deal box furnished with a lid, which can be shut so as to prevent the evaporation of the water. There are ten such boxes. Each set of five cells is connected with a telegraph wire, which is carried from the basement of the house, where the battery is placed, through holes in the ceiling of the basement, and in the floor of the consulting-room, to a pole-board conveniently fixed on the wall of the consulting-room. The wires are connected with two dials, one of which gives a current of from 5 to 45, and the other from 50 to 100 cells. A galvanometer is connected with the pole-board, so as to give an exact indication of the strength of the battery. This instrument has been built up for me by Messrs. Elliott.

A battery of a somewhat similar kind is in use in the Electrical Room of the Infirmary for Epilepsy and Paralysis, Charles Street, Portman Square; only with this difference, that a contrivance has been added for allowing the use of the electricity in different parts of the building, without moving either the machine or the patients. The battery, which is of considerable size, is enclosed in a cupboard in the consulting-room, and each set of cells is connected, not with one, as is usually the case, but with several telegraph wires. One set of these wires is conducted to a pole-board fixed on the wall over a couch upon which patients may sit or lie down while being galvanised. The cells are arranged in sets from five to five, and the different points of contact marked by numbers, so that by putting the conducting wires into one or another of the several perforated knobs, we may at once obtain all the different graduations of galvanic power which may be required. Another set of telegraph wires, which is enclosed in india-rubber casing, is carried up through the ceiling into the first floor, where a pole-board, similar to the one just described, is fixed on the wall between two beds, and where the current may be used with the same convenience as downstairs. This arrangement, which has been suggested by myself, and ably carried out by Mr. Foveaux (Weiss and Son), is found to work extremely well in practice. It is hardly necessary to mention that this battery must only be used in one place at a time.

As portable apparatus, I have for some years used a modification of Bunsen's battery, which was constructed for me by Messrs. Legendre and Morin, of Paris. This consists of thirty cells, contained in an elegant mahogany case, and is not very heavy. Each cell is four inches high, and has a circumference of five inches. The carbon used in it is that known as Deleuil's carbon, which is prepared from the deposits formed in the Paris gas-works, and is distinguished by its hardness, uniformity, durability, and its property of giving, with nitric acid and zinc, a very powerful current; one such cell, if charged with 50 per cent. nitric acid, is sufficient to put into action large induction machines. The apparatus is clean. There is no escape of acid fumes, for the cells are entirely closed up by a cover of vulcanite. The dose of electricity to be given may be exactly measured. The plates which establish the connection between the several cells are perforated, so that conducting wires may be stuck into any of them, and thus, at a moment's notice, a current of any power may be obtained. The machine would, in fact, be perfect, if it did not have the drawback of requiring to be charged and discharged every day, which, where nitric acid is employed, is one of the greatest inflictions connected with the medical use of electricity. This alone is the reason why I have for some time past given up the use of this machine, with which I was in every other respect well satisfied.

Mr. Foveaux has recently constructed a nice portable battery, which contains fifty cells of Smee's, charged with diluted sulphuric acid (1 in 8), and contained in a mahogany case. This battery is equal in intensity to Muirhead's. The plates may be immersed into the solution by means of a simple screw arrangement, and lifted out in the same way without any trouble. The cells are made of vulcanite, and deeper than is necessary for the requisite amount of fluid, by which the operator is enabled to carry the battery about without fear of spilling the liquid.

Benedict's Battery consists of thirty-six pairs of Smee's, similar to Foveaux's. Smee's battery being not nearly as constant as Daniell's,—Benedict's and Foveaux's machines are chiefly suitable for out-door practice, while for the consulting-room Daniell's is much preferable.

Stöhrer's apparatus is a modification of Bunsen's battery, charged with chromic and nitric acid, or with a mixture of diluted sulphuric acid and bichromate of potash. Twenty-four or thirty-two such pairs are combined to form a pile. The plates may be immersed in and lifted out of the liquid, so that the apparatus is always ready to act, yet no consumption of zinc or deterioration of liquids takes place when the machine is not used.

Frommhold's apparatus (Fig. 25).—This consists of thirty-two pairs of zinc, lead and platinum moor, which latter substances are substituted for silver. It is furnished with a dial and galvanometer as usual. By means of a peculiar arrangement it is possible to immerse the plates more or less deeply into the exciting liquid, so that not only intensity, but quantity likewise, may be changed during the application.

Thomsen's apparatus.—This machine has the peculiarity of containing only one galvanic pair, but which is made to furnish a sufficient amount of electricity, by utilising the principle of polarisation. The pair used is either zinc and carbon, or zinc and platinum, charged with nitric or chromic acid, and must readily decompose water. The battery itself consists of two open boxes, each of which is, by means of twenty-six platinum plates, divided into

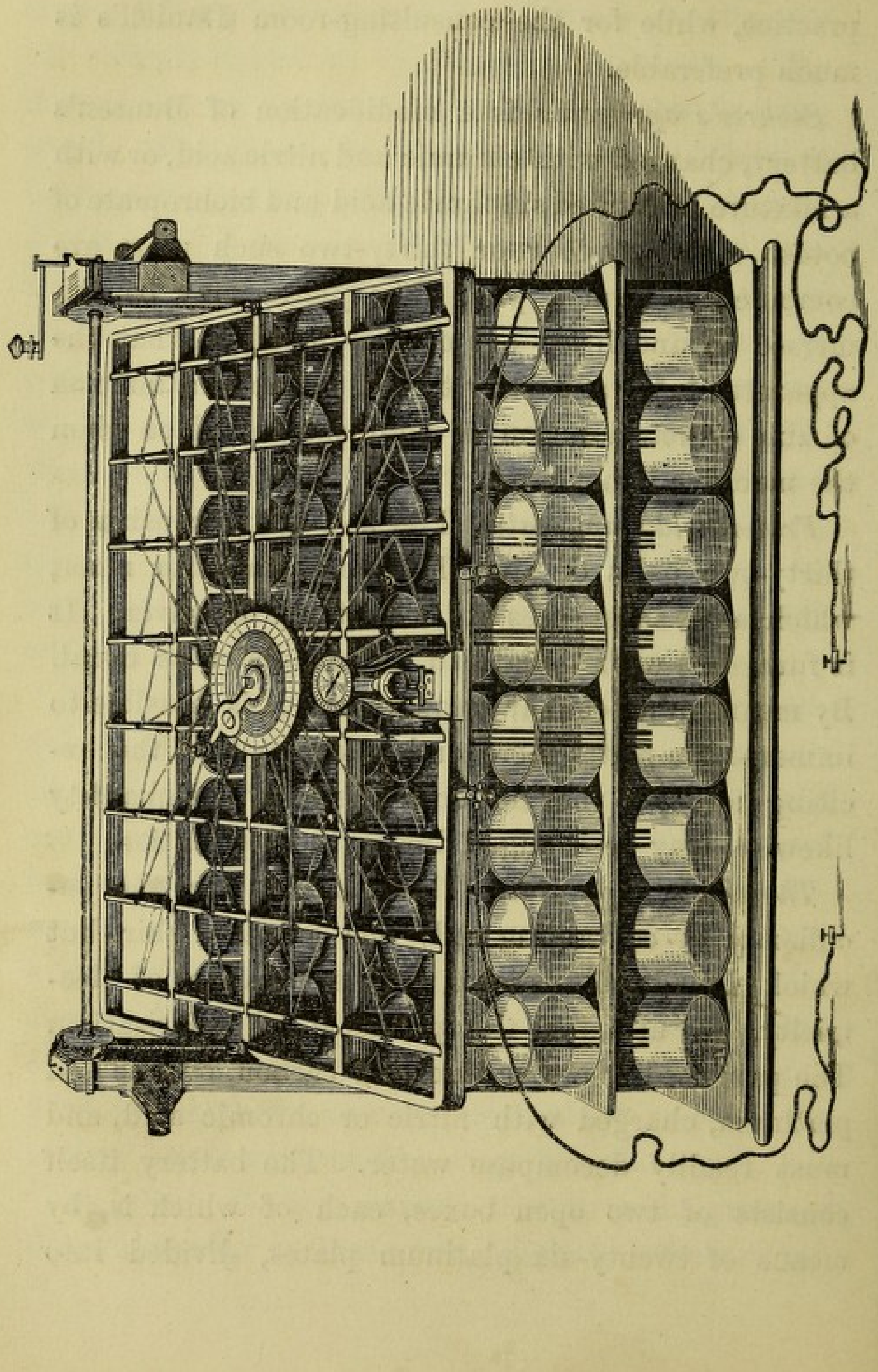


Fig. 25.

twenty-five cells, so that one side of each plate belongs to one cell, and the other to the next cell. Now we know that if two platinum plates, immersed into diluted sulphuric acid, are touched with the poles of a galvanic battery, and the latter is then removed, while the two plates are connected by means of a wire, an electric current is generated which travels in a direction opposite to that of the battery. The plates are, in fact, polarised by the deposit of hydrogen on one, and of oxygen on the other. Both these gases being in the nascent state, they quickly combine again to form water, and the electric current produced by their appearance has therefore a short duration ; on the other hand, it is easy in a very short time to charge by polarisation a large number of plates, so that, if the latter are combined to form a battery, a current of high tension may be obtained, the duration of which is prolonged by means of the following contrivance :—A flat ring, made of an insulating material, contains as many pieces of metal as there are plates in the battery, each piece being connected with the corresponding plate by means of a fine silver or copper wire. The ring is traversed by a horizontal axis, furnished at the top with two branches insulated from one another, and connected with two clamps for receiving the conducting wires of the galvanic battery. The two branches represent the poles of the pair, and carry a spring, so arranged that if one of them touches the metal pieces of the ring, the other spring touches the next. This axis may be turned round by means of a weight, or clock-work, or a hammer, such as is used in induction machines; and in this manner each plate is successively charged with hydrogen on one side and oxygen on the other. One turn of the axis therefore charges the whole battery, which is thus always ready to act. The intensity of the current is regulated by the more or less intense action of the galvanic pair, and this is regulated by interpolating a metallic wire of different lengths into the circuit, so as to increase or diminish the resistance of the pair *ad libitum*. The apparatus is expensive, but does not require any subsequent outlay, and, being portable, may in time come to be extensively used for out-door medical electric practice.

Other instruments.—The most essential instruments besides the battery are *conducting wires*, from one to three yards long, and insulated with silk or cotton, or some similar material; and *electrodes*, the form of which varies considerably, but which are, for most cases, metallic cups with a diameter of from half an inch to three inches, fixed to insulating handles, and furnished with a screw or clamp for the attachment of the conducting wires. These cups are filled with sponge moistened with warm water or salt water. The sponge must project completely beyond the metal, so that during the application the metal does not touch the skin. I have in some cases found it useful to have two sponge-cups branched off from one stem, so that two separate points may receive the influence of one pole at the same time.

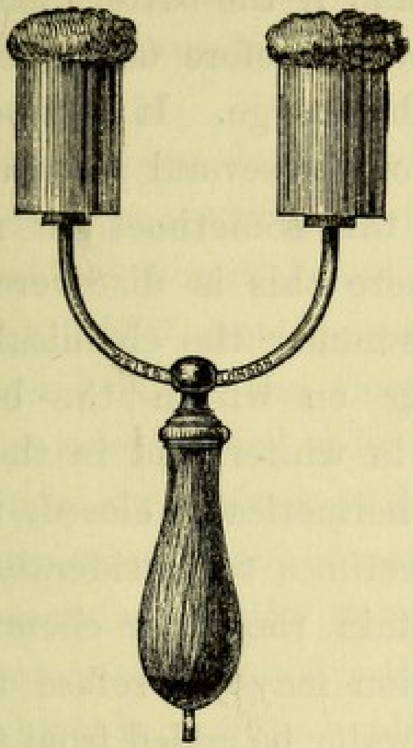


Fig. 26.

Electrodes, suitable for internal application, will be subsequently described; the terms '*conductors*' and '*directors*' are occasionally used in the following chapters as synonymous with 'electrodes.'

I always employ different conducting wires for the two poles, in order to be able to tell at once the direction of the current, viz. wires insulated by green silk for the negative pole, and such insulated by red silk for the positive pole.

The Battery at fault.—If no effect can be obtained from the battery, the fault must be either in the *battery* itself, or in the *conducting wires*, or in the *electrodes.*

Most of the constant batteries which have just been described require a fresh charge only every two or three months; and if the battery has therefore been charged a few weeks before use, it is not likely that the fault is in the charge. It may be due to imperfect connection of the several pairs, as the plates or wires used for this sometimes get rusty or out of place; and where this is discovered, it must be rectified. In summer the chemical decomposition which is going on within the battery is more extensive than in winter, and in those instruments which are not hermetically closed, the evaporation of water is sometimes so considerable that batteries which may contain the other chemical ingredients in good condition may yet refuse to act, unless a fresh supply of water be added from time to time.

Another cause of disappointment may be a bad condition of the conducting wires, which establish the connection between the battery and the electrodes. Conducting wires should be made of flexible copper thread, and be carefully insulated by silk or cotton, which are the most reliable substances. Flexible india-rubber, which is frequently used, and protects the wires better from without, is nevertheless one of the worst substances for insulation, as it contains a certain quantity of sulphuric acid, which rapidly corrodes the metal, even if the wire be first covered with silk or cotton. I have therefore long ago given up the use of india-rubber insulation, as being most deceptive and leading to great disappointment. It should also be borne in mind that conducting wires, however well they may have been insulated in the first instance, suffer a good deal from wear and tear, and should, therefore, from time to time be replaced by fresh ones.

If the battery and the conducting wires are in order, and yet no action is perceptible, the fault must be in the electrodes, which should always be scrupulously clean, and have a bright metallic surface. There is little difficulty in keeping the electrode connected with the negative pole in good order, since hydrogen and alkalies, which are evolved at the negative pole during the transmission of the current to the human body, have no corroding action upon metals. It is, however, different with the instrument used for the positive pole, which is rapidly oxidised and chlorinated, and therefore soon becomes a bad conductor. This condition of the positive electrode is a frequent cause of a battery not yielding a proper current, and should be looked to before the commencement of the application. The sponges which are used likewise require to be frequently renewed, especially when they assume a greenish-blue colour, showing that they have become impregnated with a solution of copper.

2. *Method of Medical Application of the Continuous Galvanic Current.*—Before commencing the application of galvanism to a patient, it is advisable to ascertain whether the battery is in good working order or not, more especially if it is quite new, or if it has not been used for some time past. This may

be done, first, by interpolating a galvanoscope into the circuit, when the deflection of the needle will tell the presence, and to some extent also the power, of the current which traverses it; second, by immersing the ends of the conducting wires in water, when the development of hydrogen gas at the negative pole, and the blackening of the wire at the positive pole, will give a similar indication; third, by using, instead of water, a solution of iodide of potassium and starch, when a blue colour will be produced at the positive pole; fourth, by the operator applying the lowest degree of galvanic power which he has at his disposal to his tongue, and the highest to the back of his hand. The last test is not only the readiest, but also the most important, as no other experiment gives a better hint for the selection of the galvanic power to be used in cases of disease.

Another point of importance is that, on first applying the current to a patient a very low degree of power is employed. Patients are often in fear of 'shocks,' and nothing soothes their trepidation more than the perception of a slight and pleasant sensation, instead of a severe and painful one, which they had been expecting. Moreover, it is by no means necessary for therapeutical success to employ a current so strong as to be painful to bear.

It may be laid down as a general principle that a feeble current, used for a short time, produces the greatest therapeutical effect. A current which is strong and painful to bear almost always does harm instead *of good, and more especially so when it is applied for a considerable length of time.*

The only exception to this rule of short applications is formed by certain spasmodic diseases, in which more prolonged applications are necessary than in paralytic, neuralgic, and anæsthetic conditions.

I now proceed to describe the way in which the continuous galvanic current should be applied to the different organs of the body.

a. *Galvanisation of the Brain.*—If it is intended to send the galvanic current through the whole of the cerebral substance, three different modes of application may be used, viz. first to apply one pole to the forehead and another to the occiput; second, one to the left and one to the right temple; and, third, one to the left and the other to the right mastoid process. If, on the other hand, we wish to galvanise only one hemisphere, as, for instance, in hemiplegia, it is best to put one pole over the eyebrow and the other to or near the mastoid process of the same side. With regard to the direction of the current, Benedict has recommended to place the positive pole to the cervical spine, and the negative to the right or left side of the forehead. I do not think that this direction should invariably be followed, since I have found that it is best determined by the sensations experienced by the patient. If, for instance, the patient should complain of a feeling of fulness, pain, or weight and pressure on the forehead, it is advisable to apply the positive pole there; but if such sensations are experienced at the occiput, the negative pole should be applied in front. Where the patient does not complain of the head, that direction should be chosen which appears to do most good.

A short time ago, I had a patient suffering from hemiplegia under my care, who, when the positive pole was directed to the brow, and the negative to the cervical spine, felt, after the application, so light, 'as if she could fly;' while, when the position of the poles was reversed, a slight sensation of fulness and heaviness in the head was experienced. On discovering such differences, that direction which yields the most favourable effects should always be selected.

Benedict has justly laid stress upon the necessity of *short* applications ('never more than half a minute'). Meyer recommends an application of two or three minutes' duration; but this is for many cases too long. I am in the habit of employing the current from thirty to ninety seconds at a time. The result of the first or second application generally gives the clue as to what length of time the application should last; if the shortest time seems to answer, it is not necessary to try a longer one, as sometimes the benefit already obtained is thereby counterbalanced. A current of from fifteen to twenty cells of Muirhead's battery is all that is required.

A powerful continuous current applied to the brain in the way just described may produce giddiness, fulness and pain in the head, sickness, vomiting, blindness, general convulsions, paralysis, and other symptoms of profound cerebral disturbance. The same symptoms may be caused by the too prolonged application of a more feeble current. *Sapienti sat.*

b. *Galvanisation of the Spinal Cord.*—The whole cord may be galvanised by directing one pole to the upper, and the other one to the lower portion of the spine. As a rule, it is the best plan to direct the positive pole to the point which is believed to be the seat of the disease, and the negative either to another point of the spine, or somewhere near the positive on the ribs. With regard to the direction of the current, it appears that if the seat of the disease is in the upper portion of the cord, the direction of the current should be inverse; but if we look for it in the lower part of that organ, the positive pole should be above the negative. Where one or several vertebræ are painful or sensitive to pressure, the current should be directed to them principally. As a rule, the applications to the cord must be longer than those to the brain; but it is rarely advisable to go beyond three minutes. The intensity of the current used must be regulated by the sensations experienced by the patient; if pain is caused, the current is too strong; but it is necessary to produce distinct sensations of pricking and heat. Some patients bear only ten or fifteen cells, while in others from 50 to 60 are required.

c. *Galvanisation of the Cervical Sympathetic.*—For this the negative pole is applied to the superior cervical ganglion in the stylo-mastoid fossa, below and behind the angle of the lower jaw; while the positive is placed either above the manubrium sterni, on the internal side of the sterno-mastoid muscle, or to the seventh cervical vertebra. By the latter application the upper portion of the spinal cord is included in the circuit, while by the former the pneumogastric nerve is affected. A localised application to the cervical sympathetic in the living subject is therefore impossible.

In some cases it is necessary to galvanise both cervical sympathetics; for instance, where the whole of the cerebral substance appears to be suffering; in other cases the current is applied merely to the sympathetic of the suffering side.

The application to the sympathetic should rarely go beyond one minute. A slight amount of giddiness on opening the circuit is unavoidable, and harmless; but if the giddiness should be felt for some time after the application, and be accompanied with tinnitus aurium, the application has been either too long or too strong. For the sympathetic a slightly higher galvanic power is generally required than for the brain.

Diplegic Contractions.—This term has been proposed by Remak* for designating certain reflex contractions which appear chiefly if the continuous current is used in cases of progressive muscular atrophy and arthritis nodosa, and are caused by the action of the current on the sympathetic. Accord-

* De l'application, etc. p. 27.

ing to Remak the two points from which these contractions are most easily produced are the fossa auriculo-maxillaris of the opposite side, corresponding to the ganglion cervicale superius, and to this point the *positive* pole connected with a small conductor should be applied; and the sixth cervical vertebra of the same side, to which the *negative* pole, connected with a large electrode, should be directed. Sometimes the second point is lower down on the spine than the sixth cervical vertebra; and Remak has therefore distinguished several zones, viz. the *cervical zone*, which is the spine above the fifth cervical vertebra; the *upper dorsal zone*, which goes from the fifth cervical to the sixth dorsal vertebra; and the *lower dorsal zone*, from the sixth dorsal vertebra downwards to the sacrum, or even to the lower extremity. According to the same observer these contractions are more easily produced in recent cases than in such of long standing.

Fieber,* who has studied this subject, agrees with Remak in almost every particular, except in so far as he obtained diplegic contractions, not only with the continuous, but with the induced current likewise; and that he observed them not only in progressive muscular atrophy, but also in cases of rheumatic paralysis, lead palsy, and cerebral and spinal paralysis. They may continue beyond the application, and resemble choreic movements.

* Berliner klinische Wochenschrift, 1868. No. 23.

Meyer* has observed diplegic contractions in an anæmic girl, with paralysis and atrophy of the upper extremities, in consequence of chronic arsenical poisoning; and found that they could be produced not only by placing the directors to the points indicated by Remak, but also by putting them to the right or left side of the spine, or one to the pit of the stomach and the other to the dorsal spine. It therefore appears that for causing these contractions the current need not act on the ganglion cervicale superius.

According to Benedict,† these contractions appear chiefly where there is increased reflex excitability throughout the system, and where the sympathetic is sensitive to pressure. This agrees with my experience, for I have observed them chiefly in hysterical patients, and have found that they could not be produced when reflex excitability had been diminished by treatment, as, for instance, after a course of bromide of potassium.

d. *Galvanisation of the Pneumogastric Nerve.*—This operation, which is appropriate in cases of true asthma, nervous indigestion, and diabetes, is so performed that the negative electrode is placed near the angle of the lower jaw on the carotid artery, and the positive electrode to the manubrium sterni, on the inner edge of the sterno-mastoid muscle. The application should as a rule not exceed two minutes at a time.

e. *Galvanisation of the Roots of the Spinal Nerves*

* L. c. p. 157. † L. c. p. 69.

has been strongly recommended by Benedict, and is carried out so that the positive pole is placed to the top of that portion of the spinal cord which is diseased, while the negative pole is slowly passed thirty or forty times down the sides of the vertebral column. The intensity of the current should be proportional to the sensibility of the patient and the result of each application. Where a neuralgic affection of the leg is believed to be caused by a lesion of the corresponding spinal roots, the positive pole is placed to the first lumbar vertebra, and the negative pole passed down at the side of the spinous processes of the lumbar vertebræ and the sacrum.

f. *Galvanisation of the Nerves and Muscles.*—For galvanising the nerves and muscles various methods are used. In some cases the cord is included in, while in others it is excluded from, the circuit. Where the cord is excluded, the positive pole is directed to a point of the skin where a nerve-trunk is easily accessible, and the negative pole is applied to a more peripheral part. If it is intended to include the cord, the method varies again according to the part of that organ which is comprehended; sometimes the positive pole is placed to the lumbar portion, in other cases to the dorsal, or even to the cervical portion of the cord. Other things being equal, the effect is greater the more central is the part of the cord which is acted upon. I have found, in a number of cases of paralysis and anæsthesia of the lower extremities, that a peripheral application from nerve to muscle produced no contraction or sensation, even if a powerful current was used; that a slight effect was caused by including the *lumbar* portion of the cord, while powerful contractions and sensations ensued when the positive pole was directed to the *cervical* spine, more especially to the seventh cervical vertebra. The peripheral application is generally used where the seat of the affection is peripheral; while in central affections both central and peripheral application may be employed. Where the affection seems to be seated in the vaso-motor nerves, the positive pole may be placed to the superior cervical ganglion, and the negative to the suffering parts.

The method varies further according as the poles are held fixed on the skin, or whether they are moved about. The former method was by Remak called '*stabile*,' and the latter '*labile*' application. In the present work these two proceedings are termed '*continuative*' and '*intermittent*' application. Details on this subject will be found in the fifth chapter; but it may be laid down as a general rule, which of course is liable to exceptions, that in cases of paralysis and anæsthesia, the intermittent, and in cases of spasm and hyperæsthesia, the continuative, application is to be preferred.

g. *Galvanisation of the Auditory Nerve.*—In cases of nervous deafness the application of the continuous current to the auditory nerve is worth a trial. The proceeding is as follows:—The patient being in the recumbent position, the external meatus is filled with warm water, and an insulated sound, with a metallic top, connected with one of the poles of the apparatus, is held into the water, while a moistened electrode is placed in the neighbourhood. From ten to fifteen cells are generally sufficient, and voltaic alternatives often prove very useful. The application should be intermittent, and not be prolonged beyond two or three minutes at a time.

h. *Galvanisation of the Rectum.*—In certain cases of intestinal atony, especially meteorism and tympanites, the continuous current produces bracing effects superior to those of any other remedy. In such cases a rectal conductor is inserted into the rectum for from four to six inches, the circuit being

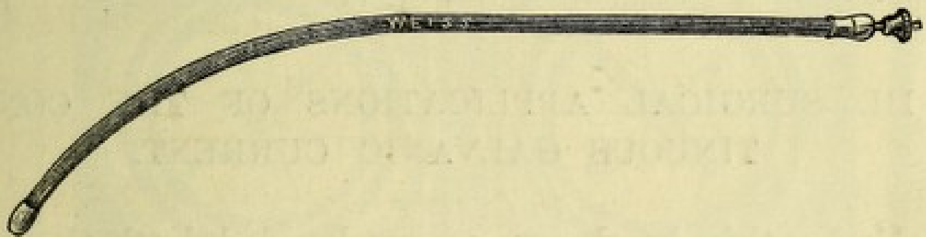


Fig. 27.

closed by the continuative or intermittent application of a moistened sponge to the abdominal parietes.

i. *Galvanisation of the Urethra.*—In cases of spermatorrhœa and impotency, the application of

Fig. 28.

the continuous current to the prostatic portion of the urethra is often followed by excellent results.

The circuit is closed in spermatorrhœa by continuative, and in impotency by intermittent, application of a sponge connected with the other pole to the groin.

k. *Galvano-puncture.*—As a rule, galvano-puncture is rarely used in the treatment of any but surgical diseases, the reason for this being that it is more painful than the ordinary application of moistened conductors to the uninjured skin. In certain cases, however, galvano-puncture may produce decided effects after the ordinary application has failed. These cases are generally such of great severity and of very long standing, or of patients whose sensibility is unusually dull. The mode of proceeding will be described under the head of 'Electrolysis.'

III.—SURGICAL APPLICATIONS OF THE CONTINUOUS GALVANIC CURRENT.

Under this head are comprehended both the galvanic cautery and electrolysis.

1. THE GALVANIC CAUTERY. a. *Batteries for galvanic cauterisation.*—We have already seen that, for utilising the *calorific* effects of galvanism, a few cells with large surface are the best apparatus, as the essential resistance of the circuit is proportionately slight in such an arrangement (p. 51). The batteries principally used for the galvanic cautery are the following:—

Middeldorpff's apparatus.—This consists of four large cells of Grove's battery (d and f), contained in four different compartments of a wooden box. The cylinders of zinc are placed in cylinders of glass containing diluted sulphuric acid, and have a surface of 312 square inches. Inside the zinc are placed

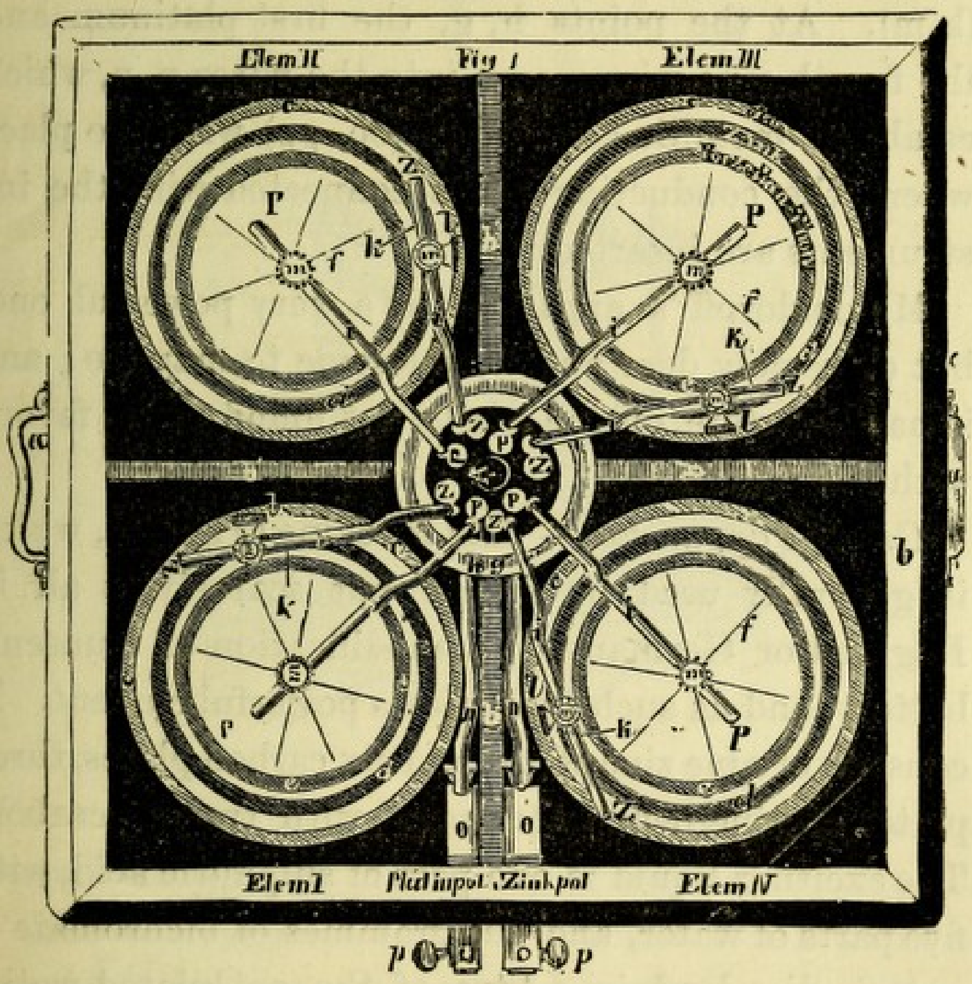


Fig. 29.

cells of unglazed porcelain, filled with nitric acid, for the reception of the platinum plates. Each plate consists of three parts, bent double, so as to form a star of six rays (f m), the surface of which amounts to 250 square inches. Both zinc and platinum are furnished with contrivances for fixing the conducting wires. In the centre of the box is the commutator (A), which contains eight small cups for the reception of mercury, which itself receives the conducting wires (i) coming from the zincs (zzzz), and platinums (PPPP), and fixed by means of a screw arrangement (k m). At the points h, g, the first platinum and the fourth zinc wire merge into the wires n, n, which establish metallic connection (oo, pp) with the place where the conducting wires connected with the instruments are inserted.

Middeldorpff's apparatus is a very powerful one, but extremely dear and troublesome to manage; and it has therefore, on the whole, not found much favour with the profession.

Grenet's apparatus.—This machine (Fig. 30), which is generally used in France, but scarcely at all in England or Germany, is a modification of Bunsen's battery, and as such furnishes a powerful current. It consists of nine zinc plates and six carbon plates, three plates of zinc being connected with two of carbon. The exciting liquid is one part of sulphuric acid, with five parts of water, and 100 grammes of bichromate of potash dissolved in a litre of the acidulated water. This being a strong charge, the battery would be very inconstant if there were not an ingenious contrivance for keeping the liquid in a state of constant agitation by blowing air into it with a pair of bellows. After this has been done for a few seconds, the wire is rendered incandescent. Grenet's apparatus is too bulky, and the arrangement of liquid and plates not easy enough; moreover, it generally requires to be discharged after having been used, or it will not again act easily, and the work of the assistant who has to manage the bellows is generally very heavy.

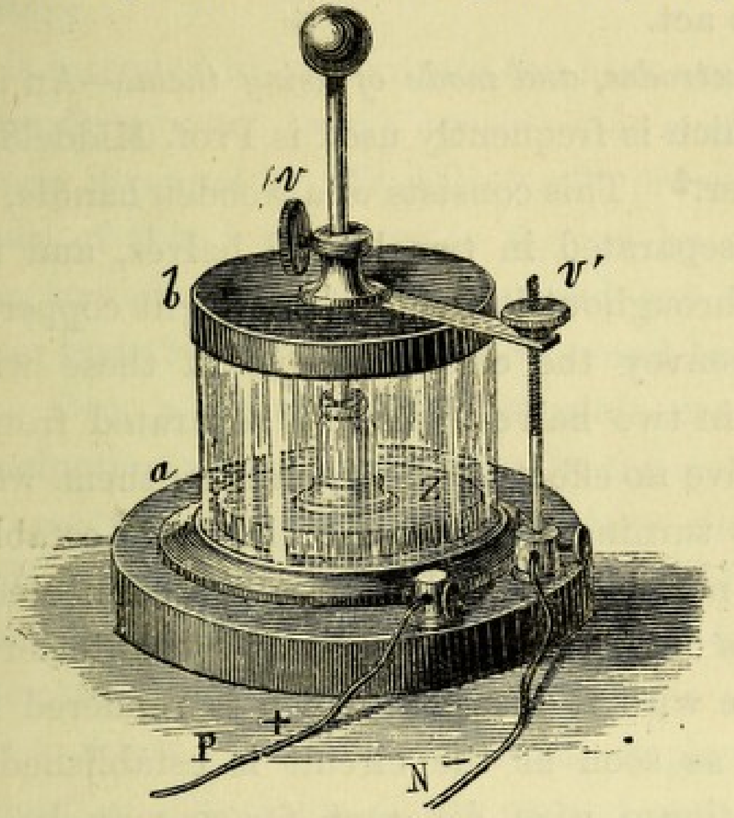


Fig. 30.

These I believe to be the chief reasons why the apparatus has not found favour out of France.

Stöhrer's apparatus.—This consists of six pairs of Bunsen's battery, charged with nitric and diluted sulphuric acid. It is powerful, and not nearly so expensive as Middeldorpff's apparatus. A regulator allows to modify the intensity of the current in an easy manner; and as the plates may be lifted out of the liquid after use, the battery is more constant than Grenet's.

Foveaux's battery.—This is composed of four large plates of Smee's battery, charged with diluted sulphuric acid. By means of a screw arrangement, the plates may be lifted out of the liquid when the apparatus is not in use, so that the battery is always ready to act.

b. *Electrodes, and mode of using them.*—An instrument which is frequently used is Prof. Middeldorpff's cauteriser.* This consists of a wooden handle, which can be separated in two lateral halves, and is traversed throughout its length by two gilt copper wires, which convey the current. One of these wires is divided in two halves, which, if separated from each other, give no effect; while by uniting them, which is done by turning a screw, the circuit is established. At the posterior end the wires are connected with the poles of the battery; while at the anterior end a platinum wire is inserted, which is rendered incandescent as soon as the circuit is established. To this platinum wire different forms may be given, according to the shape of the tissues upon which we desire to act. The instrument may, therefore, be introduced while cold into a cavity; when it is in the right place, the circuit is made by uniting the two parts of one of the conducting wires; cauterisation then takes place, and may be at once discontinued, by separating the two parts of the wire, after which the instrument can be removed without injury to the organs touched by it.

Prof. Middeldorpff has also constructed a gal-

* Die Galvanokaustik. Breslau, 1854.

vanic porte-ligature and a galvanic seton; the latter consists of platinum wires of different diameter, which are conducted by means of needles through such tissues as are to be subjected to the action of the cautery.

If it is intended to concentrate the heat evolved by the galvanic current over a considerable surface, an instrument invented by Mr. Ellis* will prove useful. The body of this instrument is formed by a silver catheter, straightened out, and the end cut off. At the upper end the catheter is slit open and broached, so as to form a socket for the porcelain cauteriser. Two conducting wires connected with the poles of a battery are placed within the catheter; their free extremities are connected with a piece of platinum wire, which is coiled around the porcelain in order to render this incandescent. The porcelain must be brought to white heat. Mr. Ellis has employed this instrument in induration of the os and cervix uteri, in ulceration of the os, prolapsus uteri, and prolapsus of the anterior wall of the vagina. In cases of this kind, a glass speculum coated with gum-elastic is first introduced into the vagina; the os is then cleansed with a piece of wool, the cautery heated, and quenched in the diseased tissue; the duration of the application and the depth of its introduction depending upon the effect required. Eschars are easily produced, and the cervix uteri is often seen to contract under the application of the cautery.

* The Lancet, 1853, Vol. II. p. 502.

2. *The Electrolytic Treatment of Surgical Diseases.*—All batteries which have been described under the

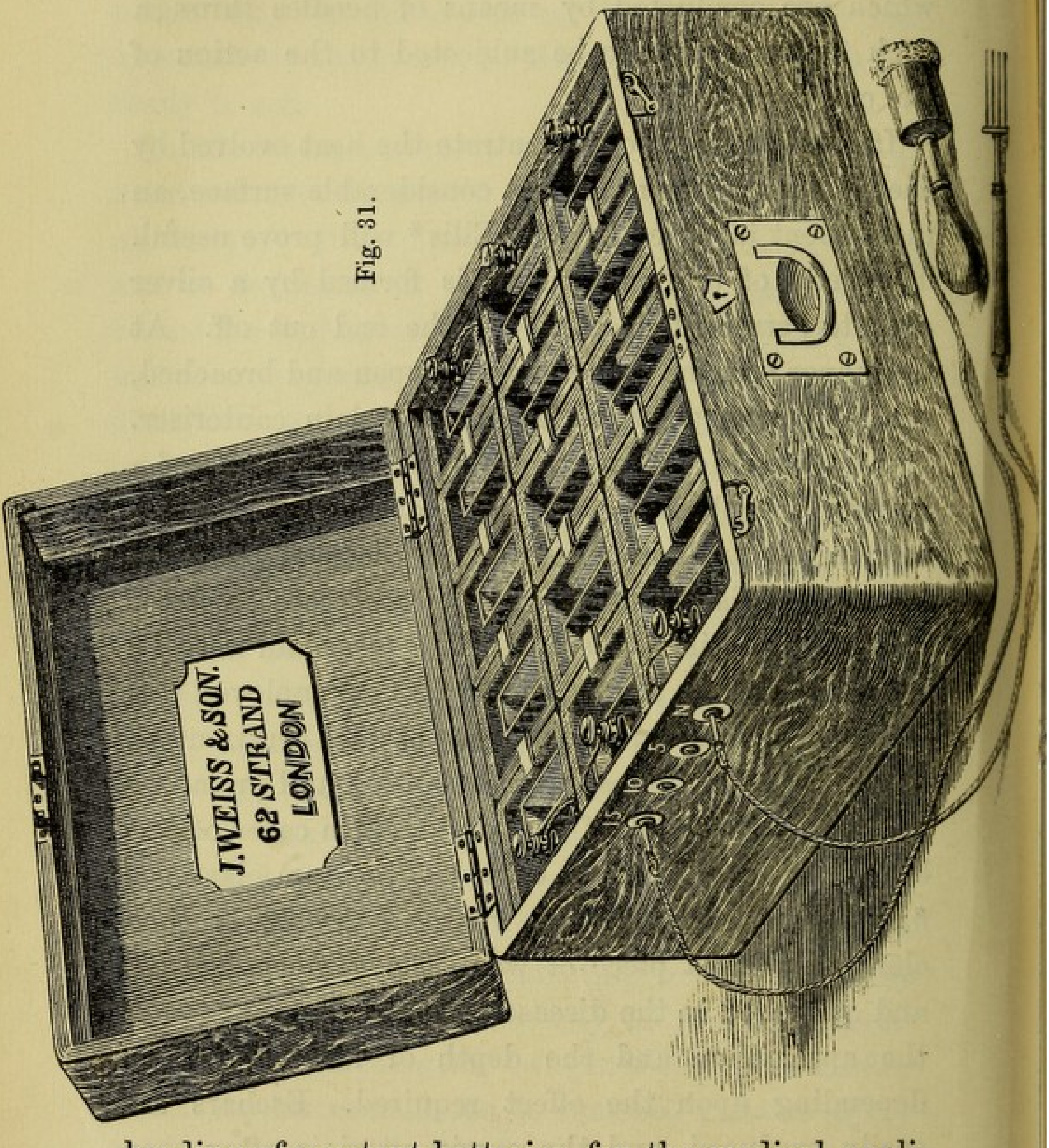


Fig. 31.

heading of constant batteries, for the medical application of the continuous current, may be usefully employed for electrolysis.

The Author's Battery for Electrolysis.—This consists of fifteen cells of Daniell's battery, so modified that the porous cell and the porcelain vase have been dispensed with, the latter being replaced by vulcanite, which is much lighter and quite as durable as porcelain; while the former is compensated for by the copper of the pair being perforated, and the holes filled up with leather, which is easily penetrated by moisture. The zinc is then immersed into water, the copper vessel being filled with a solution of sulphate of copper; and, in order to prevent the fluids from spilling when the battery is carried about, they are intimately mixed with sawdust, so that a dry pile is produced which is nearly as effective as the ordinary arrangement. The current furnished by this battery, if carefully charged, continues reliable for two or three months. During the whole of that time no thought need be given to the battery, which is always ready to act, and only gradually loses a certain amount of its intensity. Every two or three months it should be taken to pieces, the zinc cleaned, and a fresh solution of sulphate of copper substituted for the one previously used. The weight of the battery is about thirty-five pounds, and it is thus sufficiently light to be taken in and out of a patient's room. No acid fumes are developed, and the instrument is by no means unsightly.

I was first led to adopt the electrolytic treatment for the treatment of tumours in consequence of a series of microscopical observations I made some time ago, on the changes which animal structures undergo, under the influence of the chemical action of the continuous galvanic current. No observations had previously been made by any other observer in this department of microscopical research; and knowing the powerful electrolytic effects of the continuous current, I expected to arrive at some curious results in undertaking these investigations.

I have studied the action of the current upon the intimate structure of the skin and cellular tissue, muscular fibres and tendons, cartilages and bones, liver and pancreas, spleen and thyroid body, kidneys, and suprarenal capsules, testicles, breasts and ovaries. The general result of these investigations has been that no animal tissue whatever can withstand the disintegrating effect of the negative pole, and that the force and rapidity with which this disintegration is brought about are directly proportional to the electro-motive force which is employed, and to the softness and vascularity of the structures acted upon. Thus ten cells of a battery have a more thorough and rapid effect than five, fifteen more than ten, and so on; while, as regards the tissues, those containing most water, such as the muscles, the cellular tissue, the spleen, &c., are more rapidly disintegrated than those which contain less fluid. Bones and teeth withstand the action of the current for a considerable time.

A most curious and novel circumstance forced itself early on my attention; and this was, that the electrolytic action of the negative pole on animal tissues was mainly composed of two different elements, viz. of the mechanical action of the nascent hydrogen, which was, under the microscope, seen to rise in innumerable bubbles as soon as the circuit was closed, and to force itself, as it were, between the structural elements of the tissues, driving their fibres mechanically asunder; and secondly, of the chemical action of the alkalies, soda, potash, and lime, which, together with hydrogen, are developed at the negative pole of the battery.

No galvanic heat is produced if the current is applied in such a manner that the whole body, or part of the body, or animal liquids, are placed within the circuit of the battery; as is done, for instance, if a needle connected with the negative pole is inserted into the depth of a tumour, while a moistened conductor connected with the positive pole is placed outside on the skin. This is proved by the following experiment:—I immersed the two poles of the battery, at a certain distance from each other, into blood, thus letting the current travel from the positive to the negative pole, and *vice versâ*, and I then read off the temperature at the poles as well as in the liquid itself, on a Negretti and Zambra's thermometer, which allows variations of one-tenth of a degree of Fahrenheit to be distinctly determined. Now I found that whether I used five, ten, fifteen, or twenty cells of the battery, no elevation of temperature took place. The effects of a current administered in this way are therefore simply electrolytic, and have nothing whatever to do with the galvanic cautery.

Seeing that such powerful effects were produced at the negative pole on structures taken out of the body, I was naturally anxious to enquire what would be the effect of the same in the living body. Having procured some *corpora vilia*, viz. frogs and rabbits, I found that the effects were, to a certain extent, identical with those obtained on dead structures; only with this difference, that in the warm-blooded animal the action was more rapid and energetic, which is explained by the fact that water at a temperature of 98° conducts electricity better than water at 60°. While, however, the immediate effects of the current were nearly the same in dead and living structures, considerable changes in the nutrition of the parts were observed as proximate and remote sequelæ of such operations in living animals.

It was then observed that needles connected with the negative pole of the battery could be inserted into, and removed from, the body without causing any loss of blood; that the current used did not appear to give any pain to the animal beyond what was due to the introduction of the needles through the skin; and that the parts operated upon shrank sensibly after the operation, but that there was neither inflammation, suppuration, nor sloughing. If the negative pole was made to act upon blood-vessels, it was found that they were filled with a foreign body, due to disintegration of the blood, and round which afterwards a slow deposition of lamellated fibrine took place; they were thus changed into solid strings wherever the current had been made to act. It appeared fair to conclude from these observations, that the current could be safely and successfully applied to such parts of the body where shrinking and disintegration of tissue and obliteration of blood-vessels might be required for surgical purposes.

I will now say a few words about the instruments which I employ for conveying the galvanic current into the depth of the tissues. The prototype of all is a fine needle of gold or gilt steel for the negative pole, the circuit being closed by placing a moistened sponge connected with the positive pole outside on the skin.

Fig. 32.

Most of the other instruments are modifications of the needle. I use conductors from which two, four, six, and eight needles are made to branch off, to suit the requirements of the different cases as they present themselves (Figs. 33, 34, 35, 36). Sometimes circular shaped conductors are required (Figs. 37 and 38). For the treatment of piles, or ulcers, conductors with a larger surface are better suited; viz. blunt blades (Fig. 39), and round plates of different size (Fig. 40). All these conductors are made of gold or gilt metal, and insulated by ebonite.

The electrode, however, which is most universally useful is—the *serres-fines conductor* (Fig. 41), which allows the introduction of from one to six needles *ad libitum*, and in any direction that may be required. It consists of a conducting wire, which at its end is

Fig. 33.

Fig. 34.

Fig. 35.

Fig. 36.

Fig. 37.

Fig. 38.

Fig. 39.

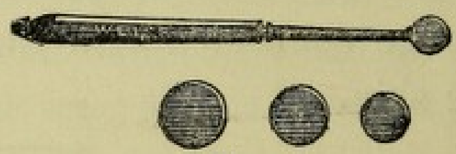


Fig. 40.

made to branch off into six or more conducting wires of equal diameter, the ends of which are connected with serres-fines, by means of which the heads of the needles may be grasped after their introduction into the substance of the tumour. Single needles are introduced more readily into the depth of the tissues than connected rows of needles; besides which, by means of this instrument the needles may be introduced in any direction that may appear most suitable, which with fixed rows of needles is not so easily practicable.

The introduction of needles through the skin must always be unpleasant to the patient; I therefore, as a rule, render the skin insensible to pain by means

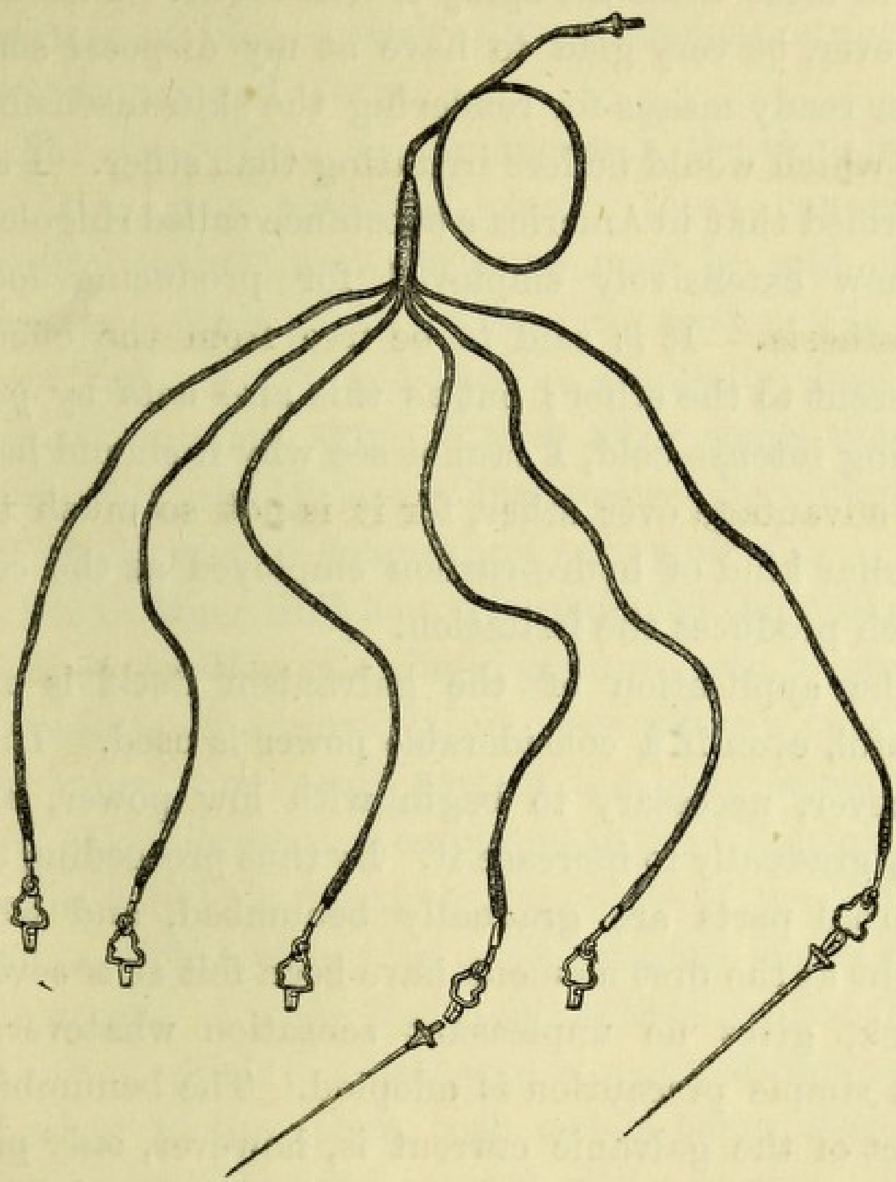


Fig. 41.

of ether spray before introducing the needles. Some patients are extremely intolerant of the ether, and represent it as very unpleasant, not so much perhaps at the time of its first application as afterwards, in the period of reaction, when the frozen skin returns to its normal condition. Sometimes the skin remains red and peels off after a single application of ether, but in most cases the spray is well borne. I should, however, be very glad to have at my disposal some other ready means for rendering the skin insensible, and which would be less irritating than ether. I am informed that in America a substance called rhigolene is now extensively employed for producing local anæsthesia. It is said to be free from the effects inherent to the ether; but as this also acts by producing intense cold, I cannot see why it should have any advantage over ether, for it is not so much the peculiar kind of hydro-carbon employed as the cold which produces the irritation.

The application of the galvanism itself is not painful, even if a considerable power is used. It is, however, necessary to begin with low power, and only gradually to increase it. By thus proceeding the internal parts are gradually benumbed, and what might at the first moment have been felt as a severe shock, gives no unpleasant sensation whatever if this simple precaution is adopted. The benumbing effect of the galvanic current is, however, only produced where the current is applied internally; outside, where the positive pole is used, a sensation of heat and pricking is felt during the whole time of the application.

The force and rapidity with which the disintegration of tissues is brought about are directly proportionate to the electro-motive force which is employed, and to the softness and vascularity of the structures acted upon. Diseases in which the electrolytic treatment proves valuable are chiefly certain tumours, diseases of blood-vessels, serous effusions, strictures, and wounds and ulcers.

The sores which are produced in the skin by the negative pole resemble exactly those caused by caustic potash; and the same may be said of the cicatrices, for these latter have no tendency to contract, but are soft and become gradually similar to the surrounding skin, so that after some time no trace of a scar is perceptible, unless the action was originally very prolonged and very powerful.

Dr. Golding Bird has recommended the prolonged local application of a single galvanic pair, to produce the effects of a moxa, in all cases where a persistent discharge from some part of the body is required. The galvanic moxa is employed in the following way: —The cuticle is raised on two points of the body by means of blisters, one being placed a few inches below the other. A piece of zinc foil is then applied to the one from which the discharge is required, and a piece of silver to the other, both metals being connected by a copper wire, and covered with a plaster. If the zinc plate be raised a few hours after the circuit has been established, the surface of the skin looks whitish, as if nitrate of silver had been applied to it. In 48 hours an eschar is produced, which begins to separate four or five days afterwards. The eschar is formed by the electrolytic action of the continuous current, in consequence of which the fluid effused on the surface of the blister is decomposed, sodium being set free at the silver plate, where by oxidation it rapidly becomes soda; and chlorine being evolved at the zinc plate, where consequently chloride of zinc is formed. The chloride of zinc, originated by electrolytic action, produces the sore, which discharges pus freely if a common poultice be applied to it. While this process is going on, the patient seldom, if ever, complains of pain, probably because the caustic acts in infinitely small portions upon the skin, in proportion as it is liberated.

(C) Faradisation. I. *History of it.*—The discovery of induction currents (1831) caused, as it were, a new era in the medical application of electricity. The use of the voltaic pile had at that time been completely abandoned, constant batteries for medical use were not in existence, and the striking phenomena shown by small and handy induction machines gave rise to the belief that at last the true medical electricity had been discovered.

The first induction apparatus suited for medical use was constructed by M. Pixii; the first physician who employed induction currents for therapeutical purposes was, according to German authors, Dr. Neef, of Frankfort, while M. Tripier ascribes this merit to M. Masson, of Paris; it was, however, undoubtedly M. Duchenne, de Boulogne, who, by his able electro-physiological researches on the functions of the muscles, gave the greatest impetus to the study of medical electricity in our time. Induction machines for medical use, both volta-electric and magneto-electric, were afterwards constructed by Messrs Saxton, Clarke, Keil, Stöhrer, Breton, Du Bois-Reymond, Horne and Thornthwaite, Duchenne, Legendre and Morin, Siemens and Halske, Bernard, Baierlacher, and others. In the older of these machines all the conditions necessary for therapeutical application were not united; for in most of them only the current induced in the second wire could be utilised, and the intensity of the current, as well as the greater or lesser rapidity of the intermittences, could not be well regulated; while in those of more modern construction the necessary qualities are generally found combined.

II. *Induction Machines for medical use.*—In this place I shall first discuss the qualities which every induction machine should possess if it is to be used for therapeutical purposes, after which a short description of those machines will be given which are principally employed by medical men at the present time.

The question has been often asked whether the apparatus should be an electro-magnetic or a magneto-electric one. Both of them have had their panegyrists and adversaries.

The alleged inconveniences of electro-magnetic machines, in which the current is induced by a galvanic pair, are that they are expensive; that troublesome manipulations, involving loss of time, precede and follow the use of the machine; that it is not ready to act at a moment's notice, as it requires charging and discharging; that acids are necessary for inducing the current, whereby not only the battery, but also the coil, are rapidly spoiled; while, on the other hand, magneto-electric rotation machines are praised as cheap, always ready to act, and not requiring acids for their use. Most of the objections to volta-electric apparatuses which have just been mentioned are not applicable to the more recently constructed machines, as they are generally not expensive, ready to act at any time, without charging or discharging, and may, with some little precaution, be kept perfectly clean.

The chief inconvenience connected with the use of magneto-electric machines is that the operator requires an assistant to turn the handle connected with the endless chain of the apparatus, which puts the soft iron armature in rotation. This inconvenience, which is especially felt whenever prolonged applications are necessary, may, it is true, be avoided by the substitution of clock-work; but by this the rapidity of the intermittences cannot be so easily regulated.

Another drawback to the magneto-electric current is that the sensation produced by it is far more unpleasant than that caused by electro-magnetism, which is due to the circumstance that the current induced by voltaic electricity rises at once from zero to its maximum, and then as quickly falls back to zero; while the variations in the density of the magneto-electric current are much slower. The magneto-electric current begins when the soft iron armature is withdrawn from the pole of the permanent magnet, reaches its maximum when the armature is between the two poles, and is finally reduced to zero when the armature arrives at the opposite pole of the magnet. The volta-electric current acts, therefore, more thoroughly on the motor nerves and muscles, and less disagreeably on the sentient nerves, while the magneto-electric current has a more jerking and spasmodic effect on the muscles and sentient nerves, and if applied to the face has a slight but decided action on the retina, which latter is scarcely at all affected by the electro-magnetic current, unless this has a very high tension. The magneto-electric current is certainly more useful in rheumatism and weakness of sight than the electro-magnetic, and before the continuous current was re-introduced into practice, the magneto-electric current was the one most suitable for those affections; but now we should always employ galvanisation rather than faradisation in such cases. At the present time, therefore, magneto-electricity is, strictly speaking, not required for medical practice, although it may still find a sphere of usefulness where no constant batteries can be procured.

Doses of electricity require to be exactly measured to suit the different constitution, age, and sex of the patient, just as remedies for internal use are given by weight; therefore every induction machine should possess a regulator, by means of which the power of the current may be easily increased or diminished. The apparatus should be able to furnish currents of very high tension, or no effect would be produced in certain cases of anæsthesia and hysterical paralysis, more especially when the electricity is applied to spots where the epidermis is very thick, such as the palms of the hands and the soles of the feet; on the other hand, a gentle current is required for delicate subjects, and when acting on the face and neck.

We have seen in the first chapter that the intensity of the electro-magnetic current depends upon three conditions, viz. the intensity of the inducing current of the battery, the transverse section and the number of convolutions of the wires, and the quantity and the more or less insulated state of the soft iron in the centre of the coil. Consequently a current will be powerful if the battery is strongly charged, if the wire is long and fine, and the soft iron employed consists of a bundle of wires covered with a layer of varnish. It would be very inconvenient if we were obliged to vary all three conditions, especially the length of the wires composing the coil, whenever it is necessary to diminish the intensity of the current. Before the researches of Professor Dove on the influence of a closed tube of brass or copper on the power of the electro-magnet were generally known, it was customary to partially withdraw the soft iron from the axis of the coil, whereby the intensity of the current was diminished in proportion as the iron was withdrawn; or to have portions of the iron connected severally with metallic knobs outside, on which a hand-plate or clock in connection with one of the poles was placed, so as to branch off either a feeble or a powerful current.

It is, however, more convenient to use the brass or copper tube as regulator, as it allows of a much nicer graduation than any other arrangement. But although the current may be very feeble when the soft iron is entirely covered by the tube, it may still be too strong for some cases; so that we further require the interposition of an imperfect conductor into the circuit, whereby the resistance to the passage of the current is increased, and the strength of the current thereby still more reduced. The instrument that best answers this purpose is a glass tube, the ends of which are furnished with metal screws for receiving the conducting wires of the apparatus. A metal rod is freely movable in the tube, which is filled with water as a bad conductor. The further this metal rod be taken out of the tube, that is, the larger the layer of water that is to be traversed by the current, the more the power of the electricity is diminished, so that at last it will no longer be felt on the skin, but only occasion a slight pricking sensation when applied to the tongue or other mucous membranes. The same instrument may serve for comparing the intensity of different induction machines; since, if the layer of water remains the same, the current furnished by a feeble apparatus will not cause any sensation in the tongue, while the current of a powerful one will be at once perceptible there.

Some induction machines are so extremely powerful, that they are not suitable for therapeutical purposes. One of these is Rhumkorff's large coil machine, in which the second wire is three miles in length, whereby the current acquires a very high tension.

The largest coil, however, which has as yet been constructed is Apps's instrument, as exhibited at the Polytechnic Institution, which is nine feet ten inches long, and two feet in diameter. The length of the primary wire is 3,770 yards, and that of the secondary wire 150 miles. The soft iron in the centre of the coil is five feet long, four inches in diameter, and weighs 125 lbs.

The action of this monster coil is excited by 48 cells of Bunsen's battery, each charged with a pint of nitric acid. The coil yields a flash of light 29 inches long, and capable of perforating five inches of solid plate glass. It has been used by Dr. Richardson for physiological researches; but it would be totally unsuitable for therapeutical application.

The intensity of the magneto-electric current depends upon the power of the fixed permanent horseshoe magnet, the number of convolutions of the wires, the distance of the soft iron armature from the poles of the magnet, and the velocity with which the wheel is turned. The most powerful magneto-electric apparatus which has been constructed is that of Mr. Henley. In this machine there are two permanent magnets, each of which is composed of thirty horse-shoe steel magnets two feet and a half long and from four to five inches broad; the induction coils attached to these magnets contain about six miles of wire. The tension of the current circulating in this wire is likewise far too high for therapeutical use.

An induction apparatus fit for medical use should furnish two currents, viz. the *primary or extra-current of the thick wire, and the secondary current of the fine wire.* Duchenne has laid stress upon the fact that there is a difference in the physiological action of the primary and secondary current, the former of which acts, according to him, chiefly on the contractile power of the muscles, while the latter has more effect on the sentient nerves and on the retina, when applied by moistened conductors to any point of the face or scalp animated by the fifth pair. Duchenne has referred this difference of action to a special elective power in each of the currents, and is borne out in this supposition by M. Bouvier; but no doubt the view first put forward by M. Becquerel * is more correct, viz. that the difference in the physiological effects of the two currents is chiefly due to the difference which exists in their tension. Duchenne's observations are accurate enough, but his explanations

* Traité des applications de l'Électricité, etc. Paris, 1857.

are unsatisfactory, as much difference naturally arises from the physical condition of the wires; a current circulating in a short and thick wire possesses less tension than one passing through a long and fine wire. The primary current has therefore only a trifling effect on the skin, which offers great resistance to the passage of electricity; and more effect on the contractile power of the muscles, which are better conductors of it; while the secondary current, which possesses a high tension, does not only powerfully affect the muscles, but also the skin and retina. For the same reason a layer of water is more easily traversed by the secondary than by the primary current. Messrs. Breton Frères have shown by an experiment, in which the arrangement of the wires was modified, that the effect which has been attributed by Duchenne to the secondary current, may be obtained from the primary, and *vice versâ*. I do not, however, agree so far with M. Becquerel as to think that tension alone explains everything connected with the different physiological action of the two currents; for it should be recollected that the primary or extra-current always moves in the same direction, and has therefore feebly electrolytic effects; while the secondary current, which alternately moves in different directions, has the electrolytic effect of one intermittence neutralised by that of the next. It appears probable that this circumstance is, next to the difference in tension, of influence as far as the physiological effects of induction currents are concerned.

Another important point in the construction of an induction apparatus is the *rheotome*, *cut-current*, or *contact-breaker*, an instrument by which the circuit is successively opened and closed, and the use of which is evident, since induction currents exist only on making and breaking the circuit, but not while it remains closed. The rheotomes mostly used are the toothed wheel, the mercury rheotome, and the hammer.

a. *Toothed Wheel.*—The axis of a toothed wheel is connected with one pole of the battery, while the other is placed in contact with an elastic plate, which rests against the teeth of the wheel. As soon as a rotatory movement is imparted to the wheel, by means of a handle, the elastic plate leaps from one tooth to another, and each leap produces a rupture of the circuit, which is immediately closed again; so that, if the motion of the wheel is continued, a succession of interrupted currents is caused, which is slow or rapid according to the velocity with which the handle is turned. Although this instrument is ingenious, it presents the inconvenience of not being self-acting, and requiring an assistant to put it in motion.

b. *Mercury Rheotome.*—This consists of two insulated vessels filled with mercury, two needles, and a rod. The needles are parallel with each other, and fixed transversely to the rod, which can be moved more or less rapidly by the hand or by clock-work. The circuit is closed when the needles are plunged in the two vessels, and opened if the contact between the needles and the mercury is broken. At the moment the needles emerge from the mercury, a spark is produced, by which the mercury is oxidised; its surface is therefore soon covered with a black powder of suboxide of mercury, which prevents a perfect contact between the needles and the liquid metal. It is obvious that a rheotome which is rapidly spoilt by the action of the current is devoid of practical importance.

c. *The Hammer.*—This contrivance, which was invented by Dr. Neef, of Frankfort, and made more

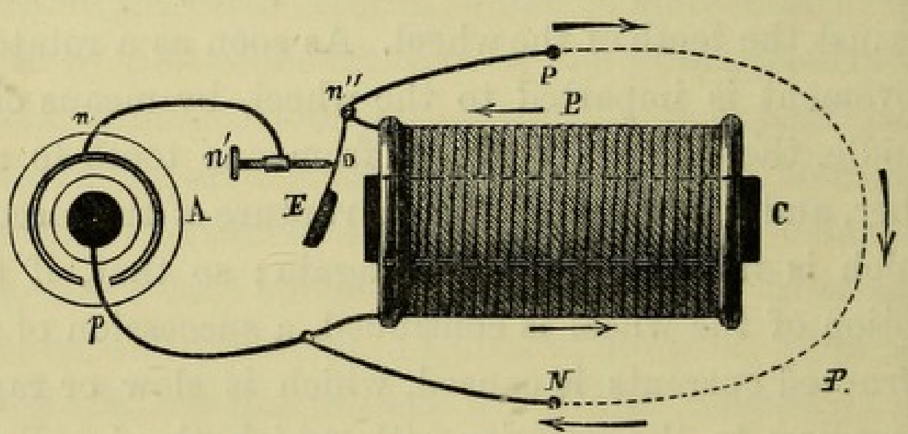


Fig. 42.

generally known by M. de la Rive, to whom the invention is sometimes wrongly attributed, is the best of all rheotomes hitherto constructed, as it is self-acting and nearly indestructible, allows of very rapid or slow interruptions of the current, and moreover notably increases the physiological effects of the same. The hammer (D E) consists of a small stem of soft iron placed beneath or above the induction coil (B); one end of this stem is fixed to a piece of metal (n″) outside the coil, while the other end, which is moveable (E), is put in motion by the temporary magnetism of the soft iron (C) in the centre of the coil. A platinum spring is soldered to the lower surface of the hammer, and rests upon a piece of copper, likewise covered with platinum. The metal stem communicates with one of the poles (n) of the battery (A), and the piece of copper covered with platinum with the other pole (P). Hence it results that the circuit is closed each time that these come in contact with each other, whereby the soft iron in the centre of the coil is magnetised, and therefore attracts the moveable end of the hammer. In consequence of this the circuit is broken, since the contact between the spring of platinum soldered to the lower surface of the hammer, and the piece of copper covered with platinum, has ceased. The central soft iron therefore loses its magnetism, and the hammer drops by its own weight into its previous position. The circuit is thus again closed, owing to which the soft iron regains its magnetism; the hammer is then once more attracted to the electro-magnet, and the circuit again interrupted. At each interruption a small spark passes between the two pieces of platinum, which causes this metal to be slowly oxidised. The surface of the platinum therefore requires to be occasionally cleaned; but a well-constructed hammer may, to all intents and purposes, be said to be indestructible.

The physiological effects of induction currents differ according to the rapidity with which they succeed each other. A rapidly-interrupted current has more effect on the nutrition and tonicity of paralysed muscles and on the sentient nerves of the skin, than one that is slowly-interrupted; but in cases where there are any symptoms of irritation, and likewise in very delicate persons, slow intermittences are preferable; every good induction apparatus should therefore be furnished with a contrivance for changing the rate of succession of the currents. This is generally accomplished by working a screw (n′ Fig. 42), which withdraws the spring of platinum soldered to the hammer from the piece of copper covered with platinum. If the distance between the two is small, the currents succeed each other rapidly; if it be increased, their succession is retarded. The differences in the slow or rapid succession of induction currents

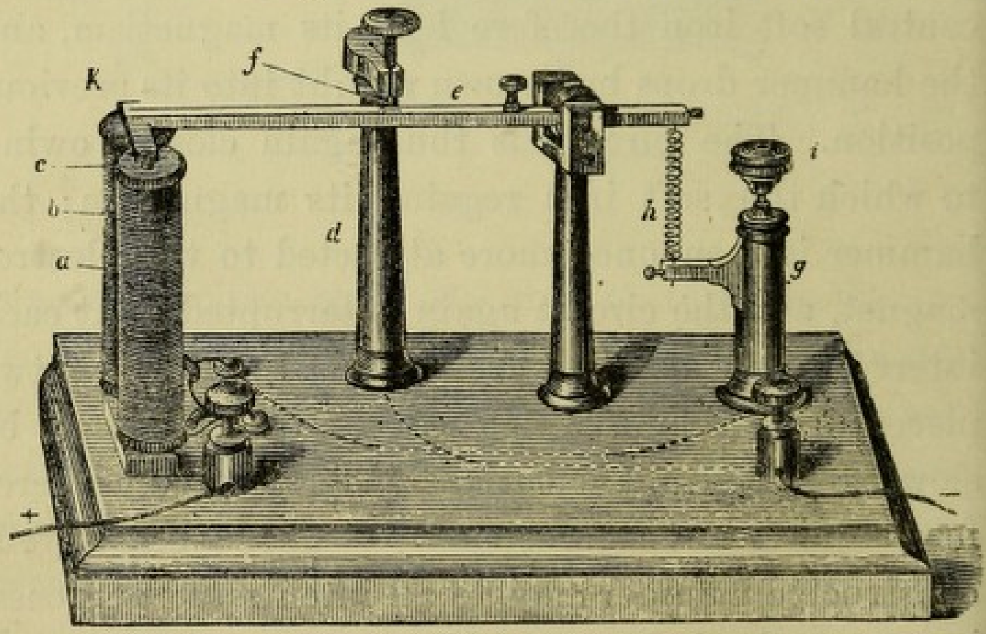


Fig. 43.

are readily distinguished by the different musical sounds produced by the play of the hammer.

Fig. 43 shows a somewhat different arrangement of the hammer. *a* and *b* are coils of copper wire, in the centre of which soft iron wire (*c*) is placed. + is the clamp for the positive wire of the battery, − for the negative. *k* is the stem of soft iron fixed to one end of a lever (*e*), and placed above the soft iron of the coil. *f* is the platinum point towards which the lever moves, and by means of which the current proceeds to the brass rod *d*, from where it returns to the battery. *h* is the spring by means of which the lever *e* is brought in contact with the platinum point, while *i* represents a screw which regulates the tension of the spring.

Several other contrivances have been proposed for effecting a continuous interruption of the induced current, such as Maelzel's métronome, which is used by musicians, etc.; but the hammer is superior to any other arrangement, and has therefore been universally adopted by mechanicians.

I now proceed to describe very shortly some induction machines which are at present or were formerly commonly used in medical practice.

a. *Electro-magnetic Machines.—The apparatus of Neef and Wagner* (Fig. 44) is of historical interest, as it was the first of this kind which was used in medicine. *a* + is the positive, *g* the negative wire, *b* and *d* are cups filled with mercury for the entrance of the wires. *f* is the commencement, *e* the end of the coil. *c* is the hammer, and *m* a copper wire which connects the hammer with the cup *d*. As soon as the battery is connected with the coil, a musical sound indicates that the machine is acting.

In *Du Bois-Reymond's apparatus* (Fig. 45) the battery is one of Bunsen's, Daniell's, or Stöhrer's. A is a clamp for receiving the negative wire of the battery,

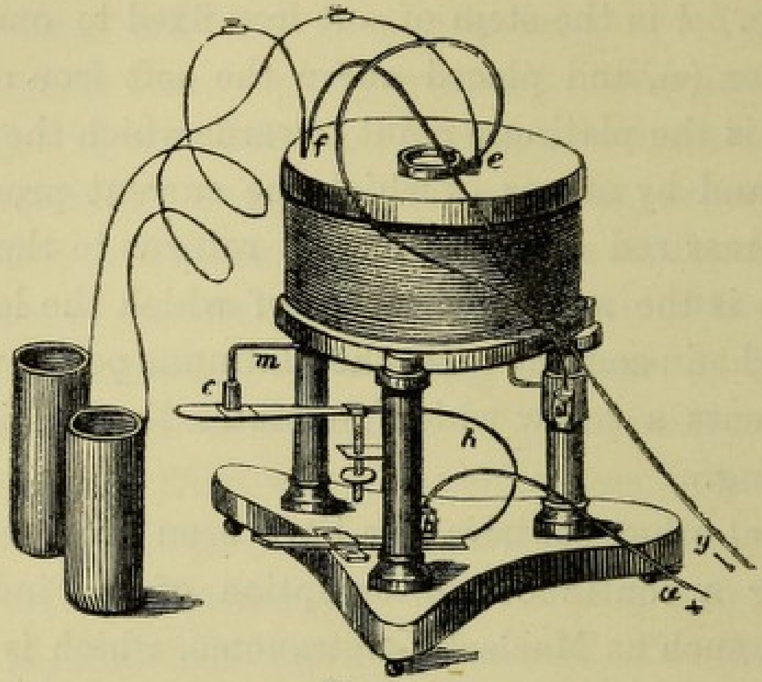


Fig. 44.

B a spiral of wire wound round a soft iron, shaped like a horseshoe, C the coil filled with soft iron wire, and

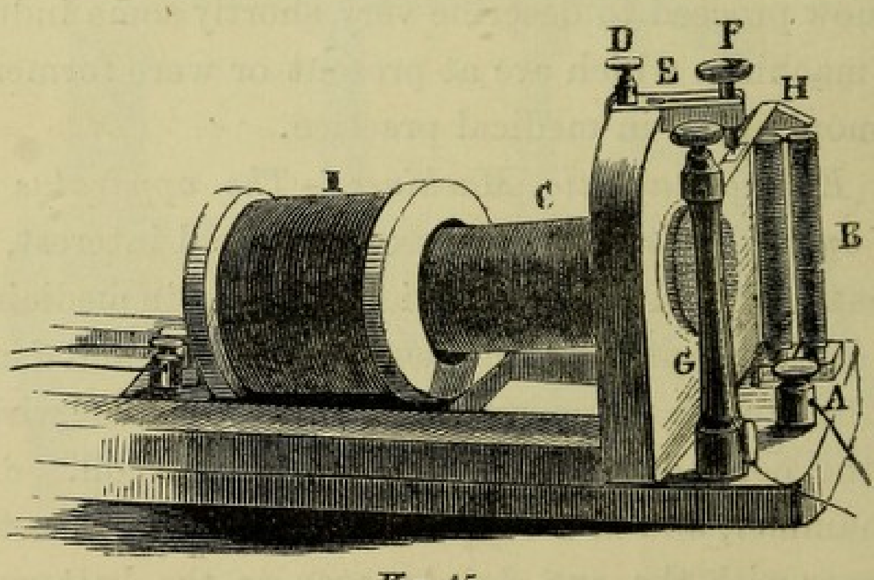


Fig. 45.

surrounded by spirals of copper wire, and D the end of this wire. E is a piece of brass which supports D and the fixing screw F, which is pointed with platinum. The positive wire of the battery proceeds to a pillar of brass, G, which at its top receives the hammer, H, and the circuit is successively made and broken by H coming in contact, first with F, and then with B. I is the 'sledge,' a cylinder which may slide on brass rails over part or the whole of the coil C, and thus regulates the intensity of the current. The secondary current may be collected from the clamps connected with I; the clamps giving the primary current are not represented in the annexed diagram. Du Bois' apparatus is excellent for the consulting-room, but not so good for out-door practice.

Siemens and Halske's instrument (Fig. 46) is a modification of Du Bois' apparatus. A A′ are clamps for

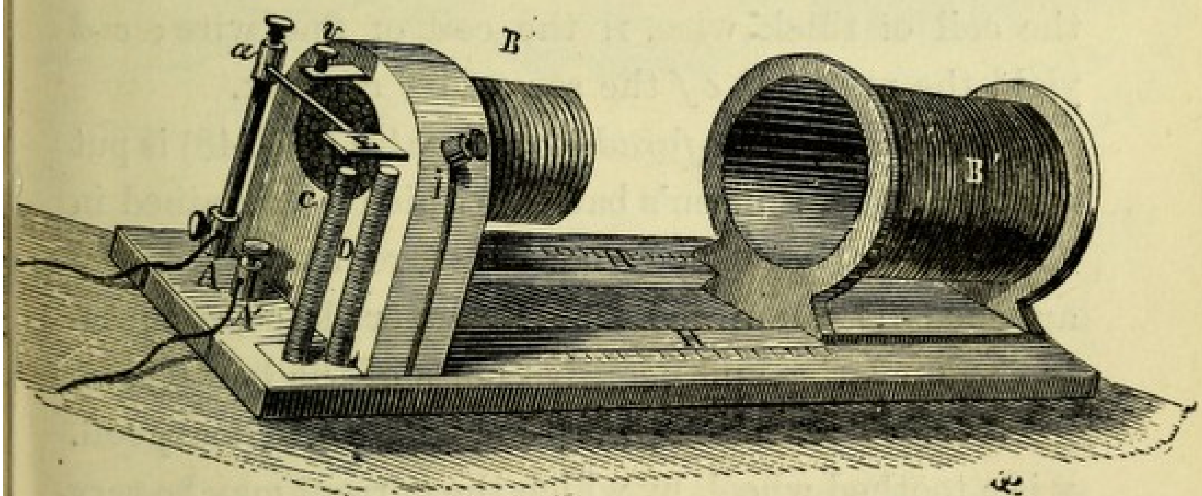


Fig. 46.

receiving the conducting wires of the battery, and connected with the primary wire of the coil. E is the hammer fixed to the pillar *a*; *v* is the screw for making the current. C is the bundle of soft iron wire, contained in the cylinder B, D the soft iron wire in the form of a horseshoe, as in Du Bois' apparatus. B′ is the coil of fine wire furnishing the secondary current; the sledge being arranged as before.

Benedict's apparatus (Fig. 47) is likewise a modification of Du Bois'. The current enters at *a b*; I is

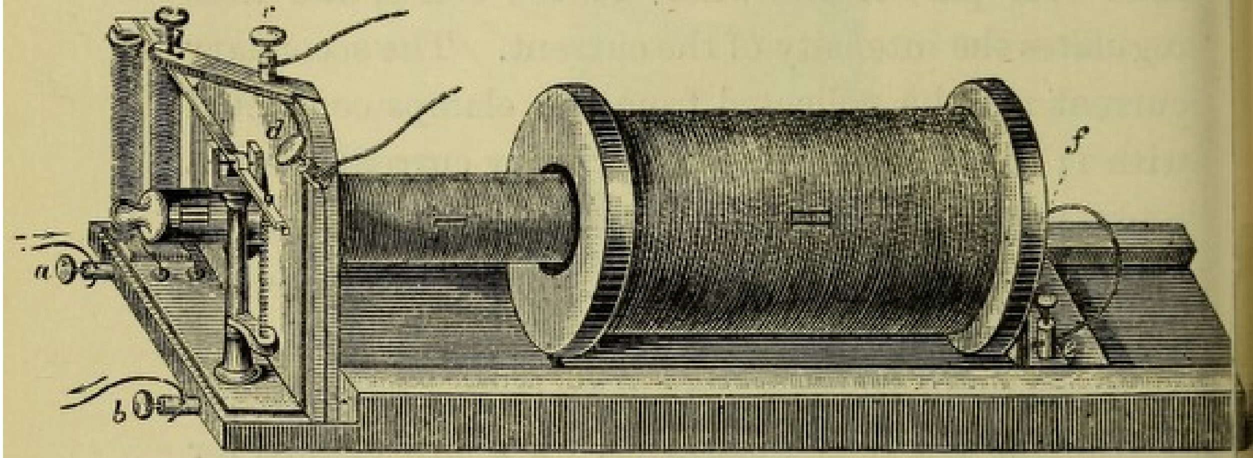


Fig. 47.

the coil of thick wire, II the coil of fine wire; *c d* yield the primary, *e f* the secondary current.

Duchenne's 'volta-faradic' apparatus (Fig. 48) is put in action by a Bunsen's battery, which is contained in the lower drawer of the wooden box represented in the annexed diagram. A and B are copper plates, connecting the positive and negative poles of the battery, by means of the platinum pieces C D, with the primary coil. K is a toothed wheel, by which the current may be very slowly interrupted; H I is the hammer which allows of rapid intermittences. E F yield the secondary current, L is the copper tube which regulates the strength of the current. G is a glass tube filled with water, by which a further diminution of the power of the current may be effected. Duchenne's apparatus is too large and heavy for out-door practice, but would be a good instrument for the consulting-room,

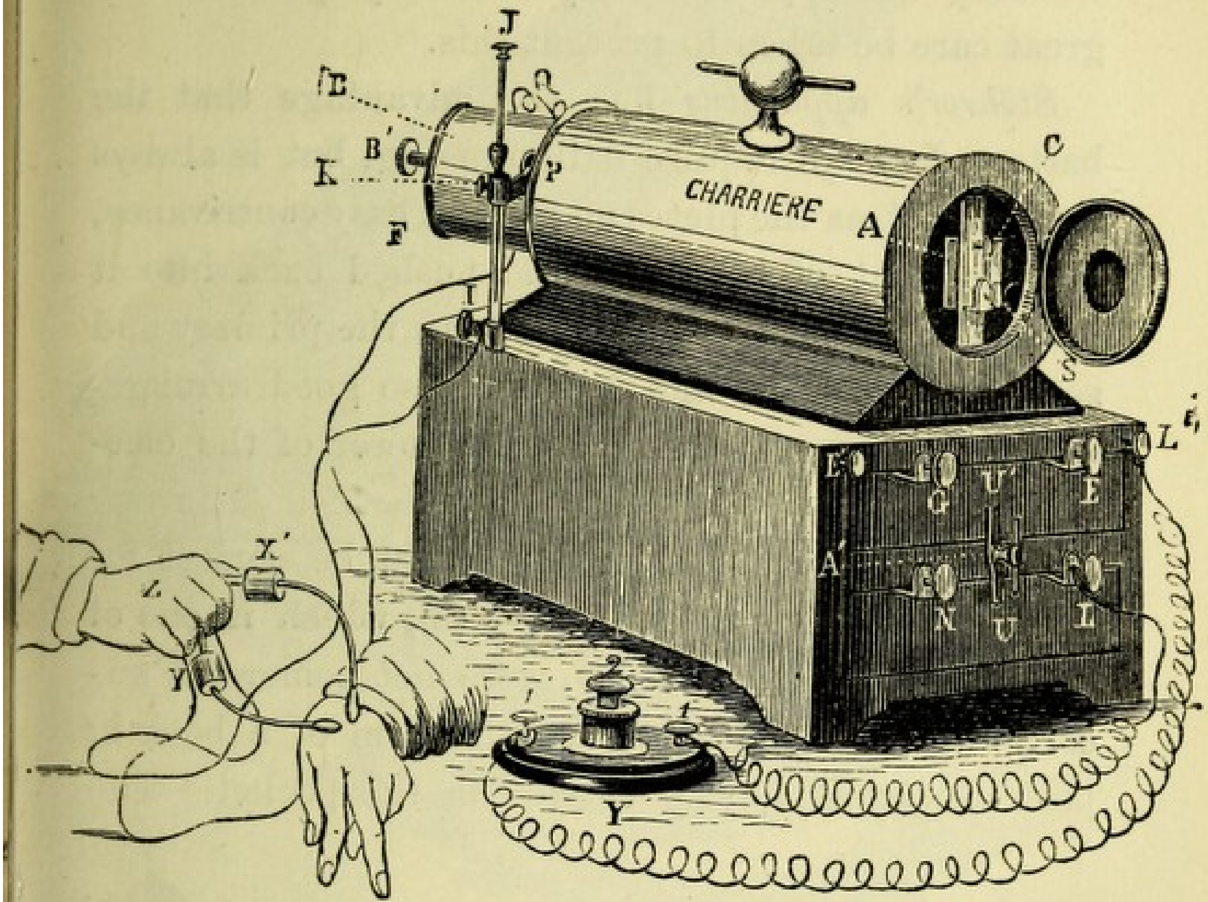


Fig. 48.

if put in action by a different battery, as the one used in it requires charging and discharging every day.

Legendre's apparatus is very generally used in France, on account of its portability and cheapness. It is a good apparatus, and one that, if kept in proper order, never fails to act. It furnishes the primary and secondary current, has a brass tube for regulating the power of the current, and a screw arrangement for rendering the intermittences rapid or slow. The principal objection to it is the battery, which is one of Bunsen's, and requires daily filling with nitric acid, whereby the apparatus may be easily spoilt, unless great care be taken to prevent this.

Stöhrer's apparatus has the advantage that the battery does not require daily nursing, but is always ready to act, as the plates may, by an easy contrivance, be lifted out of the liquid and pushed back into it for use or disuse. It furnishes both the primary and secondary current, and has likewise good arrangements for the regulation of the power of the electricity.

Gaiffe's apparatus (Fig. 49) would be perfect for out-door practice, if the battery (L), which is one of deuto-sulphate of mercury, were not somewhat uncertain in its action. It has the form of a book in post 8vo., and may be carried in the pocket. The

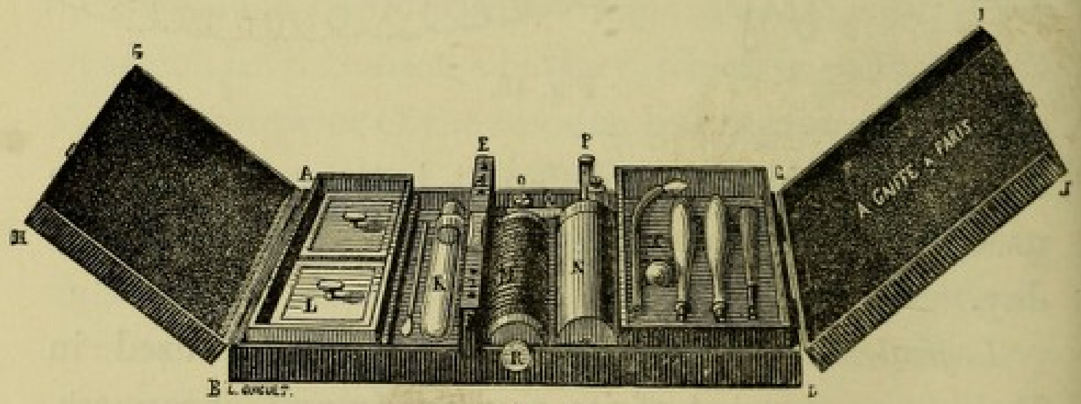


Fig. 49.

necessary electrodes N T are contained in the box. M is the coil, Q the hammer, O its screw, and K a tube containing a provision of the deuto-sulphate.

Quite recently M. Gaiffe has utilised the chloride of silver battery, which has already been described (p.

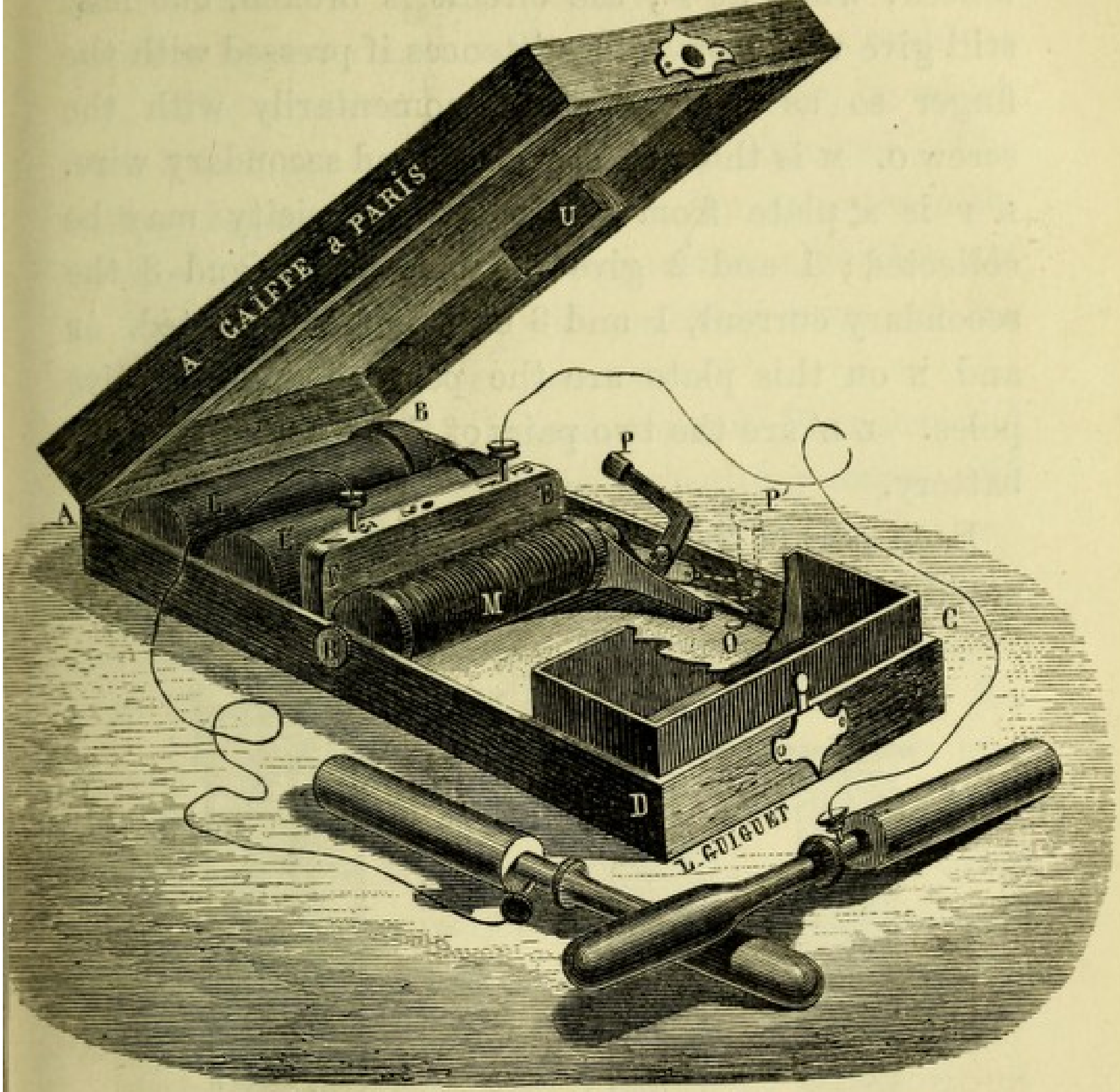


Fig. 50.

40). A B C D are the four corners of the box in which the apparatus is contained, and which has the form of an octavo volume. The box is divided into two partitions by the plate E F; one of them contains the battery, the other the coil. U is a piece put into the lid of the box, which prevents it from being closed before the hammer P is in its proper position. When the hammer is at P, it gives rapid intermittences; when at P′, the circuit is broken, but may still give very slow intermittences if pressed with the finger so as to connect it momentarily with the screw O. M is the coil of primary and secondary wire. E F is a plate from where the electricity may be collected; 1 and 2 give the primary, 2 and 3 the secondary current, 1 and 3 both currents united. P and N on this plate are the positive and negative poles. L L′ are the two pairs of the chloride of silver battery.

Each pair of this battery (Figs. 51 and 52) is composed of a zinc plate (Z) and a chloride of silver plate

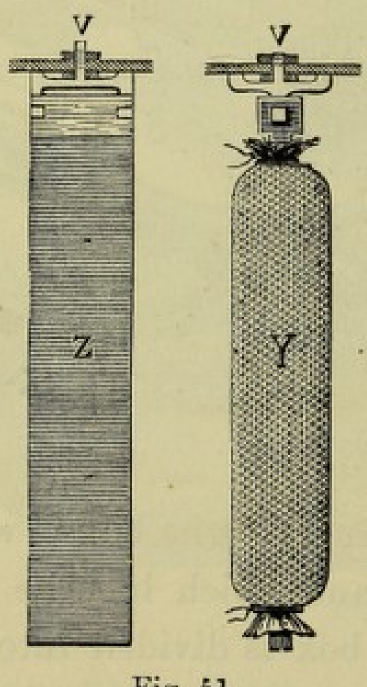


Fig. 51.

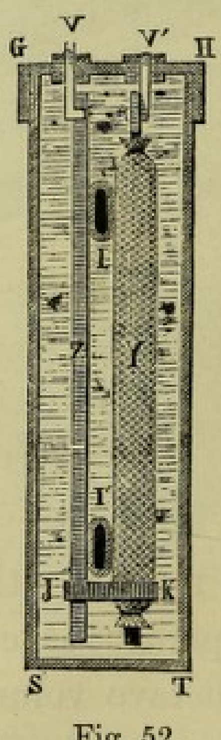


Fig. 52.

(Y). V is a clamp of silver which conducts the electricity to the external surface of the vase of vulcanite containing the battery (G H S T), which is hermetically closed by the top G H. The conducting wires are received at V V′. The plates are kept in their proper position by the vulcanite band J K, and the cushions I I′. The exciting liquid is simple water, in which from 3 to 5 per cent. of table-salt is dissolved. The battery begins to act only about ten minutes after having been charged. This apparatus, which has not as yet been fairly tried, will probably turn out the best portable induction apparatus.

To sum up, I should recommend Siemens and Halske's apparatus for the consulting-room, and Gaiffe's for out-door practice.

c. *Magneto-Electric Machines.*—*Pixiis' machine* was the first rotation machine used in medicine, but is now no longer employed. In this instrument the magnet was made to rotate, while the soft iron was fixed. In all rotation machines which have subsequently been constructed the reverse takes place. The instruments of Saxton, Ettinghausen, Keil, Dujardin, and Breton Frères are likewise out of use.

Stöhrer's apparatus (Fig. 53) consists of a horizontally-placed horseshoe magnet, composed of five pieces, and a soft iron armature, surrounded by coils of wires, a rheotome, and an axis for turning the armature. 1, 2, 3, 4 are steel nozzles, connected with the wires of the armature, and so arranged that, by half a turn of the armature, 1 and 3 enter into action, while by the other half 2 and 4 are touched. A toothed wheel serves for a more rapid interruption of the current.

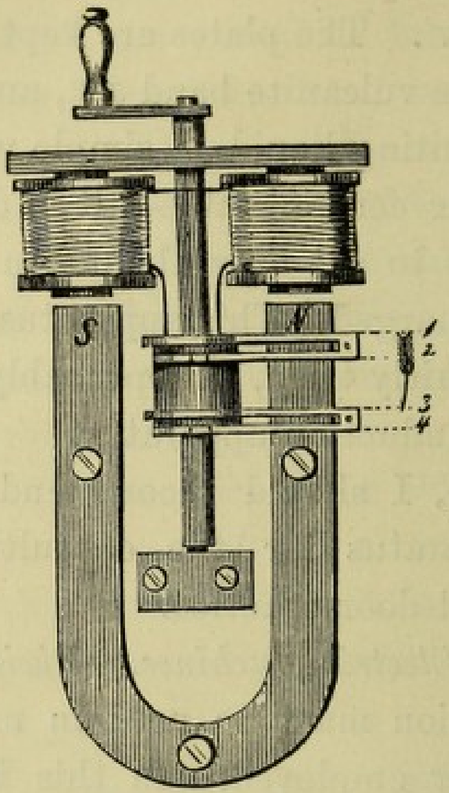
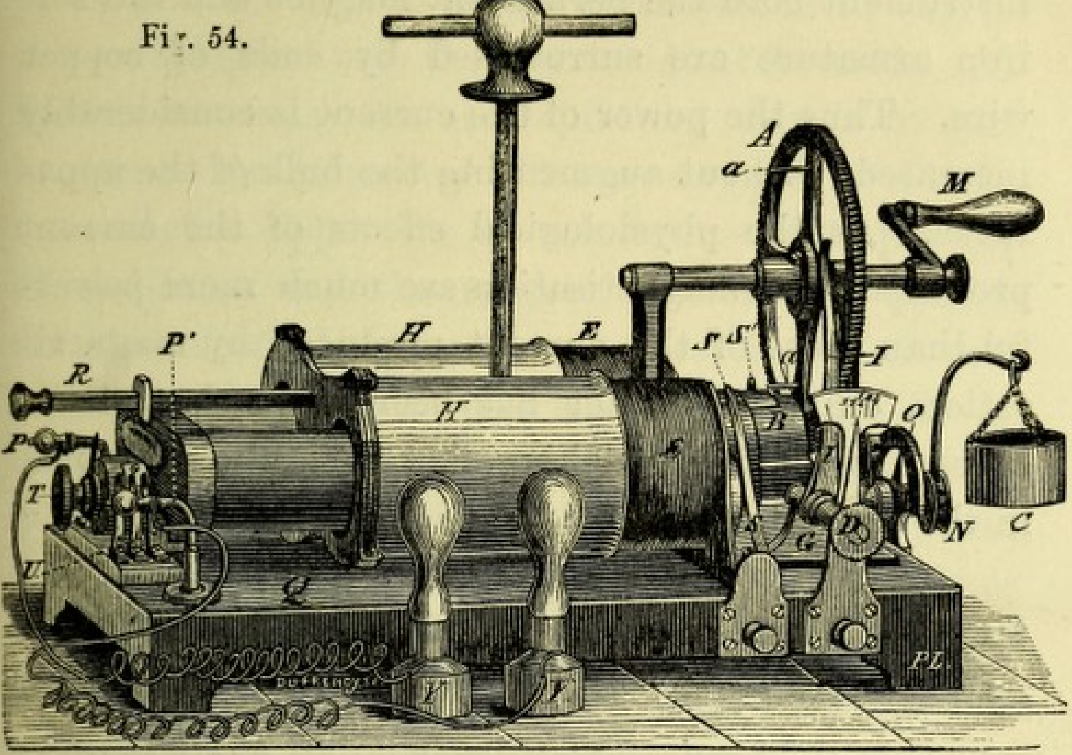


Fig. 53.

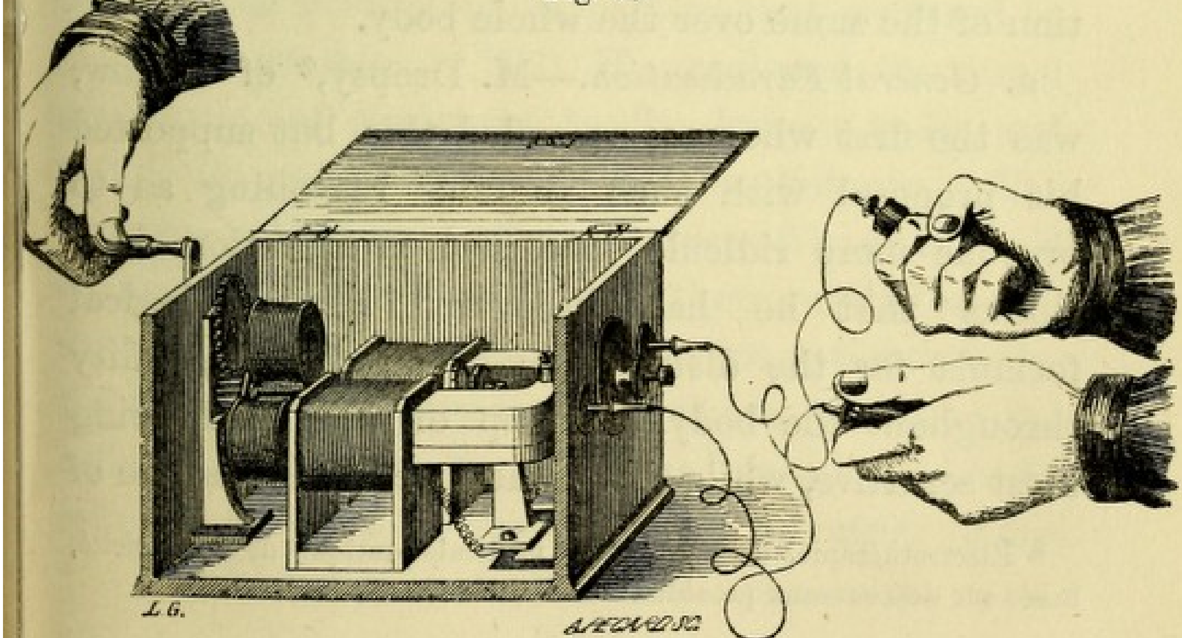
Duchenne's Magneto-electric Machine (Fig. 54) is too heavy and complicated for medical practice. M is the handle, by means of which the soft iron armature (G) is put in rotation. A is a wheel furnished with 64 teeth, so arranged that 32 intermittences of the induced current are produced by one revolution; and as the wheel may be turned twice in a second, 62 intermittences may be produced in that space of time. N is a screw by means of which the armature may be approached to, or withdrawn from, the magnet. H is the copper tube which regulates the intensity of the current, B S S, the rheotome. There is a coil of thick and fine wire (E), one end of which is connected with the knob P, for inserting one conducting wire, while the other end communicates with the support G, which is

Fig. 54.



connected with the second knob, P, by means of D, which regulates the intermittences of the current.

Fig. 55.



Gaiffe's Magneto-electric Machine (Fig. 55) is the best which has hitherto been constructed. In this instrument both the permanent magnet and the soft iron armature are surrounded by coils of copper wire. Thus the power of the current is considerably increased, without augmenting the bulk of the apparatus. As the physiological effects of the current produced by demagnetisation are much more powerful than those of the current produced by magnetisation, only the former has been utilised, and the current of Gaiffe's machine therefore always moves in the same direction.

III.—METHODS OF EMPLOYING ELECTRO-MAGNETISM AND MAGNETO-ELECTRICITY.

The method with which Duchenne's name is more particularly connected consists of the *localised* application of induction currents; while several other observers have recommended a more *general* application of the same over the whole body.

a. *General Faradisation.*—M. Dropsy,* of Cracow, was the first who recommended this, but supported his proposal with such singular reasoning as to provoke more ridicule than serious attention. He thinks that he has discovered a physiological formula for the distribution of electric sensibility throughout the body, the top of the head being most sensitive, while there was a gradual decrease of

* Électrothérapie, ou application médicale pratique de l'Électricité, basée sur de nouveaux procédés. Paris, 1857.

sensibility in proportion as we proceed downwards. This formula is, according to Dropsy, altered in diseases, and the object of the treatment is to change the pathological into the physiological formula. All that is necessary for accomplishing this is to put, by means of a bifurcated director, one pole of a magneto-electric apparatus in connection with the top of the head and the epigastrium, while a quadrifurcated electrode is made to connect the other pole of the machine with both hands and feet. By so doing, the pathological formula of all curable diseases is gradually changed into the physiological one, and *pari passu* the patient recovers. No diagnostic or methodological qualms need disturb the serenity of the mind of an operator guided by Dropsy's law; but, unfortunately, all curable diseases are not so easily eradicated as the Cracovian doctor would make us believe.

M. Seiler,* of Geneva, has recommended a method which is a worthy counterpart to that proposed by M. Beckensteiner (p. 292) He condemns the direct application of electricity to the human body, and thinks it preferable to act from a distance. The operator holds two electrodes traversed by an induced current in his hands, and passes them gently through the air, at a certain distance from the patient's body. By this ingenious proceeding, which M. Seiler has called 'galvanisation by influence,' pain is said to be relieved, the muscles strengthened, curvature of the

* De la Galvanisation par influence. Paris, 1858.

spine, laryngitis, asthma, prolapsus uteri, consumption, and a host of other diseases cured. The remarks already made on M. Beckensteiner's method, apply equally to Seiler's mode of using electricity.

A more serious attempt to introduce general faradisation into medical practice was made by M. Gubler,* who proposes to place both hands and feet in four separate basins filled with salt water, and then send an induced current right through the body for 15 minutes at a time. He has seen good results of this method in cases of general weakness, loss of appetite, impotency, etc.

Messrs. Beard and Rockwell,† of New York, carry out a somewhat different mode of general faradisation, which they believe to be especially suitable for cases where a general tonic effect is desired, as in dyspepsia, rheumatism, amenorrhœa, chorea, constipation, anæmia, and other diseases associated with deficient vital energy. They recommend the following *modus operandi*:—'Male patients remove their stockings and all their outer and under clothing from the upper part of the body, and place their feet on a piece of copper, to which the negative pole is attached, while the operator applies the positive electrode, which is either a moistened sponge or his hand, when the current passes through his own person into the body of the patient; ladies remove their dress and loosen

* De l'Électrisation générale, considérée comme agent tonique et stimulant diffusible. Bulletin de Thérapeutique. December 1863.

† The Medical Use of Electricity with special reference to General Electrisation. New York, 1867.

their under garments, and throw over their shoulders a shawl or sheet to prevent exposure. The most thorough form of application demands that the entire surface of the body should be gone over with some regard to order. Special pains should be taken to avoid the scapula, clavicula, sternum, crest of the ilium and tibia, inasmuch as these and other bony prominences are very sensitive to the electric current.' Messrs. Beard and Rockwell are convinced 'that no instrument that human skill shall devise can ever equal the hand in flexibility and power of adaptation,' and they say that the operator can, by increasing or diminishing his grasp of the sponge, modify the strength of the application without disturbing his apparatus. When used in this way the current must pass through the body of the operator. 'To this the system appears soon to become accustomed, just as it does to the use of tobacco, alcohol, opium, haschish, or coca; with this difference, however, that the effects of electricity are, if anything, positively beneficial.' Messrs. Beard and Rockwell say that a person living in New York has during the past 35 years allowed the stream to pass through his own body on an average for about five hours each day, or about seven years of his life; that up to the present time the general health of the person alluded to has been excellent, and he has suffered from no disease that can even remotely be ascribed to electricity. They appear to have obtained good results from their method in cases of neuralgia, chorea, amenorrhœa, rheumatism, and similar affections, and look upon general Faradisation as a tonic and corrective of the greatest efficacy. There can be little doubt that by thus acting on, and modifying the condition of, the sentient nerves of the skin, and to some extent also of the motor nerves and muscles, benefit may result from the American method in cases of certain functional nervous affections; but it is equally clear that the *modus operandi* must be extremely tedious to both operator and patient. Generally speaking, such an application cannot take less than half an hour, and yet it cannot possibly, in many instances, be as useful as the application of the continuous current for two or three minutes. The choice, under these circumstances, cannot be difficult. Moreover, the inconvenience to the operator by the American method must be very considerable, as the fingers are extremely sensitive to faradic electricity. Yet I can conceive that in certain conditions of the nervous system the American method may be very useful.

b. *Localised Faradisation.*—This method was invented by M. Duchenne,* de Boulogne, who, being convinced that all previous methods of applying electricity were wrong, applied himself to solve the problem whether it was possible to localise electricity in the skin without acting on the organs beneath it, or to make it traverse the skin without irritating it,

* De l'Électrisation localisée et de son application à la physiologie, la pathologie et la thérapeutique. Paris, 1855; 2nd edition, Paris, 1861.

for acting on a nerve or muscle. The following facts are the basis of his system of localised Faradisation:—

When the skin and the electrodes are dry, and the epidermis very thick, as it is in many persons whose business exposes them much to the air and hard work, the two currents proceeding from an induction apparatus meet on the surface of the epidermis without penetrating the skin. They produce sparks and a sort of crepitation, but no physiological effects whatever. When dry conductors are put on such parts of the skin as are sensitive to electricity, the person subjected to the experiment perceives a sensation of pricking and heat, which varies according to the intensity of the current. But when the skin and the electrodes are moistened, neither sparks, crepitation, nor sensation of heat are caused, but other phenomena occur which show that the electricity acts on a muscle, nerve, or on the surface of a bone. In the last case, severe pain of a peculiar character is caused by the current penetrating to the nerves of the periosteum; and it is therefore considered bad practice to place moistened electrodes on the surface of the bones. When the directors are placed on the surface of a muscle the latter contracts, and a sensation is produced which is not peculiar to the skin, but always accompanies the electro-muscular contraction, and which is owing to excitation of the sentient nerves of the muscles. Finally, when the conductors are placed on the surface of a motor nerve, contractions of all the muscles animated by this nerve are the result.

Duchenne has, therefore, distinguished two different methods of electrifying the muscles, viz. by localising the faradic stimulus in the nervous plexuses or branches, which communicate their excitation to the muscles animated by them ('indirect muscular faradisation'); and by directing the current to the muscular tissue itself ('direct muscular faradisation'). In both cases the skin and the electrodes should be moistened. For the muscles of the trunks and the limbs moistened sponges are used, which are placed in metallic cups fixed on insulating handles. For limiting the electric force to the smaller muscles, such as those of the face or the interossei and lumbricals, small conical directors, which are likewise fixed on insulating handles, are used. These conductors may be covered with moistened leather, fingers of gloves, or sponge.

Duchenne discovered that, if the electric current is directed to certain particular points of the skin, muscular contractions are much more easily produced than when the directors are applied to other parts. These points he called 'points of election;' but he did not state, nor indeed perceive, that they are the points of entrance of the motor nerves into the muscles. This was done by Remak,* who contended that the degree of contraction of a muscle was exactly proportionate to the quantity of motor nerve-fibres

* Ueber methodische Elektrisirung gelähmter Muskeln. Berlin, 1855.

embraced by the current at its point of application; and that there was no direct action upon the muscular tissue itself, which was thrown in commotion merely in consequence of the excitation of the motor nerves. He, therefore, proposed to call Duchenne's indirect muscular faradisation 'extra-muscular excitation;' and direct muscular faradisation 'intra-muscular excitation.' This theory was more fully developed by Prof. Ziemssen,* who first clinically determined the precise localities of these points of election and marked them upon the skin with nitrate of silver. He afterwards dissected the motor branches of the nerves in dead bodies, and marked their points of entrance into the muscles, when it was discovered that the results of the two series of experiments agreed with each other. A third series of observations was undertaken on bodies immediately after death, when the excitability of the nerves and muscles was still extant. The motor points were first determined by faradisation, then marked with nitrate of silver, and afterwards the test of dissection was applied, in order to see whether they really corresponded to the points of entrance of the motor nerves into the muscular substance.

From these observations Ziemssen concluded that, if the epidermis be moistened, and moistened electrodes are somewhat forcibly pressed against the skin, the induced current will pass through the corium, panniculus, fasciæ, and layers of muscular substance,

* Die Elektricität in der Medicin. Berlin, 1857; 3rd edition, 1866.

to the nerves, and rouse their specific energy, without acting so much on the nerves of the skin as to cause reflex action or severe pain. The electricity, however, penetrates into such depths only at those points where the negative and positive currents enter the body. Between these two points of entrance the current follows the liquids in the tissues, and does not cause any excitation, unless it be very powerful; but even in the latter case the chief effects are manifested, not in the whole circuit enclosed between the two poles, but in the more immediate neighbourhood of the same.

The effects obtained by intra-muscular faradisation are more powerful with large than with small electrodes. Thus, for instance, if a moistened conductor with a small surface is placed on the pectoralis major, or deltoid muscles, only a few fasciculi of the muscles are made to contract, even if the current be powerful; but if electrodes are used which have a diameter of an inch or more, the whole substance of the muscle enters at once into contraction, even if the current be not very powerful. Moreover, the current, if applied by means of large electrodes, has far less effect on the sentient nerves, and consequently causes less pain than if a small conductor be used. This also holds good where a direct action on the motor nerves is produced; and it is therefore advisable, for both intra-muscular and extra-muscular Faradisation, to use large electrodes in preference to small ones. The electrodes which I generally use are two inches in diameter. It is different if we wish to faradise muscles with a very small surface, or fine nervous fibres, either for clinical demonstration or for the purpose of diagnosis. In such cases a fine electrode must be used, if a decisive result is to be obtained.

Remak and Ziemssen have both denied that there is an irritability proper of the muscular fibre, and therefore did not believe it possible to produce muscular contractions by direct electric excitation of the tissue of the muscles. The existence of Hallerian irritability has, however, now been amply proved (p. 211), and it has been shown that the molecular equilibrium of the muscles may be directly disturbed by the electric current just as well as the equilibrium of the motor nerves, and that the contractions are observed as soon as the equilibrium of either motor nerves or muscles is disturbed. We have already seen (p. 226) that the equilibrium of the motor nerves is more easily disturbed by the electric current than that of the muscles; and that therefore, if we wish to cause direct muscular contractions by electricity, a current of greater power must be applied than is necessary for producing contractions by acting on the motor nerves. This is confirmed by the fact that muscular contractions may be produced if the electrodes are directed to such points of the muscle where motor filaments do not exist; but they are certainly more easily brought about if the motor nerves be faradised. In the majority of cases, however, the contraction produced by placing electrodes upon the belly of a muscle is composed of two elements, viz. faradisation of the muscles and the nerves.

1. *Faradisation of the Motor Nerves and Muscles.*—This requires exact knowledge of the anatomical position of the nerves and muscles. In the arm the electric stimulus may be limited to the *median nerve* on the inner and inferior third of the humerus next to the brachial artery; and to the *ulnar nerve* in the space between the olecranon and the internal condyle. The *radial nerve* is accessible to faradisation at the junction of the two upper thirds with the lower third of the humerus; while the *musculo-cutaneous* may be reached in the axilla. As regards the lower extremities, we may faradise the *crural nerve* in the groin, outside of the femoral artery; and the *sciatic* either on its origin in the pelvis, through the posterior wall of the rectum, or near the tuberosity of the ischium behind the head of the femur.

The *obturatorius* nerve may be reached near the foramen obturatorium, by placing the electrode vertically to the ramus horizontalis pubis. The *peroneal* nerve is accessible at the posterior circumference of the capitulum fibulæ, while the *tibial* may be faradised in the middle of the posterior surface of the knee-joint.

The *portio dura* may be acted upon in the external opening of the ear by pressing a moistened conical conductor to the lower side of the meatus. But as this proceeding is very painful, it is better to faradise the nerve after it has emerged from the stylo-mastoid foramen, between the mastoid process and the condyloid process of the lower jaw. The larger branches of the pes anserinus may be faradised where they emerge from the parotid gland.

In the supra-clavicular region the directors, placed over the collar-bone, act on the *brachial plexus*. On the top of the supra-clavicular triangle they are in connection with the external branch of the *spinal accessory nerve*. The *phrenic* nerve is found on the anterior surface of the scalenus anticus.

Those who wish for more explicit information on faradisation of the nerves and muscles will find it in Duchenne's and Ziemssen's works; but as anatomy is only learned by dissection, thus faradisation is only mastered by practice on the living man.

Duchenne is of opinion that the muscles, like the nerves, do not all possess the same degree of excitability, and that it is therefore necessary carefully to measure the electric dose for the different muscles. He states likewise that the electro-muscular sensibility, that is, the sensation excited by the electro-muscular contraction, differs in different muscles. These differences, however, arise probably in great part from the more or less delicate condition of the skin which covers the muscles.

2. *Faradisation of the Skin.*—By this proceeding we are capable of exciting the sensibility of the nerves of the skin in the highest degree without injuring

that organ. If a current of high tension is applied to the skin by means of a wire brush, erythema is produced, which, however, disappears soon after the application; but destructive effects are never caused. If we faradise the skin, this as well as the conductors must be dry; for if it be moist, the electric current will traverse it and proceed to the muscles.

As the sensibility of the skin varies in different parts of the body, there should be different proceedings for cutaneous faradisation. The following are the principal methods which seem to fulfil all the conditions required:—

a. *Faradisation by the Electric Hand.*—The patient takes hold of one of the conducting wires of the apparatus, while the other wire is touched by the operator. The skin of the part which is to be faradised is then dried with a little violet powder, after which the operator rapidly passes the back of his disengaged hand over the points to be acted upon. If a somewhat strong current be applied, the electric hand produces a decided but rather pleasant sensation on the face, but acts only little on other parts of the body. Here a crepitating noise produced by the rapid passage of the electrified hand over the skin is the only perceptible phenomenon. By increasing the intensity of the current distinct sensations may, however, be caused even there.

b. The second proceeding is *faradisation by blunt metallic directors*, which are fixed on insulating handles. The skin should be dry as before; but if the epidermis be very thick or hard, as it is on the palms of the hands and the soles of the feet, it may be slightly moistened in order to diminish its resistance to the passage of the electricity. Where it is necessary to cause a powerful effect on a certain point, the electrodes are held for some time continuously in contact with the skin. Blunt metallic directors, though acting energetically on the skin of the face and of the trunk, are often insufficient for the hands and feet, whatever may be the intensity of the current.

c. In such cases fine *metallic wire-brushes* are employed, which are fixed on insulating handles. The skin should be lightly touched by these wires, but sometimes it is necessary to leave them longer in contact with it. By this proceeding very severe pain may be caused, and if the proposal to substitute electric shocks for the 'cat' as a punishment in the army were ever carried in effect, faradisation of the skin by metallic wire-brushes, with the maximum power of a good apparatus, would be the best method for it.

I have already alluded to the exquisite faradic sensibility of the skin of the face. A current of low tension applied there causes an effect which is not felt in any other part of the body. Faradic sensibility is stronger near the middle of the face—that is, in the eyelids, the nose, and the chin—than on the cheeks. On the forehead there is not so much sensibility as on the face, and on the scalp still less.

The neck and trunk are more sensitive than the extremities; the cervical and lumbar region more than the other parts of the back; the inner and anterior surface of the extremities more than the external and posterior parts of the same. The skin of the hands and feet is only affected by a current of high tension. Faradisation of the skin has proved useful in cases of anæsthesia, neuralgia, and hysterical paralysis.

3. *Faradisation of the Internal Organs.—The drum of the ear* may be faradised in certain cases of nervous deafness, more especially if the continuous current should have failed to do good. The proceeding is the same as that adopted for galvanisation of the auditory nerve (p. 326); only care must be taken to put the negative electrode into the water filling the meatus, and the positive one outside. A reverse arrangement of the poles does not produce the characteristic physiological effects which have been previously described (p. 161).

In cases of loss of smell, a gentle induced current applied to the *mucous membrane of the nose* has been sufficient to restore that sense. A moistened director is placed on the nape of the neck, and an insulated conductor with a metallic top conducted over the whole of the Schneiderian membrane. For stimulating the *optic* and *gustatory* nerve, however, the continuous current is preferable, as it has a much more decided influence on those organs than induction currents.

Faradisation of the *rectum* and of the muscles of the *anus* has been used for the cure of atony of that portion of the bowel, prolapsus ani, etc., and may be useful where want of muscular tone is the cause of the disorder. A conductor which has been previously described (p. 327) is introduced into the rectum, and connected with one of the poles of an induction apparatus; another moistened electrode being applied outside, near the anus. Previous to this operation the rectum should be cleared out by enemata. The anus of healthy persons is extremely sensitive to faradisation, so that even a feeble current applied to it may cause tenesmus; but where there is much want of tone in this part, even a powerful current is borne without inconvenience.

Faradisation of the *bladder* has been beneficial in atony and paralysis of that organ. For this purpose

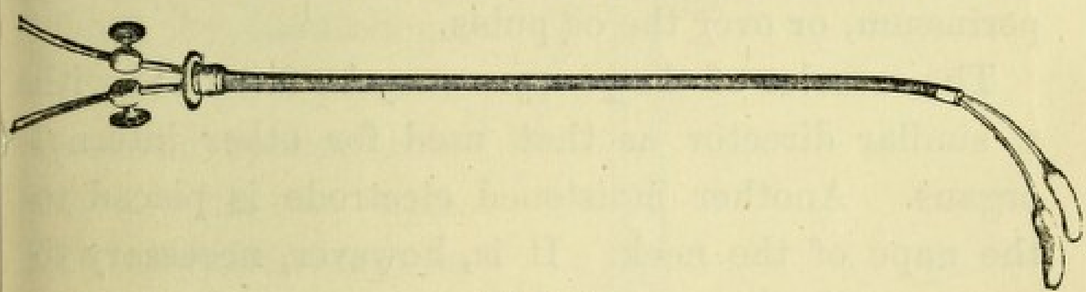


Fig. 56.

Duchenne has recommended an instrument composed of two flexible metallic wires, contained in a caoutchouc tube with a double channel, so that they are insulated from one another. That end of the instrument which is to be introduced into the bladder is so shaped that the wires, on being approached to each other, present the form of an ordinary catheter

When the instrument is in the bladder the outer ends of the wires are moved forward for about an inch or so, whilst the caoutchouc tube remains in its place, and the inner ends of the director are thus removed from each other. The bladder should be emptied before the operation, as otherwise the neutralisation of the two contrary electricities would not be effected through the muscular tissue of the organ. The conducting wires of the induction apparatus are connected with the outer ends of the wires of the director, after which the current passes through the tissue of the bladder. As Duchenne's instrument easily gets out of order, it is much better to introduce into the bladder a simple director, such as has already been described for galvanisation of the urethra (p. 327), while the bladder is filled with urine, and to place an ordinary moistened electrode to the perinæum, or over the os pubis.

The muscles of the *pharynx* may be faradised with a similar director as that used for other internal organs. Another moistened electrode is placed to the nape of the neck. It is, however, necessary to use a gentle current for this purpose, as a strong shock might have a bad effect on the glosso-pharyngeal, pneumogastric, and spinal accessory nerves which are situated in the neighbourhood.

Faradisation of the *larynx* has proved useful in aphonia resulting from loss of power in the vocal cords. The larynx may be faradised directly or indirectly. Direct faradisation of the larynx has been chiefly practised by Dr. Morell Mackenzie and Prof. Ziemssen, of Erlangen, and consists in introducing one electrode into the glottis, with the aid of the laryngoscope, while the other director is applied externally. Dr. Mackenzie lets the patient wear a necklet connected with one of the conducting wires of the apparatus, and then introduces a metallic sound, which is insulated by caoutchouc, and ends in a piece of moistened sponge connected with the wire. This instrument may be introduced without faradising any parts with which it may at first come in contact; for it is only after the sponge is, in the laryngeal mirror, seen to be upon the vocal cords, that the

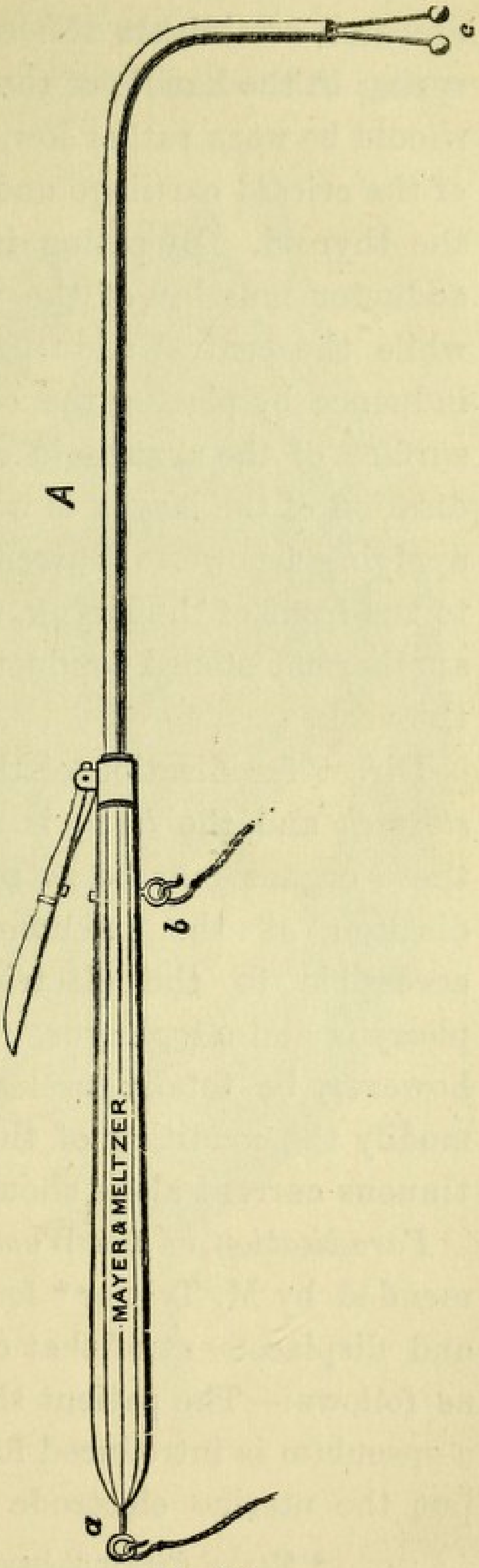


Fig. 57.

operator, establishes the circuit by touching a little spring in the handle of the instrument. The necklet should be worn rather low, so that it covers the sides of the cricoid cartilage and the space between it and the thyroid. By acting in this manner, the lateral adductor muscles of the vocal cords are faradised; while the central adductor may receive the faradic influence by placing the conductor on the posterior surface of the arytænoid cartilages. External faradisation of the larynx is much easier. It consists in applying a powerful current by means of a wire brush to the front of the larynx, the circuit being closed by another moistened conductor placed to the nape of the neck.

Direct faradisation of the *heart* and the *lungs*, the *stomach* and the *liver*, is not possible; but some of these organs may be acted upon indirectly by faradisation of the pneumogastric nerve, which is accessible to the electric stimulus through the pharynx and œsophagus. Such an operation would, however, be totally useless, as, if it is desired to modify the condition of the pneumogastric, the continuous current alone should be employed.

Faradisation of the Womb has been highly recommended by M. Tripier* for the cure of engorgement and displacement of that organ. The proceeding is as follows:—The patient should lie on her back, and a speculum is introduced for allowing the operator to put the uterine electrode A in connection with the

* Manuel d'électrothérapie, p. 548. Paris, 1861.

external os, after which an olive-shaped director B is introduced into the rectum, and a metallic plate

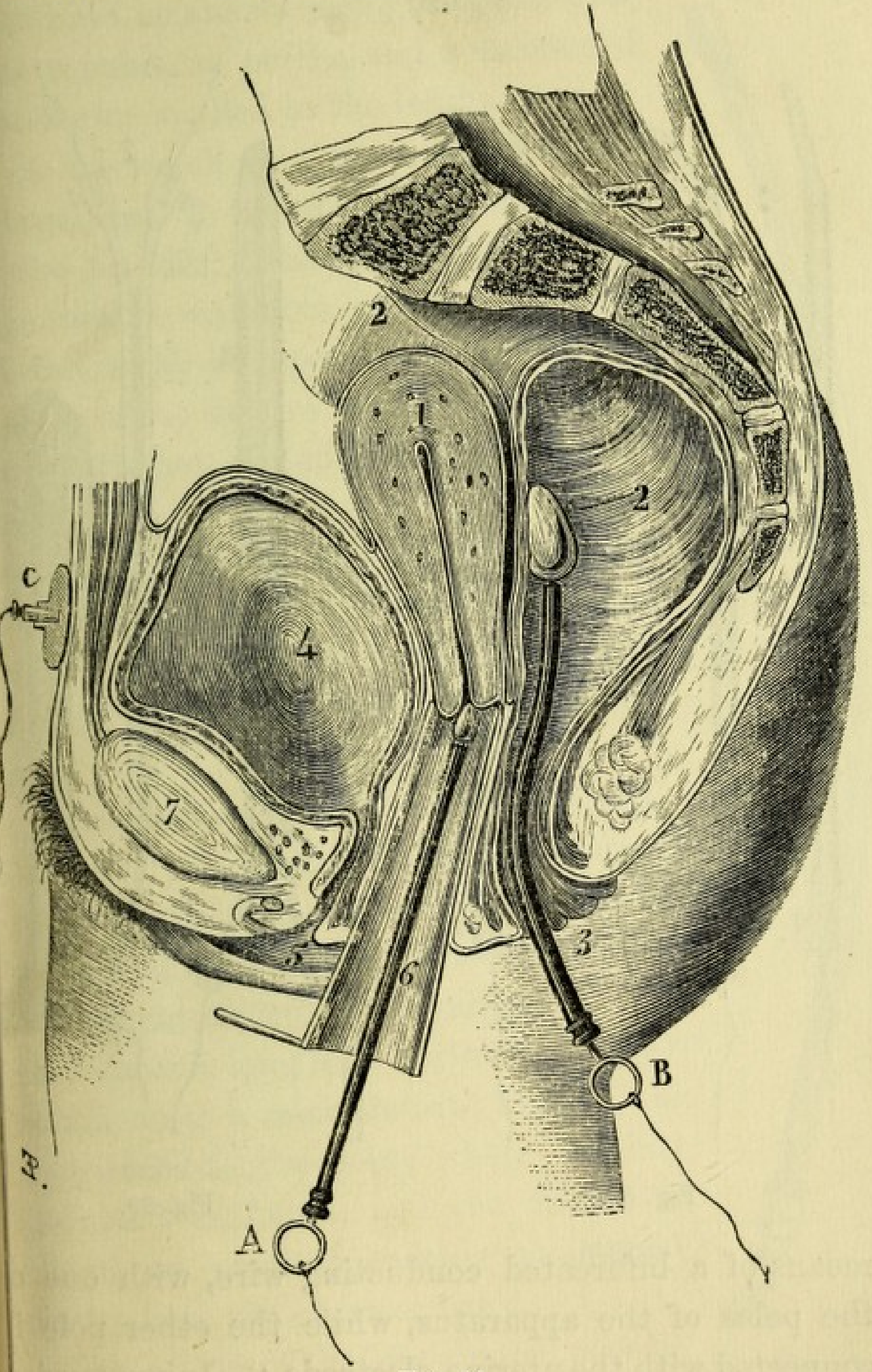


Fig. 58.

covered with moistened lint or sponge is placed over the os pubis. This latter and B communicate, by

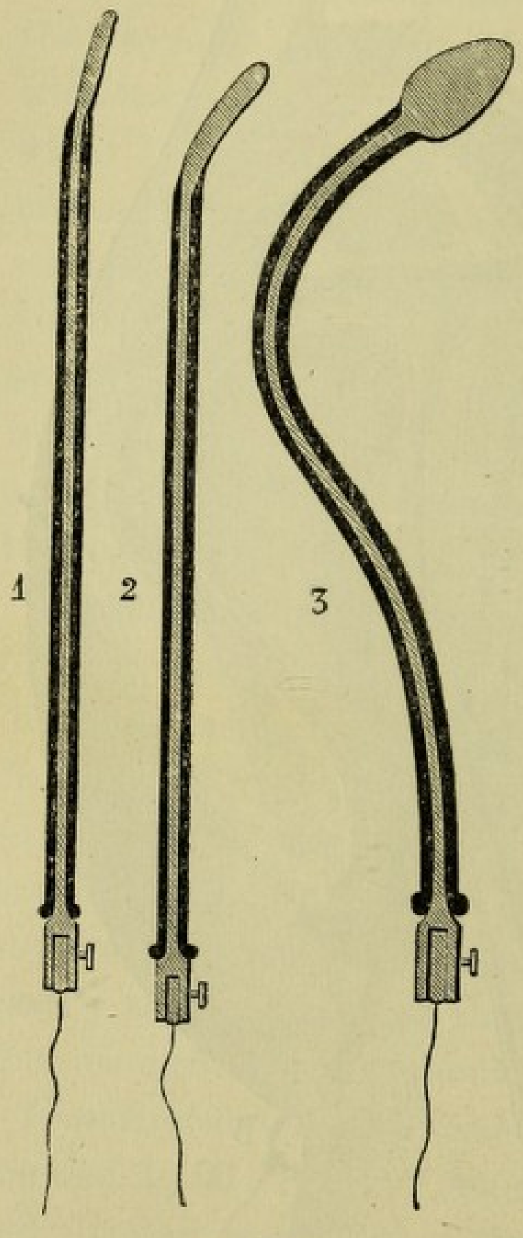


Fig. 59.

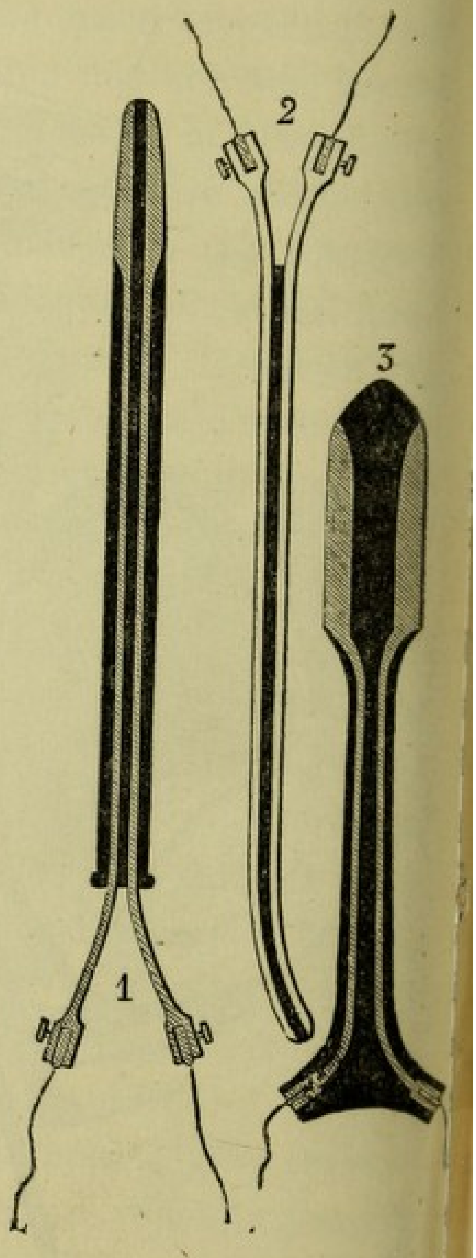


Fig. 60.

means of a bifurcated conducting wire, with one of the poles of the apparatus, while the other pole is connected with the uterine electrode A. In unmarried women or where, in the married, the engorgement is not combined with displacement, the womb may be faradised by simply using the plate over the os pubis, as before, and a moistened conductor applied to the lumbar region. 1 is the womb in a state of simple engorgement, 2 the rectum, 3 the anus, 4 the bladder, 7 the symphysis pubis, 5 the meatus urinarius, and 6 the vagina distended by the speculum. The application of the current to the womb should generally not exceed five minutes at a time.

Fig. 59 shows the simple visceral directors for uterus, bladder, and rectum, and Fig. 60 the double electrodes for the same organ, as used by M. Tripier.

Faradisation of the Œsophagus will only rarely be required ; but I have used it successfully in a case of paralysis of the muscular fibres of that organ, with consequent difficulty of swallowing. In such cases a long and flexible insulated sound with a metallic top (Fig. 61) is introduced to the point where the impediment is found, and the circuit is closed by putting another moistened electrode to the chest or back.

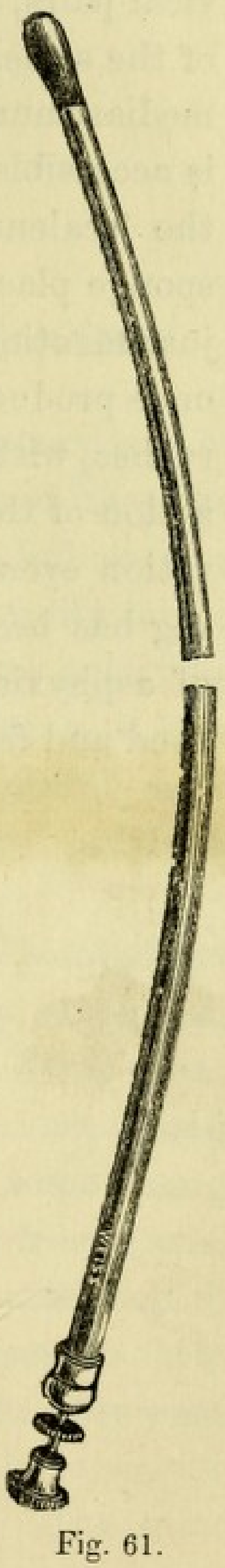


Fig. 61.

The action of the *diaphragm* may be

roused by faradisation of the phrenic nerve, which, taking its rise from the third, fourth, and fifth cervical pairs, proceeds downwards and inwards in front of the scalenus anticus muscle, before it reaches the mediastinum and the diaphragm. The phrenic nerve is accessible to electricity on the anterior surface of the scalenus anticus. Conductors of moistened sponge placed in metallic cups are held to the points just mentioned, when an artificial inspiration is at once produced; the thorax is expanded, and the air rushes with some force into the lungs. By faradisation of the phrenic it is possible to maintain respiration even some time after death; and the proceeding has been successfully employed in several cases of asphyxia, where other means had already been used and failed.

CHAPTER IV.

ELECTRICITY AS A MEANS OF DIAGNOSIS.

After galvanism had been used for some time in the treatment of paralysis, it was observed that the muscles which were no longer under the influence of volition, responded in some instances readily to the electric current, while in other cases no, or only very feeble, contractions were obtained. Hence it was concluded that galvanism might be useful as a means of diagnosis in certain obscure paralytic affections.

Every means of diagnosis, when first pointed out as such, has been over-rated, carelessly employed, and then pronounced to be worthless. Forty years ago the prejudice against auscultation was very strong in this country, chiefly in consequence of some young enthusiasts, who brought the stethoscope from Paris, having undertaken, without paying any attention to the general symptoms of the various cases, to form the diagnosis by the physical signs alone; they were constantly in error, and their undue pretensions brought discredit on the whole system. The same has been the case with the microscope, the ophthalmoscope, and other valuable means; nor has electricity been exempt from this fate. Observations on the excitability of the paralysed nerves and muscles were carelessly made, conclusions hastily drawn, and therefore the greatest confusion produced. As an instance, it may be mentioned that in August, 1850, M. Martinet read a paper before the Paris Academy of Medicine, in which he stated that the presence of electro-muscular contractility was the distinctive character of cerebral, hysterical, and rheumatic paralysis, while its absence was an indication of disease of the spinal cord; yet all these assertions are incorrect!

No department of our subject is at the present time so little developed as that relating to the diagnostic value of the various forms of electricity. There can be little doubt that as time advances a more scientific use of galvanism and electro-magnetism will enable us to ascertain the exact condition of the nervous centres, the motor, sentient, and vaso-motor nerves, and of the muscles, with far greater accuracy than we can do at present, and that electricity will thus become a most valuable test, not only in paralytic affections, but also in many other neuropathic and myopathic conditions. At present it is almost exclusively the various forms of paralysis the nature of which may be to a considerable extent determined and illustrated by galvanisation and faradisation. By these proceedings we can ascertain any alterations of the physiological law of contractions which have occurred; whether there is diminished or exalted excitability of the nerves and muscles; what is the power of current required to cause contractions; whether in using the continuous current there is contraction on opening the circuit, or galvano-tonic contractions; what is the influence of the direction of the current; whether during the application an increase or diminution of excitability becomes perceptible, etc. With the means at present at our command it is, however, impossible to ascertain any alterations of the current proper of the nerves and of its positive and negative phases, which may have taken place; but it appears highly probable that such alterations occur in most diseases of the nervous system, and, if known, would make our treatment of them more scientific and more successful. Here there is therefore a large field open for future researches, which will no doubt yield abundant results as soon as our appliances shall have reached that degree of perfection which is indispensable for such investigations.

I.—CEREBRAL PARALYSIS.

To Dr. Marshall Hall * the merit is due of having first directed the attention of the profession to the value of electricity in the diagnosis of paralytic diseases. He contended, in a paper on the condition of the muscular irritability in paralytic limbs, that

* Medico-Chirurgical Transactions, 1839.

cerebral and spinal paralysis were in totally opposite conditions with regard to the excitability of the muscular fibre in the affected limbs. By cerebral paralysis he understood that which removes the influence of the brain,—paralysis of spontaneous or voluntary motion, such as is produced by disease of the brain itself, or by disease of the dorsal portion of the spinal cord; while by spinal paralysis he meant that which removes the physiological influence of the cord. He further asserted that in cerebral paralysis the paralytic limbs were always moved by an electric influence which is slighter than that required to affect the healthy limb; or that if both limbs were agitated, it was uniformly the paralytic limb which was more shaken than the other. In spinal paralysis, on the contrary, he found that the excitability of the muscles was diminished or even annihilated. This induced him to think that galvanism might afford a source of diagnosis between

{ 1. Hemiplegia of the face, and
{ 2. Paralysis of the facial nerve.

{ 3. Hemiplegia of the arm or leg, and
{ 4. Disease of the nerves of these limbs.

{ 5. Disease of the spinal cord in the dorsal region, and
{ 6. Disease of the cauda equina in the lumbar region.

Dr. Hall concluded that in cerebral paralysis the excitability of the muscular fibre became augmented from want of the application of the stimulus of volition, the brain being, in his opinion, the exhauster, through its acts of volition, of the muscular irritability; the spinal cord, on the contrary, being the special source of the power of the nerves of exciting muscular contractions, and of the irritability of the muscular fibre. In spinal paralysis, therefore, the irritability of the muscular fibre would be diminished, and at length become extinct, in consequence of its source being cut off. The same principle would explain the greater influence of certain respiratory acts (such as yawning, sneezing, coughing, &c.) on paralytic limbs, and also the greater susceptibility of the paralysed muscles to the influence of strychnia in cases of cerebral paralysis.

The first who objected to Dr. Hall's theory was Dr. Pereira,* who, in 1841, made a number of observations on paralytic patients, which convinced him that in certain cases of hemiplegia the muscles of the paralysed limbs responded very little to the electric current, while those of the healthy limbs were powerfully contracted. In 1845, Dr. Copland † stated that in cases of cerebral paralysis the paralytic muscles were not more excitable than the sound muscles, but, on the contrary, less so. The most elaborate criticism, however, of Dr. Hall's theory was given by Dr. Todd,‡ who refuted Dr. Hall's view of

* Elements of Materia Medica and Therapeutics, 2nd edition, vol. ii. p. 1300.

† A Dictionary of Practical Medicine, vol. iii. part 1, p. 42.

‡ Medico-Chirurgical Transactions, 1847.

the brain being the exhauster of muscular irritability, by pointing to the physiological fact that the healthy action of a muscle is promoted by exercise within reasonable limits, and that whatever restricts that exercise is injurious to the nutrition of the muscle, and consequently to its irritability. He afterwards adduced the evidence of thirteen cases of cerebral paralysis, to prove that in certain morbid conditions of the brain the excitability of the muscles of the paralysed limbs was not augmented. Dr. Todd used the continuous current, electro-magnetism and magneto-electricity, and found that the results obtained were not affected by the instrument employed. He observed that in a certain number of cases the paralysed muscles responded readily to the galvanic stimulus, and even displayed a greater amount of vigour than those of the healthy limbs. In these cases the muscles of the palsied limb always exhibited some degree of rigidity; and the vigour of their action in obedience to the galvanic stimulus was proportionate to the amount of rigidity within certain limits. In another class of cases electricity produced little or no contraction, and in these the muscles appeared more or less wasted. In a third class of cases he found that, while the paralysis was almost complete, the galvanic stimulus excited equally the muscles of the paralysed and those of the healthy limbs; and these were generally cases of apoplexy occurring in persons previously healthy and not advanced in years.

Dr. Todd also concluded that the state of the *muscles* had comparatively little effect in the production of these phenomena, which he thought to be due to the state of *nervous force* in the paralysed limbs. In cases where the stimulus produced little or no contraction, force was *depressed* in the nerves of the paralytic limb; in cases where the galvanic current excited stronger contractions in the muscles of the paralysed limb than in those of the healthy limb, the nervous force was *exalted*; and in the third class, where there was no perceptible difference between the two, nervous force was *normal.* He therefore contended that galvanism might, in cases of hemiplegia, serve as a test to distinguish between an irritant and a depressing lesion of the brain, but not as a means of distinguishing between cerebral and spinal palsy.

In 1850, M. Duchenne,* of Boulogne, recorded some observations on the state of electro-muscular sensibility and contractility, and strongly objected to the mode of experimentation employed by Dr. Marshall Hall, the only true way to arrive at a satisfactory result, according to him, being the localisation of the electric current in the tissue of the paralysed muscles. He gave as the result of his experience that muscular contractility was normal in cerebral paralysis, there being no difference between the muscles of the healthy and of the paralytic limbs of such patients. This statement I can only explain by assuming that

* Archives générales de médecine, 1850. Vol. xxii. p. 4.

Duchenne tested the muscular irritability in a few cases only of cerebral paralysis, and that these happened to be such as are described by Dr. Todd in the third class, in which the muscles retain their normal condition.

I have tested the nervous and muscular excitability in more than a hundred cases of cerebral paralysis, and can fully corroborate Dr. Todd's observations. In a certain number of cases the excitability is diminished, the muscles are flaccid, and the polarity of the nerves depressed; in another class of cases the excitability is increased, there is early rigidity of the muscles, and an irritative lesion of the brain; and, finally, in a third class of cases no difference can be observed in this respect between the healthy and the paralytic limb. In the cases in which I have tested muscular excitability I have employed both modes of experimentation, viz. sending the current right through the limbs, and localising the current in the affected nerves and muscles. Both methods yielded nearly the same results; but local faradisation and galvanisation made the differences of muscular contractility appear more striking.

I shall now give a few cases illustrative of the three classes which may be distinguished in paralysis resulting from cerebral disease.

CASE 2.—*Hemiplegia, resulting from cerebral hæmorrhage; muscular contractility diminished.*

R. V., aged 57, of originally vigorous and plethoric constitution, but now somewhat debilitated by an antiphlogistic treatment: has never had any serious illness, with the exception of pneumonia, ten years ago, from which he soon recovered. Six months before I saw him he had an attack of apoplexy, accompanied with loss of consciousness for nearly three hours, and paralysis of the whole right side. Speech was not affected. He did not know of any cause of his affection, but mentioned that his father had died from paralysis. He had sometimes suffered from palpitations of the heart, but auscultation showed the heart to be healthy. The distortion of the face soon disappeared, and the muscles of the arm and leg also regained some mobility. He wrote, however, a very unsteady hand, and had difficulty in dressing and feeding himself; walking was very troublesome.

His judgment, speech, and memory were not impaired; there was no pain in the head or limbs. The face and tongue were straight, and the movements of the eyes quite easy. The skin of the right side was cold and flabby. Pulse 76, weaker in the right than in the left radial artery. There was a feeling of numbness in the right arm and leg, which were not so sensitive to the prick of a pin as they should be. The muscles of the same side were relaxed and somewhat wasted, and the extensors more so than the flexors. There was no rigidity of the muscles, either in the upper or in the lower extremity. Passive extension of the fore-arm upon the arm, and of the leg upon the thigh, could be made without any resistance being offered by the muscles. The faradic stimulus, administered in moderate dose and with slow intermittences, did not cause the paralysed extensor muscles of the right arm to contract, while the corresponding muscles of the other side answered well to the current. The same was the case with the muscles animated by the peroneal nerve.

CASE 3.—*Hemiplegia, with irritation of the brain and augmented muscular excitability.*

In December, 1858, a patient of the name of King was under the care of Dr. Todd, in King's College Hospital; he had had repeated attacks of apoplexy, and probably suffered from a tumour in the brain, which kept up continual irritation. The patient suffered at that time from ptosis of the left upper eyelid, and from paralysis of the right side, with marked rigidity of the flexor muscles. I tested the excitability of the muscles, and found it slightly increased in the paralysed leg, and very much so in the paralysed arm. When I directed a gentle current to the belly of the extensor communis digitorum of the right fore-arm, a sudden and powerful extension of the fingers took place, which were before firmly closed by rigidity of the flexors; the same current directed to the left side did not induce any movements in the fingers, and much more power was required for producing the same amount of contraction in the healthy as in the paralysed side. It was also noticed that the *inverse* current excited somewhat stronger contractions in the *paralysed* side than the direct, while the *direct* current excited somewhat stronger contraction in the *healthy* side than the inverse. These experiments were repeated several times, and always with the same result, in the presence of Dr. Todd, Dr. Conway Evans, and a large number of students.

CASE 4.—*Hemiplegia, with normal excitability of the muscles.*

L. T., aged 62, has long been in a gouty condition, and had an apoplectic fit seven years ago, in which she lost her speech and consciousness, and the use of the left side. After six months a gradual improvement took place, especially in the leg. When I saw her in November, 1858, the speech was still impaired, walking troublesome, and the motion of the left thumb and fore-finger very limited. Although these two fingers had then scarcely been used for seven years, the excitability of the extensor and abductor muscles of these fingers was quite normal, as they moved freely under the influence of a gentle current. The same was observed in the recti of the thighs.

II.—PERIPHERAL PARALYSIS.

Dr. Marshall Hall has termed *spinal paralysis* that which is observed when the muscle is functionally separated from the cord, as, for instance, by mechanical injury to a nerve. This peculiar view taken by Dr. Hall has been almost generally misunderstood; as most authors have taken Hall's 'spinal paralysis' as synonymous with paralysis from disease of the spinal cord. It is, however, evidently meant to include those cases which arise either from mechanical injury to a nerve (traumatic paralysis), or from pressure by an effusion, which may be of a rheumatic, gouty, or syphilitic character. As much confusion has arisen from Marshall Hall's nomenclature, it is much better to drop the term proposed by him altogether, and substitute the word 'peripheral' for 'spinal' paralysis. Recent researches have thrown considerable light on the changes which occur in this form of palsy, as far as the galvanic and faradic excitability of the nerves and muscles is concerned, and have thereby enabled us to make both the prognosis and treatment of these affections more certain.

To M. Baierlacher * the merit is due of having first employed the continuous current as a means of diagnosis in such cases, and of having shown that *galvano-muscular* contractility may still exist after *farado-muscular* excitability has disappeared. He observed the case of a woman, aged 28, who suffered from paralysis of the portio dura of one side. Faradisation had no influence on the muscles, nor was there any change in this particular after three weeks' treatment. He then applied a continuous current of fifteen cells, which caused strong contractions in all the paralysed muscles. After three such applications there was considerable improvement, and after four more the paralysis had almost completely disappeared.

M. Schulz † has recorded several cases of facial palsy, in which the induced current did not cause any contractions on the paralysed side. He observed that a current of eight cells of Bunsen's battery produced a considerable contraction on opening as well as on closing the circuit, whether the current was direct or inverse, while a current of the same power did not affect the muscles of the healthy side. On increasing the power of the current to twenty cells, the muscles of the healthy side responded on opening and closing, yet even then the extent of contraction was more considerable in the paralysed side. As time went on, the exalted excitability of the paralysed muscles gradually diminished, and at last completely disappeared. This diminution of galvano-muscular excitability was simultaneous with the recovery of the power of volition over the muscles, and at the same time the muscles commenced to respond again to the faradic current.

M. Moritz Meyer ‡ has observed the case of a woman, aged 48, who suffered from facial palsy of the left side, and where faradisation did not cause any contraction whatever,

* Baierisches ärztliches Intelligenzblatt, 1859. No. 4.

† Wiener medicinische Wochenschrift, 1860. No. 27.

‡ Die Electricität in ihrer Anwendung auf Medicin. 2te Auflage, 1861, p. 323.

while a continuous current of six cells produced considerable movements in them. The patient gradually recovered under the influence of the continuous current. Another similar case fell under the notice of Professor Ziemssen.* A young man, aged 18, had had facial palsy of the left side for three weeks, and faradisation locally applied to all the facial muscles individually, and to the branches of the portio dura of the affected side, did not cause any contractions, even if a powerful current was used; while the continuous current applied in the same manner caused regular and vigorous contractions on making the circuit in all the muscles, while on breaking it they responded feebly. The galvano-muscular contractions of the corresponding muscles on the healthy side were not nearly as powerful as on the paralysed side, and the application of the continuous current to any paralysed muscle individually, or to the nervous fibre animating the same, was not able to restore its excitability to faradisation or volition. If very slow intermittences of the induced current were used, so that one closing and opening was effected in two seconds, it appeared that there was in the healthy side a strong contraction on closing, and a feeble contraction on opening the circuit in each muscle, while in the paralysed side there was no contraction whatever, either on closing or on opening. A few weeks afterwards the deformity of the face was diminished, but the galvano-muscular excitability considerably decreased, and this latter then completely disappeared. In two months the left side had regained its voluntary power, only the eyelids could not be entirely closed; yet even then neither galvanisation nor faradisation caused any contractions. The same patient was examined two years and a half afterwards, when the face was perfectly healthy, during rest as well as during physiognomical expressions. Sensibility, however, was considerably diminished on the left side. Faradisation caused contractions

* Die Electricität in der Medicin, 1866, p. 76.

in all the muscles which had been previously paralysed, but the response was not nearly so strong as on the healthy side. The same condition was observed on applying the continuous current, eight cells of which caused distinct movements on the right side, while no effect was produced on the left. On increasing the power of the current the muscles of the left side were seen to contract, but more feebly than those on the right side. In another case recorded by the same observer the excitability of the motor nerves to volition, faradisation, and galvanisation was completely abolished, while the paralysed muscles had preserved their irritability to the continuous current, and responded to direct galvanisation with a sluggish contraction.

Meyer has found that those cases of facial palsy in which farado-muscular excitability is merely diminished, but not completely gone, show the same aspect as regards the continuous current, and are more favourable as far as prognosis is concerned, inasmuch as they generally recover within a few weeks, while, on the other hand, those palsies in which faradisation produces no effects whatever a week after they have come on, and where a feeble continuous current causes vigorous contractions, are of worse import, because recovery ensues only after many months, and even then remains incomplete. In these latter cases Meyer believes the seat of the paralysis to be in the facial nerve during its transit through the petrous portion of the temporal bone, and looks upon the galvano-muscular contractions as reflex movements produced by stimulation of the ganglion geniculatum. The latter hypothesis is, however, not tenable.

M. Neumann,* when observing a case of this kind, conceived the idea of rapidly interrupting the continuous current by means of a mechanical contrivance in order to arrive at a rationale of these phenomena, and noticed that if the interruptions were extremely rapid, no effect was produced in the paralysed muscles, while the healthy muscles of the other side of the face responded as usual. From this he concluded that the duration of the current was of paramount importance in these cases. When this is more than instantaneous the current has a more considerable effect on the paralysed than on the healthy muscles; but when the stimulation is merely instantaneous, no effect is produced, even if a powerful current be applied. He observed the same thing in the nerves and muscles of frogs which were dying. Before the excitability of the structures was quite gone, there was a stage which often continued for several hours and in which the most powerful faradic current failed to produce contractions, while a weak continuous current caused decided effects.

M. Brückner † has recorded several cases of fatty degeneration of the muscles, which confirm Neumann's statements. Faradisation failed to cause contractions, while on closing the continuous current of twenty cells a response took place. He also observed that the contraction on closing the circuit did not occur so rapidly as it does in healthy muscles, but was

* Virchow's Archiv für Anatomie und Physiologie, 1864, p. 54.

† Deutsche Klinik, 1865. No. 30.

somewhat retarded; that if the circuit was slowly opened and closed, the movements were more extensive than if there was a rapid succession; that if the direction of the current was quickly changed, the strength of the contractions increased; and that there was no effect at all if the continuous current was applied instantaneously. These facts were observed in the peroneal, crural, sciatic, and tibial nerves. M. Eulenburg,* who has likewise studied these conditions, has assumed different specific energies of the motor nerves, viz. the power to respond individually to volition, faradisation, and galvanisation; and thinks it probable that, in certain conditions of changed molecular arrangement, one of the other of these energies, or even two of them, may be totally gone, while the third remains intact. This would be an analogy to the abolition of certain kinds of sensation, which is frequently observed in locomotor ataxy, where the sense of touch may be normal, while sensibility to pain or the sense of temperature may have completely disappeared.

Professor Erb,† of Heidelberg, has experimentally studied the conditions which are now under consideration, and has come to the important conclusion that as far as these alterations of excitability are concerned, *nerves and muscles obey totally different laws.* In all cases of exalted galvanic excitability only the muscles answer in this manner, and those observers are in

* Deutsches Archiv für klinische Medicin, 1866. Bd. ii. Heft 1.

† Ibid. 1868. Bd. iv. p. 566.

error who have assumed the existence of increased galvanic excitability of the *nerves*, together with lost faradic excitability of the same. In fact, where there has been an injury to the motor nerves, the excitability of the *nerves* appears to be completely gone, not only to the induced but also to the continuous current.

Soon after the paralysis has set in, whether it be caused by rheumatic effusion, or by contusion and division of the nerve, the excitability of the *nerve* to both forms of electricity begins to diminish. In one of Erb's cases this diminution was, during the first few days of the illness, preceded by a slight increase of it; and he considers it not improbable that this condition may be characteristic of so-called rheumatic palsies. Soon afterwards, however, viz. in man from the end of the first week, and in injured nerves of rabbits even before that time, a considerable diminution of excitability takes place, which proceeds gradually from the seat of the disease to the periphery, the point of entrance of the nerve into the muscle being the last to lose it. This decrease of excitability is shown in two ways, for not only has the power of the current required for causing a slight contraction to be continually increased, but on the other hand the contractions caused by even a strong current constantly diminish in extent; so that, towards the end of the second week, faradic as well as galvanic excitability of the nerves has completely disappeared. The duration of this stage varies according to the cause of the palsy, the intensity of its effect upon the nerve, and the rapidity with which the process of regeneration is carried on. In rabbits, the nerves of which have been bruised, it lasts from five to six weeks: where the nerves have been divided its duration is longer; and in facial palsy of rheumatic origin it may extend over many months, and even years. After a time the excitability of the nerves is gradually restored. The statements of different observers regarding the mode in which the nerves regain their excitability vary considerably, and have led them to assume various groups and degrees of palsy, which are, however, not so distinctly separated in nature. In most cases, there appear, simultaneously with the return of voluntary motion, traces of faradic as well as of galvanic excitability, although at first only if a high power be used. Both kinds of excitability seem to return almost simultaneously, and the contractions then steadily increase from day to day, so that at last a feeble current is sufficient to bring them about. If the nerve be then acted upon by the continuous current, the contractions follow the usual law which obtains for the physiological condition of the living nerve.

The cases are, however, exceptional where electric excitability is completely restored to its original standard; for it generally remains somewhat below par. All these conditions do not appear to have any direct relation to the recovery of voluntary power.

The *muscles* follow totally different laws under these circumstances. Within the first few days of the palsy there is no decided alteration of direct galvanic or faradic excitability, and it is only towards the end of the first week that a diminution of it is observed. The faradic excitability continues to sink, whether the current be slowly or rapidly interrupted, and whether the primary or secondary current be used ; galvanic excitability, on the contrary, now commences to rise, and becomes within a few days exalted considerably beyond the normal standard, so that a much weaker current than is necessary for causing contractions in healthy muscles will produce decided effects on the paralysed muscles. We have already seen that this is owing to the physical difference of the continuous and induced current, it being the instantaneous duration of induction currents which renders them incapable of exciting the muscles, and a continuous current of equally instantaneous duration having no more effect than faradisation. But there is at this period not only an increase in the amount of excitability, but also an alteration in its quality. If healthy muscles are acted upon by the continuous current, the negative pole has a more powerful effect than the positive, and the closing contraction is stronger than the opening ; while the positive pole produces effects chiefly on opening, especially after the current has acted for some time. In paralysed muscles, however, the effect of the positive pole increases much more rapidly and considerably than that of the negative pole, so that it soon becomes equal to the latter, and sometimes even stronger. At the same time the effect on closing becomes greater than that on opening; and finally, an effect takes place with the negative pole on opening, which is equally powerful and sometimes even stronger than the effect on opening at the positive pole.

The form of muscular contraction produced by *direct muscular excitation* differs considerably from the contraction caused by the excitation of healthy nerves. The latter is extremely rapid, while the former is slow and sluggish; and even if the current used be comparatively feeble, tonic contractions of long duration may be caused. The shortening and elongating of the paralysed muscle occurs much more slowly than that of the healthy muscle, and corresponds to the form of contraction observed by Fick in the sphincter of the fresh-water mussel, in which there is considerable prolongation of all the successive stages of the contraction (p. 187).

After a certain time galvanic excitability again diminishes, but no alterations are then perceptible in its quality. The first signs of this diminution seem to occur about three months after the commencement of the disease. Within the following weeks this diminution becomes still more distinct; a higher power is required for causing contractions, and the extent of the latter is much decreased. After a time the effect on opening becomes less, and appears more tardily than that on closing, even at the positive pole. This latter, however, still causes an equally distinct closing contraction as the negative pole. At a later time we succeed in obtaining feeble contractions by direct muscular faradisation, more especially in those muscles the nerves of which have likewise regained their faradic excitability. Galvanic excitability now sinks below the normal standard; for while on the healthy side eight cells may suffice to cause contractions, from ten to fourteen cells may be necessary on the paralysed side, and the contractions themselves become continually weaker.

These final alterations of electric excitability do not seem to bear any constant relation to the return of voluntary motor power, nor to the extent of the same. A curious fact which has been noticed at this time is an increased excitability of the muscles to mechanical stimulation. This occurs later than the increase of galvanic excitability, viz. towards the end of the third week, after which it rises rather rapidly, and again disappears in the third or the fourth month of the disease.

Professor Erb has likewise studied the morbid anatomy of these conditions.

It appears that within the first few days after an injury to the nerve has taken place the marrow coagulates, and is dissolved into several cylindrical pieces, which are at first rather long, but afterwards become shorter. At the same time the diameter of the fibres is considerably increased; the cylindrical pieces just mentioned are gradually changed into irregular oil-globules, between which fine granules of fat appear, which after a time become so numerous that they predominate over all other formations. About the third week, and afterwards, there is less of marrow and fat, the diameter of the fibres becomes smaller, the preparations clearer, and nuclei and fibres in the process of regeneration are perceptible. Of the original fibres scarcely anything remains except a small and pale band with irregular outline, in some parts of which small globules of fat, marrow, and nuclei may be recognised. This band consists of the original primitive fibre and the cylinder axis, which remains uninjured. The degeneration proceeds in every case from the point where the injury has occurred towards the periphery; and regeneration proceeds in a like manner. From the substance of the marrow which has been preserved fresh masses of marrow are deposited round the cylinder axis. At first only a small dark line is perceptible, but after a time a delicate layer, with a double outline, appears, which proceeds more and more towards the periphery. These young regenerated fibres are very small, thoroughly homogeneous, and only slowly increase in width. When they have become completely developed the conductivity of the nerve is restored.

At the point where the nerve has been injured phenomena of adhesive inflammation of the neurilemma set in, viz. swelling, proliferation of cells, thickening, and finally shrinking, of connective tissue.

An identical process occurs in the neurilemma along the whole peripheral course of the nerve. Soon after the injury has taken place, there is a considerable accumulation of granular cells in the neurilemma; these cells gradually assume the shape of spindles, and the neurilemma is at the same time thickened; the connective tissue becomes tougher and firmer, the cells disappear, and fibres take their place. Since the nervous fibres are now enclosed in a firm sheath, the hardness of which is further increased by cicatricial shrinking, the regeneration of the nerves is of course much retarded; but in course of time this impediment is likewise removed, and the nerves are completely restored to their physiological condition.

These anatomical alterations correspond closely with the changes of electric excitability which have been previously described. The decrease of electric excitability, which occurs soon after the commencement of the paralysis, would coincide with the increasing degeneration of the nervous marrow; and if this degeneration has reached a certain stage the electric excitability is entirely gone. As soon as the fibres have become regenerated electric excitability returns, and increases in proportion as the fibres grow. The slow return of excitability, and its long persistence in a degree which is lower than in the normal condition, would then be due to the impediment which is offered to the regeneration of the nervous fibres by the proliferated and shrinking neurilemma.

No doubt can exist that there are certain pathological conditions of the nerve where it is insensible to electricity and yet obeys the orders of volition, which is probably due to the persistence of the cylinder axis.

The anatomical alterations of the *muscular fibres* consist chiefly of atrophy, which appears in the third week; at the same time the transverse stripes become slightly indistinct. There is no fatty degeneration of muscular tissue, but an increase of nuclei, which often appear in large crowds. The contractile substance is altered so that the fibres show a great tendency to undergo amyloid degeneration. Large numbers of cells appear in the interstitial connective tissue, the mass of which is also increased, so that the consistency of the muscle is greater. The connective tissue after a time assumes a cicatricial character, whereby, after the conductivity of the nerves has been restored, complete recovery of the muscular fibres is much impeded.

It is more difficult to trace the relation between these anatomical alterations of muscular fibres and the changes of their electric excitability than it is with regard to the nerves. The diminution of direct faradic and galvanic excitability which is observed in the first two weeks coincides with the alteration of excitability in the nerve, although this latter does not disappear so rapidly. As during that time no striking alterations appear as yet to have taken place in the muscular fibres themselves, it may be assumed that these first changes of excitability are to be referred rather to the intra-muscular branches of the nerves and their terminations than to the muscles themselves. Concurrently with the diminution of excitability, which is caused by the separation of the nerve from the centre, muscular excitability is diminished; but it does not completely disappear, because the contractile fibre with its inherent irritability is still in existence. The above-mentioned alterations of excitability are observed towards the end of the second week; there is diminished effect of currents of instantaneous duration, increased effect of currents of long duration, and preponderating effect of the positive pole. These coincide, as regards time, with the commencement and increase of the proliferation of muscular nuclei, and those alterations which result in amyloid degeneration and the proliferation of interstitial connective tissue. The diminution of excitability which appears at a later time coincides with the cessation of these anatomical processes, and the atrophy of the muscular fibres, which is rendered more or less permanent in consequence of the cicatricial retraction of the hypertrophied connective tissue.

These phenomena are of importance for the diagnosis of palsies in which these alterations of excitability are observed. They show us with certainty that the paralysing lesion has completely interrupted the conductivity of the nerve, and that degeneration of the nerve has been the consequence.

They also show us the seat of the paralysing lesion, inasmuch as they occur only in the motor and vaso-motor peripheral nerves, and not in central paralysis.

The prognosis of such peripheral palsies appears therefore in the first instance dependent upon the cause of the paralysis, and is more favourable where this can be rapidly removed. Before the cause is removed any therapeutical measures, which are peripherally applied to the paralysed nerves and muscles, must inevitably fail. Experience shows that in cases of facial palsy of this kind a few months must elapse before the first traces of motility reappear, and even then more time is required for the complete restoration of voluntary power. Recovery is often incomplete, and distortion of the face, or at least a certain stiffness and rigidity, may remain.

Professor Erb's investigations are almost entirely confirmed by a series of researches which have about the same time been made by Professor Ziemssen and M. Weiss,* who experimented on rabbits, in order to determine the relations of motor nerves and muscles to both the continuous and induced current, in artificially produced interruption of nervous conduction. They operated on the sciatic and on the peroneal nerve, either by excision of a small piece or by ligature. The latter proceeding they found on the whole preferable, because it was possible, by a more or less tight tying of the

* Deutsches Archiv für klinische Medicin, 1868. Bd. iv. p. 579.

thread, to produce palsies of longer or shorter duration, and also because the injury thus made allowed healing by first intention.

The immediate consequence of the operation in all cases was paralysis of the whole set of muscles animated by the injured nerve, which continued for a time proportionate to the severity of the lesion made. The average was four weeks with the ligature, while, after excision of a piece of the nerve, the palsy lasted six or seven months, or even more. Considerable wasting of the leg followed, even where it was paralysed only for one month. Where it remained paralysed for six months, the wasting was not only excessive, but the muscles became rigid and shortened, so that flexions of the knee and ankle-joint took place. After the injury had been repaired the contraction and rigidity of the muscles disappeared rapidly, the muscles increased in bulk, and voluntary movements returned.

Ziemssen and Weiss found the alterations of excitability of the injured nerve and the paralysed muscle to the continuous and induced current to vary according to the severity of the lesion, but follow a definite law as regards their first appearance and progress. They corroborate Erb's discovery, that the relations of the *nerve* to electricity are totally different from those of the *muscle* to the same agent.

In most cases it was found that from twenty-four to forty-eight hours after the operation, the nerve had completely lost its excitability to the electric stimulus. There was sometimes on the first or second day an apparent increase of excitability, which, however, was not due to any changes in the nerve itself, but merely to an increased electric conductivity of the skin consequent upon the operation. The minimum duration of the loss of excitability was three weeks, and the maximum seven months. The central end of the nerve regained its excitability for days, or even weeks, before the peripheral end of it. Galvanic excitability generally returned a few days before the faradic, in the central as well as in the peripheral end. The degree of excitability, both galvanic and faradic, was always much greater in the central than in the peripheral end. The return of excitability in the nerve appeared to be simultaneous with the return of farado-muscular contractility and the disappearance of exalted galvano-muscular excitability.

With regard to the *muscles* paralysed by the operation, it appeared that *faradic* excitability was diminished even on the first day, and completely gone on the fifth to nineteenth day after the operation. This diminution took place more gradually the nearer to the centre the injury had been made. Where the injury had been severe, farado-muscular excitability disappeared completely, and the paralysis continued longer in proportion; when traces of it reappeared, a very powerful current was at first required to show that it was returning.

Galvano-muscular excitability remained unchanged on the first day, but was increased on the second, so that a feeble continuous current, which had not the least effect on healthy muscles, caused powerful contractions in the paralysed ones. This exaltation of excitability began to decrease again in the third to seventh week after the operation, and fell then either to the normal average, or even below it. In a few cases no such exaltation was at all perceptible, but these occurred in animals which were before the operation uncommonly sensitive to the galvanic stimulus. In the large majority of cases galvano-muscular excitability persisted throughout the affection; it was lost only in those where a somewhat large piece of the nerve had been excised; and in these cases galvanic and faradic excitability fell much in the same proportion. With regard to the direction of the current, it appeared that the negative pole, which in healthy muscles has more effect than the positive, had in these cases, just on the contrary, less influence than the positive, which was by far the most effective.

The loss of muscular contractility in peripheral paralysis is in some instances a very valuable guide to diagnosis. Duchenne has recorded a case in which he noticed loss of contractility in the paralysed muscles of the shoulder, by which he was led to the diagnosis of local injury to the nerves; and afterwards a syphilitic exostosis was discovered, which compressed certain branches of the cervical and brachial plexus. In most instances the excitability of the muscles appears to be lost very soon after the lesion of the nerve has occurred.

III.—PARALYSIS FROM DISEASE OF THE SPINAL CORD.

In such cases the electro-muscular contractility is frequently diminished in the affected muscles, but it is occasionally quite normal, although the bulk of the muscles may have notably decreased and they may refuse to obey the orders of volition.

IV.—HYSTERICAL PARALYSIS.

We often meet in hysterical women with a more or less complete paralysis of one or both lower extremities, which is usually caused by anxiety or excitement.

According to Duchenne, the electric excitability of the muscles is normal in all cases of hysterical paralysis, while the electro-muscular sensibility (that is, the sensation excited by the electro-muscular contraction) is nearly or totally gone. But such is by no means always the case, for I have found that in a certain number of cases of hysterical paralysis the excitability of the muscles is considerably diminished, especially where the affection is of long standing. Duchenne's assertions are generally correct for recent cases.

CASE 5.—*Hysterical Paraplegia; diminished excitability of the muscles.*

In May, 1858, I saw, in consultation with Dr. Todd, a lady, aged 28, unmarried, who had nearly lost the use of her legs in consequence of a fright. Her gait was staggering, and when not sufficiently supported the limbs gave way and she fell to the ground. The disease wandered about the limbs, sometimes attacking more the right, at other times more the left, leg; for a short time the right hand became affected, and writing and playing on the piano were difficult or impossible. When I first saw her she dragged the right leg as a piece of inanimate matter; the foot swept the ground, and being inclined to turn inside, the inner edge of the shoe was generally torn after it had been worn for a few days. When in the sitting posture, she was scarcely able to raise the foot or to turn it outside, or to move the toes; she experienced very great difficulty in getting up from a chair, and in getting into and out of bed; and she found it almost impossible to press the pedals of the piano and the harp. On administering a feeble faradic current to the rectus of the *left* thigh, the muscle immediately contracted, but the same current was not strong enough to move the rectus of the *right* thigh, and although I notably increased the intensity of the current, whereby the sensation of a powerful thrill through the thigh was produced, only feeble vibrations appeared in the fibres of the left rectus. The same state was observed in the peronei and tibiales muscles; but after faradisation had been used for some weeks, the nutrition was so far restored that all the muscles of the right limb responded as readily to the current as those of the left.

V.—LEAD PALSY.

Paralysis consequent on lead-poisoning affects by preference certain sets of muscles, leaving others nearly or totally intact. The arms and hands suffer, while the lower extremities remain comparatively well, and in the arm the flexor muscles are spared and the extensors attacked. Generally the extensor communis digitorum is first affected; the extensors of the fore-finger and of the little finger follow in their turn; and at last the extensores carpi radialis and ulnaris, the triceps and deltoid, and the muscles of the ball of the thumb become weak or paralysed. In cases of this kind the faradic excitability of the muscles is always much diminished, and often entirely lost, not only where atrophy has been the consequence of lead-poisoning, but also where the bulk of the muscles is only slightly diminished; and the excitability of the muscles remains in some cases impaired even after voluntary movements have regained their former power.

CASE 6.—*Lead-palsy; excitability of the muscles gone.*

S. R., a painter, aged 28, has had several attacks of lead-colics, from which he recovered under medical treatment. Six weeks before I saw him, he had pain in the joints and twitches in the legs. He now complains of the dropping of the left wrist, and of obstinate constipation. A blue line on the gums is distinctly visible. All the extensor muscles of the left fore-arm as well as the deltoid were paralysed; and the patient could only raise his fingers if the first phalanges were supported, showing that the interossei and lumbrical muscles had not suffered. The back of the fore-arm appeared hollow in consequence of atrophy of the extensors. He found it difficult to raise the arm, and impossible to extend it to a right angle with the body. The flexor muscles were not affected. The right arm was weak, but not paralysed. The lower extremities were in no way affected. On applying a somewhat powerful current to the deltoid muscle, only slight vibrations appeared in its fibres, which were wasted, but no contractions could be produced in the extensors on the back of the fore-arm. Faradisation was used every other day for about four weeks, after which the patient had recovered a considerable degree of power in the muscles, the bulk of which had much increased; but even then the excitability of the extensors of the left arm was much less than of those of the right.

The diagnosis between cases of lead-palsy and other kinds of paralysis has not only a theoretical but also a practical interest, as in the former the application of electricity must be combined with a constitutional treatment, while some other forms of palsy yield rapidly to galvanism alone. When a patient states that he has never to his knowledge been exposed to the influence of lead, this statement is no proof that the paralysis may not after all be caused by lead; for it is often introduced into the system without the patient being at all aware of it. Nor is the paralysis of the extensor muscles always preceded by, or simultaneous with, symptoms which belong to the constitutional disease, and which would, if present, facilitate the diagnosis. The electric response of the muscles is therefore a most valuable auxiliary for diagnosis, as it will in many cases enable us to recognise with certainty whether there is lead or no lead in the system.

Meyer* has recorded a very instructive case, in which he recognised by faradisation that the patient was suffering from lead-poisoning. A hatter, aged 38, had for five months suffered from stiffness and weakness in both hands, which rendered him unable to use them. No further symptoms were or had been present previously. Meyer examined the muscles faradically, and found that the extensor digitorum communis muscle did not respond even to a powerful current, and that a very slight sensation only was caused in it, while all the other muscles of the arm answered well to faradisation. He therefore suspected the existence of lead-poisoning, although the occupation of the patient was not one in which lead is used, and although there were no other symptoms pointing to the presence of lead in the system. Faradisation was then resorted to, but thirty-seven applications had no beneficial effect. Two months later the patient was worse, and he then mentioned, in reply to inquiries about lead, that he had for years used snuff packed in lead-foil. The analysis of this snuff showed the presence of a considerable quantity of lead in it. Snuff was now prohibited, and sulphur baths and saline purgatives administered for four weeks. The palsy was then again attacked by faradisation, and the patient recovered.

VI.—RHEUMATIC PARALYSIS.

In this form of palsy the electro-muscular contractility is, according to Duchenne, normal, while the sensation excited by the electro-muscular contraction may be stronger in the suffering side than in the healthy parts. This is true for recent cases; but in those of long standing I have almost invariably found the excitability of the muscles impaired.

* L. c. p. 172.

VII.—PROGRESSIVE MUSCULAR ATROPHY.

Farado-muscular contractility is, in this disease, quite proportional to the more or less atrophic condition of the fibres. The more the bulk of the muscle is diminished, the weaker is the contraction exhibited by it. In this disease electricity enables us to distinguish the state of almost every muscle and part of a muscle, whether normal or atrophied. Thus, for instance, I have seen cases in which not the whole substance of the extensor communis digitorum was atrophied, but merely that portion which extends the middle finger. This was distinguished by placing the electrodes of an induction apparatus upon the belly of the extensor communis, when only the fore-finger, the fourth, and the little finger were extended, while the middle finger remained quite or nearly motionless. The same may be observed if the current is directed to the interossei and lumbrical muscles, when only one or two of them may respond, while the others are not affected, even if a powerful current be used.

CHAPTER V.

ELECTRO-THERAPEUTICS.

The therapeutical sphere of the various forms of electricity has of late become so much enlarged, that those who have not given attention to the gradual progress of this subject, will probably think the catalogue of diseases in which the use of this agent is now recommended too long, and object that a remedy which is employed for complaints of such very different character is not likely to do good in any. But it should be considered, in the first instance, that 'electricity' or 'galvanism' is not *one* single thing, but that there are *four* different forms of it, each of which possesses peculiarities of its own, which distinguish it from its fellows; while from one of them, viz. the continuous current, again, three radically different effects may be obtained, according as we use its catalytic, electrolytic, or cauterising action. Then, again, it must not be lost sight of that modern pathology justly attributes a far more important influence to the vaso-motor system of nerves in the production of disease than was done formerly, and that an agent which has been experimentally shown to possess most constant and powerful effects on the vaso-motor nerves, is *à priori* likely to be effective in diseases caused by a pathological condition of the same. An instance of this is to be found in Basedow's or Graves's disease, where the application of galvanism would appear *à priori* unreasonable, unless we were guided by the principle just enunciated. Finally, it should be understood that I by no means wish to convey the idea that *all* diseases which are discussed in this chapter must of necessity be treated by some form of electricity. I firmly believe that, in the large majority of cases which come under our care in the course of practice, there are three or four different ways of curing the patient; and it is the object of therapeutical science to find out the safest, quickest, and least unpleasant mode of doing so. This, however, can only be accomplished by comparing the results obtained from different methods of treatment, which will eventually lead us to adopt the best. In the following chapter it has been attempted to show what a scientific use of the various forms of electricity can accomplish for the alleviation or cure of disease; but it is by no means intended to urge its exclusive adoption in place of other remedies, which in some complaints may be equally, or perhaps even more, effective. Certain morbid conditions are only mentioned in order to state that, for the present at least, no beneficial effects can be expected in them from electricity. On the other hand, there are affections in which *nothing but electricity* can do real good, and for these its employment will be most strongly recommended; while, finally, there are some in which electricity may be resorted to, either after other modes of treatment have failed, or where physician and patient incline more to electricity than to physic, or to a mere dietetic and hygienic kind of treatment.

The precise mode in which electricity produces its therapeutical effects is still to a great extent shrouded in mystery; but much more is now known of it than was the case formerly.

Static Electricity is a powerful excitant, especially for the sentient nerves, and may be used with benefit wherever it appears desirable to produce a profound modification of their condition. It appears to have greater effects in anæsthesia than any other form of electricity, and may likewise be used as a counter-irritant in headache and certain forms of neuralgia and spasm.

The effects of the *continuous galvanic current* are much more complicated than those of static electricity, and in some instances do not as yet admit of a satisfactory explanation. We easily understand its thermic and electrolytic effects, in cases where the current is made to do the work of the actual and the potential cautery; but its mode of action on the nervous system, when this is in a state of disease, remains at the present time more or less matter of hypothesis.

Remak * distinguishes three principal effects of the continuous current, viz. the catalytic, the anti-spasmodic, and the anti-paralytic. The first of these are, according to him, chiefly seen in inflammatory conditions and their consequences. He has called them catalytic, because an analysis of the facts observed by him has shown that, where the continuous current removes a morbid condition of the tissues caused by defective circulation, or by effusions, this effect is not merely due to simple electrolysis, but that the principal part in it is played by dilatation of the blood-vessels, whereby circulation and absorption are facilitated. Such catalytic effects are to be observed in inflammatory conditions of the brain, which cause tremor and spasm; in inflammation of the spinal cord, with consequent palsy of the lower extremities, bladder, and rectum; in chronic painful rheumatism of the joints, muscles, tendons, periosteum, nerves, and in certain spasmodic affections caused by local irritation; in inflammation of the joints caused by injury or rheumatism; in effusions which are the consequence of inflammation, especially in dropsy of the joints; and in painful and inflamed tumours. Concerning the mode of application, Remak is guided by the view, that a conveyance of liquids is effected between the two poles, and which proceeds in the direction from the positive to the negative. He therefore advises to place the negative pole to the inflamed part, and the positive somewhere in its

* L. c. p. 203.

neighbourhood; but as soon as symptoms of effusion are present, the position of the poles should be reversed. Again, where the character of the inflammation is erethic, the positive, and where it is torpid, the negative, pole should be employed by preference near the seat of disease.

The *anti-spasmodic effects* of the continuous current are, according to the same observer, partly due to its increasing the power of volition over the muscles affected by spasm or tremor, and to its removing catalytically any irritation which may cause the spasm; and partly to a direct reduction of the exalted excitability of the nerves or muscles, which causes local spasms. These effects are chiefly seen in the treatment of reflectory spasms, such as blepharo-spasm and histrionic spasm; in the commencement of shaking palsy; in nystagmus; in scrivener's palsy, stammering, and chorea.

The *anti-paralytic effects* of the continuous current may be observed in hemiplegia and paraplegia, where the disease causing these affections has not too profoundly affected the nutrition and structure of the brain and cord; and also in anæsthesia, atrophy of the muscles, traumatic paralysis, and secondary paresis. Remak ascribes these effects to the current causing dilatation of the blood-vessels of the nervous centres, which, if contracted, do not allow the blood freely to circulate, and also to its action on the nerves of the heart and of respiration; whereby a more healthy metamorphosis of matter is caused.

Ziemssen * has subjected Remak's propositions to a severe criticism, but is nevertheless obliged to confess that they are, to some extent, warranted by the practical results obtained from the use of the continuous galvanic current. No doubt they will have in time to be considerably modified, as our experience of the effects of the current becomes enlarged; but until now nothing better in the way of an explanation has been offered.

There is one point, however, which Remak has not touched upon, and which I am inclined to consider of importance. Du Bois-Reymond and his school have shown that the most important vital phenomena which occur in the nerve consist of different electrical conditions of the same; and it may therefore be assumed that in disease of the nerves, their electrical conditions must be considerably altered.

Now it is known that the continuous current has a powerful influence on the electricity of the nerve (Electrotonus, p. 103); and it is, therefore, by no means improbable that in many cases, especially of functional nervous affections, it may act by restoring the systemic current of electricity to its proper condition. No form of electricity, except the continuous current, has electrotonic effects, in Du Bois-Reymond's sense; and this would therefore, to some extent, explain the superiority of the continuous current over other forms of electricity in the treatment of certain purely nervous affections. Further

* L. c. p. 67.

remarks on this subject will be made under the heading of 'Spinal Weakness.'

The mode in which *faradisation* acts is much better understood, as it is not nearly so complicated as the mode of action of the continuous current. For paralytic affections, the propositions which I have laid down in the first edition of this work are still in perfect consonance with our present enlarged knowledge of this subject.

They are as follows :—

a. *The faradic stimulus is capable of disturbing the molecular equilibrium of the motor nerves and muscles, so as to produce the state in which they are physiologically active. This disturbance, if judiciously produced, does not cause any injury, but tends to re-establish or to ameliorate the lost or impaired function of the motor nerves and muscles.*

As the first part of this proposition is derived from the teachings of electro-physiology (p. 177), I will only say a few words on the latter part, which is an induction from my own therapeutical experience.

There are two kinds of paralytic affections which are often beneficially affected by faradisation, in which by this proposition only we are able to explain the success of the treatment. I allude, in the first place, to cases in which the excitability of the paralysed muscles to the faradic stimulus is *preserved,* and, in the second place, to cases in which it is *lost.* Now if, as has often been contended, faradisation acted beneficially only by producing contraction, and thus improving the nutrition, of the paralysed muscles, cases like those just mentioned could not possibly be ameliorated or cured by it; since in the former class of cases the nutrition of the muscles is perfect, as they respond freely to a gentle current; and in the latter, no contraction of the muscles is produced. Yet cases of cerebral, rheumatic, and hysterical paralysis, in which the paralysed muscles have quite preserved their contractile power, are often considerably and rapidly ameliorated by faradisation; while on the other hand, cases of lead-palsy and of traumatic paralysis recover under its influence, although in the commencement of the treatment the paralysed muscles do not respond even to a current of high tension. In such cases the beneficial effect cannot be explained by the electricity producing contractions of the paralysed muscles, for no contractions are produced; nor by its causing an increased supply of arterial blood to the limbs, for no increase is observable, either in the temperature or in the bulk of the muscles; but only by the supposition that the current restores that mobility to the molecules of the nerves and muscles which is necessary to enable them to be physiologically active.

b. *The faradic stimulus allows the necessary alternate contraction and expansion of the muscles, without which their nutrition is generally soon seriously impaired.*

This fact having never been called in question, I merely adduce the evidence of the observations of

Dr. John Reid which have been previously mentioned (p. 216.)

c. *The faradic stimulus, by producing contractions of the muscles, and thus augmenting the chemical changes in, that is, the oxidation of, the contractile tissue, causes a more abundant supply of arterial blood to it, which is evidenced by an increase of heat and bulk in those parts which have been faradised, and which in its turn augments the nutrition of the muscle.*

This proposition has likewise been fully proved in the second chapter of this volume (pp. 233–240).

In anæsthesia, hyperæsthesia, and spasm, faradisation acts in the same manner as static electricity, viz., by modifying the condition of the sentient nerves of the part submitted to its influence. The particular kind of this influence has been previously described (p. 242).

The differences existing between the physiological and therapeutical effects of electro-magnetism and magneto-electricity have already been noticed in another part of this volume (p. 347).

If it has been decided to adopt an electric treatment in a given case, and the special form of electricity to be used, as well as the mode of its administration has been fixed upon, it further remains to determine how often it should be used, and when the treatment should be discontinued. In rare cases one or two applications of electricity are sufficient to cure a patient; such being chiefly instances of hysterical and reflex paralysis, loss of voice, muscular rheumatism, and amenorrhœa. In most cases, however, it is necessary to use electricity for a month or six weeks, either daily or on alternate days, according to the severity of the affection for the cure of which it is employed. If the patient is well before the month is over, it is not necessary to continue the treatment; in some instances it may even be hurtful to do so. An example of this latter kind will be found in the section on neuralgia. As all nervous affections are distinguished by their great tendency to relapses, it is often advisable to prescribe subsequently a second or even third course of galvanism, if symptoms which have in the first instance yielded to it should re-appear at any time after it has been discontinued. If the patient should not be well at the end of a month or six weeks, it is generally better to discontinue the treatment for two or three months and then to recommence it. A second course of galvanism often rapidly cures symptoms which have obstinately resisted the first. The only complaints in which the galvanic treatment should be continued without any interruption until the patient is well, are progressive muscular atrophy and diabetes, if it has been decided to resort to it in such cases.

I now proceed to consider the therapeutical effects of the different forms of electricity in those diseases for the relief or cure of which they have been, or are to be, medically employed.

I.—DISORDERS OF THE MIND.

Whether any form of electricity may eventually prove substantially useful in disorders of the mind, is at present a matter of doubt and uncertainty. As far as I am aware, no alienist physician has ever yet resorted to a methodical use of it in patients of this kind, while most of those who occupy themselves specially with the therapeutical application of electricity, are, as a rule, not consulted in such cases. Amongst the best authors on electro-therapeutics, Meyer, Ziemssen and Tripier are quite silent on this subject. Remak, on the contrary, states that he has seen good results from the use of the continuous current in morbid conditions of the brain accompanied by disordered mental functions. He concluded from the occurrence of symptoms of disease of certain cerebral nerves in such cases, that the seat of the pathological process was at the base of the brain; but it is more likely that in his cases the affection occupied the pons Varolii, diseases of which, when they have existed for some time, are almost invariably accompanied by symptoms of mental disturbance.

Benedict * is of opinion that these secondary mental disturbances are caused by an affection of the vaso-motor nerves, and may therefore be cured by galvanisation of the sympathetic. He thinks that such applications promote the absorption of effusions,

* Loc. cit. p. 203.

and thereby remove pressure on the nervous matter. Symptoms of mental disturbance generally occur in consequence of diffuse degeneration of the grey matter of the hemispheres, and not so much upon more local pathological processes within the skull.

Benedict has recorded three cases in which mental symptoms were improved by galvanisation. One of these was the case of a musician, aged 42, who was in bed with general prostration, and suffered from vertigo, impaired memory, deficient power of application, and distressing sensations in the head. The continuous current was applied along the spine; after six applications the patient could walk without support, and by further treatment all the head-symptoms were considerably improved, so that he could return to the active exercise of his profession. The second case was that of a cabman, aged 57, who amongst other cerebral symptoms, suffered from extreme weakness of memory, and was apt to burst into tears on the slightest occasion. After a few weeks' galvanisation, he was much better in every respect, and laughed when his previous depression of spirits was alluded to. He was enabled to return to his business. The third case was that of a half-idiotic boy, who was likewise improved by galvanisation of the brain, although not to any very great extent.

I have had, in the course of practice, somewhat frequent opportunities of observing the beneficial influence of the continuous current, in cases where, in consequence of impaired cerebral nutrition, mental symptoms had made their appearance; and I feel convinced that, in well selected cases, highly satisfactory results may be obtained by a judicious mode of galvanisation. Physicians to county asylums, where such cases abound, would find this subject an interesting study, and I should be glad if the following remarks were to induce some of them to give it their special attention.

The study of the effects of the continuous current in such cases is very much facilitated by the circumstance that each application should rarely exceed two or three minutes.

Loss of Mental Energy from Imperfect Cerebral Nutrition.—Cases frequently occur which cannot be classified either as paralysis, or insanity, or any other definite disease of the nervous system; but the symptoms of which are evidently due to impaired nutrition of the grey matter; and, if unchecked in their progress, would in course of time, undoubtedly merge either into paralysis, or insanity, or both. In such cases I believe galvanisation of the nervous centres to be one of the most rational modes of treatment.

CASE 7.—A merchant, aged 48, widower, consulted me in March 1867, for nervousness and irritability of temper. He had for years past experienced considerable anxiety in business, to which he attributed his illness. He complained of a sensation of weight and pressure at the top of the head and in the temples, and of dizziness, chiefly on stooping and looking upwards. His memory and power of application were very much impaired. The speech was somewhat affected, so that the patient would stop in the middle of a sentence, hesitate for a few seconds, and then abruptly finish it. Whenever anything unexpected or disagreeable occurred, he became very much flushed in the face, had sensations of tingling resembling a slight electric shock running down his hands, and would for the time completely lose the faculty of speech. The right pupil was larger than the left, and the sight was often dim. The temperature of the right cheek was 88° and that of the left 87° F. The right ear was also hotter than the left. The pulse was sometimes intermittent and irregular, and the patient complained of palpitations of the heart and shortness of breath in walking, more especially on going upstairs, but there was no disease of the heart or lungs in this case. The tongue was dry and thickly coated, the appetite indifferent, and a sense of fulness and heaviness was experienced after meals. The action of the bowels was irregular. The urine contained an enormous excess of phosphates, but not of urea, and the expulsive power of the bladder was diminished. The patient had become very stout during the last few years, and his muscles were extremely flabby. He rarely took active exercise, as it seemed to make him worse. He had already taken iron and quinine, strychnia, belladonna, and bromide of potassium, but without any improvement. For the last eighteen months he had felt too feeble to attend to his business.

In this case galvanisation of the spine, the cerebral hemispheres, and the sympathetic, was resorted to with satisfactory results. Almost all the morbid symptoms gradually yielded to it, and ten weeks after the commencement of the treatment the patient was enabled to return to his business. He found that he could work well for about a couple of hours, but that when he went beyond that, the symptoms of pressure on the head and tingling in the arms were apt to return.

The patient had another but much shorter course of galvanisation in November 1867, and again in June 1868, when several of the old symptoms had re-appeared. On both these occasions they yielded rapidly to the influence of the continuous current; and when I saw the patient last (May 1869) he was, although not strong, yet in good health, and had been enabled, by restricting his hours of work, to attend to his business without any interruption.

Dipsomania and Excessive Spirit Drinking.—I am strongly inclined to believe that a systematic use of the continuous current would prove of much service in dipsomania. I have up to the present time only treated one case of this affection, with apparently good effects; although the time elapsed since the patient was discharged (sixteen months) is not sufficient to know whether the effect has been permanent. But I have seen a considerable number of cases in which mental depression and nervousness were so great that the patients had long been in the habit of taking large quantities of stimulants, in order to deaden the acuteness of their wretched sensations; and where the morbid desire for alcohol was rapidly checked as soon as they were fairly brought under the influence of the continuous current, applied in an ascending direction to the spine, the cerebrum, and the cervical sympathetic. One of these cases is the following:—

CASE 8.—In June, 1868, a lawyer, aged 37, married, came under my care, who had in consequence of overwork and anxiety, got into a state of complete nervous derangement. He was utterly incapable of any mental or bodily exertion before he had taken three or four ounces of brandy (in the morning), and was in the habit of consuming rather more than a pint of spirit every day. He hated the very sight and smell of brandy; but if he did not take it, such horrible thoughts came into his head as to render life perfectly intolerable. His judgment and intellect were not impaired, but he had not the slightest control over the dreadful ideas which constantly flitted across his brain if not under the influence of alcohol, and which were chiefly of a homicidal and suicidal character. Tonics of every kind made him worse, and several alteratives of considerable efficacy (such as bromide of potassium and bichloride of mercury), had apparently increased his debility to such an extent as to render a prolonged course of them impracticable. Under these circumstances the application of the continuous current to the nervous centres seemed expedient. Within a week from the commencement of the treatment the patient was able to discontinue the brandy in the morning. After three months he had come down to half a pint of sherry for dinner, and took no spirits whatever. His mental and bodily health improved *pari passu*, and when I saw him again in March, 1869, he appeared perfectly well, and had lost every symptom of his previous illness. In this case the galvanism was applied forty-five times. No medicine was given.

Opium-Eating.—In this country opium-eating is often contracted during severe attacks of neuralgia, or after family afflictions. The habit is very rarely broken through, if it has once gained the mastery over the patient, as the feelings of depression and despair which invade the mind after the comforting effects of the opium have disappeared are so acute as to be almost unbearable, and only yield to a fresh supply of the drug. Under such circumstances the continuous current has several times proved to me of service.

CASE 9.—A lady, aged 48, widow, had commenced to take laudanum after the loss of her husband, six years ago. When she came under my care in October, 1867, she complained of indigestion and weakness in the back, which latter prevented her from standing or walking. She had a great aversion to taking medicine, and consulted me chiefly with regard to the application of galvanism in her case. She never mentioned to me that she was in the habit of taking opium, but laid stress on the symptoms of constipation and want of sleep. The latter symptom only induced me to resort to the application of the continuous current to the head and sympathetic, while for the weakness in the back I should have been satisfied with an application to the spine. No medicine was given, except Friedrichshall-water for constipation, with good results. Under the influence of the continuous current, the sleep improved, and the back became much stronger, so that the patient was soon enabled to take a good deal of active exercise. Although after a time she appeared in fair health, she still appeared anxious to continue the galvanic treatment; and one day confessed to me that she had been in the habit of taking large quantities of laudanum for years past, to which she attributed her illness; but ever since the galvanism was first applied, she had felt less desire for opium, and that she had gradually discontinued the use of it. She was afraid that if the galvanism were given up the desire for opium would return, and as she found herself much better without it, was anxious not to be obliged to do so again. A short time afterwards the galvanic treatment was, however, discontinued, the patient being desired to return if any symptoms of opium-hunger should present themselves, but up to the present time this lady appears to have had no return of that morbid desire.

Excessive Smoking.—Tobacco-smoking is often resorted to for the same reason as spirit-drinking and opium-eating, viz. to allay nervous irritability and depression; and is by many people carried to such an extent, as to seriously injure, not only the function of digestion, but also the nutrition of the nervous system. Such patients say that they '*must*' smoke, as others *must* drink. In several cases of this kind which have been under my care, the use of the continuous current, coupled with strong remonstrances on my part, has enabled the patients to break themselves of the habit.

Hypochondriasis.—In this form of mental disease I have reason to believe that the use of the continuous current would often be attended with the best results. The immediate effects of a galvanic treatment in such cases are almost always very gratifying; but I am at present unable to judge whether the results are permanent, as I have only recently resorted to this treatment. Other modes of combating this affection so frequently prove futile, that a trial of galvanisation in them cannot be too strongly recommended. It seems to do good chiefly in those cases where the hypochondriasis arises from imaginary or real disease of the sexual organs (sexual hypochondriasis, spermatorrhœa, impotency).

II.—PARALYSIS.

While only slight evidence exists up to the present time concerning the beneficial effects of galvanism in disorders of the mind, a very extensive experience has already been accumulated on its use in paralytic conditions, where, in the absence of other remedies having a direct curative influence on the paralysis, electricity finds a most legitimate and useful sphere of action.

1. *Cerebral Paralysis.*—The most frequent form of cerebral paralysis is hemiplegia, which is caused either by the rupture of bloodvessels and subsequent hæmorrhage into one of the cerebral hemispheres; or by extensive laceration of the tissue of the thalamus opticus and corpus striatum, in consequence of softening; or by embolism of an important cerebral artery. Such pathological processes impede the conduction of the orders of volition, which, in the normal state of the brain, are carried through the fibres of the corpora pyramidalia to the motor nerves of the opposite side of the body, to the muscles, so that these become incapable of executing voluntary movements.

If the patient survives the paralytic stroke, a process of reparation soon afterwards commences in the cerebral substance, which is more or less thorough according to the degree of the paralysing lesion. Where an extensive laceration of cerebral tissue has taken place, the paralysis will, in all probability, remain permanent; but where there has been merely an effusion of a small quantity of blood, the symptoms are rather caused by the clot pressing upon the brain-matter, than by destruction of cerebral tissue; and in such cases the patient's health maybe perfectly restored. At first the fluid parts of the blood which has been effused are absorbed, and an organised membrane, a cyst, is formed round the clot, which in course of time is likewise absorbed. The cyst then shrinks up, and at last only a cicatrix is found. In a certain number of cases this process of reparation is accompanied by a gradual amelioration of the paralytic symptoms, and thus spontaneous recovery may take place. In other instances the gradual shrinking of the cyst acts as an irritant on the brain, when the paralysed muscles assume a rigid condition, and the motor nerves appear to undergo various morbid alterations. Finally, the cicatrix may have been formed, and there may be no rigidity of the muscles, but the paralysis still continues in a more or less degree, owing to the function of the injured hemisphere remaining in abeyance, in consequence of hyperæmia, serous effusion, or the effects of shock.

Embolism of cerebral arteries occurs in patients who are subject to organic affections of the aortic or mitral valves due to former endocarditis. Particles of fibrin are suddenly separated from the warty growths on the valves, and being carried along with the stream of blood, plug up a cerebral artery. In such cases the prognosis is generally unfavourable, not only because softening takes place in the neighbourhood of the embolus, but also because there is great probability of further attacks occurring in course of time, even if the first symptoms should have been removed by the establishment of collateral circulation. These cases are, however, much rarer than those owing to the rupture of a blood-vessel in the brain, which latter furnish by far the largest proportion of all cases of hemiplegia.

When an extensive laceration of cerebral substance has taken place, or when by the shrinking of the cyst considerable rigidity of the paralysed muscles has been caused, the prognosis is not favourable. But where the clot, and consequently the cicatrix, is not very large, the prospects are much better, even if no spontaneous recovery takes place. It is doubtful whether the process of reparation itself and the formation of the cyst may be promoted or accelerated by the use of galvanism; but it seems certain that by cerebral galvanisation, the parts in the neighbourhood of the paralysing lesion, which have become unable to fulfil their function, through hyperæmia, serous effusion, or shock, may sometimes, by the galvanic stimulus, be enabled to regain their function.

The following important case occurred in Benedict's practice * :—

A merchant, aged 69, had had an attack of right hemiplegia in August 1862, with loss of consciousness and language. In May, 1863, the leg had recovered, but all the muscles of the fore-arm and hand, with the only exception of the muscles of the ball of the thumb, were paralysed; and the flexors and pronators were contracted. Electro-muscular contractility was considerably diminished. The

* Loc. cit. p. 227.

continuous current was applied to the left cerebral hemisphere, and *immediately afterwards* the patient could flex the wrist and the phalanges. After five more applications he could extend the metacarpo-phalangeal joints fairly well, and the phalangeal joints pretty well.

I have never seen such immediate results in hemiplegia, merely from galvanisation of the injured cerebral hemisphere; but I have found that patients of this kind progress more rapidly towards recovery, when cerebral is combined with peripheral galvanisation; and therefore now generally employ both methods together.

Only the *continuous* current should in such cases be applied to the injured cerebral hemisphere. Faradisation by a feeble current has no effect on the nervous centres, and it might do harm if a high degree of power were used. Several cases have occurred in M. Duchenne's * practice, where, by the injudicious application of faradic electricity to patients who had suffered from hæmorrhage into the brain, another apoplectic attack was caused.

The period at which cerebral galvanisation should be resorted to, is variously fixed by different observers. Remak has recommended to galvanise early the sympathetic and the cerebral vessels of the opposite side, in order to promote the absorption of the clot; but most authors are agreed not to commence the galvanic treatment too soon after the attack, although the continuous current may certainly be employed long before the induced current. As a rule, I should

* 'De l'électrisation localisée,' etc., p. 274.

advise to begin using galvanism when two or three months have elapsed since the attack took place.

It is certain that in the large majority of cases, cerebral galvanisation alone is not sufficient to produce decidedly beneficial effects; while peripheral galvanisation or faradisation almost always prove of service. In such cases it must be assumed that the paralysis is no longer exclusively due to the injury of the affected hemisphere, but more to the loss of vital energy of the nerves and muscles of the affected limb, the molecules of which seem to have lost that mobility which otherwise enables them to respond to the orders of volition. Whether in such cases galvanisation or faradisation should be resorted to, will depend upon the individual aspect of the case under treatment; and it may be laid down as a general rule, that where the electro-muscular excitability is normal, galvanisation, and where it is diminished, faradisation should be employed. It is often useful to combine both methods, or to employ one after the other has been used for some time and failed.

We have already seen (p. 398) that in some cases of hemiplegia the paralysed muscles are relaxed, the limbs loose and flaccid, and if the forearm is flexed upon the arm, or the leg upon the thigh, no resistance to that movement is experienced. The paralysed muscles present a striking contrast to the firmness and plumpness of those of the sound side, and they are more or less wasted according to the length of time which has elapsed since the paralytic seizure. In such cases there is generally only little response to the galvanic stimulus, and the heat and nutrition of the limbs is much below par. Some of these cases recover spontaneously, while others only slightly improve as time goes on. If from four to six months have elapsed since the seizure, and the recovery is still imperfect, faradisation is a valuable means of restoring power to the motor nerves and muscles which remain paralysed, and require a stimulus in order to regain their function. Moistened electrodes should be directed to the suffering nerves and muscles in the way described above (p. 378). The old-fashioned way of using the induced current in these cases, viz. to let the patient hold one conductor in the right and the other one in the left hand, or to place his feet in two separate vessels filled with salt water and connected with the poles of a battery, is to be strongly deprecated, as by such a proceeding painful and irregular commotions are caused in the paralysed as well as in the healthy muscles, which are indiscriminately affected. This method of operation can therefore not be beneficial to the patient. On the contrary, it has often done harm. The intermittences of the induced current should be slow, so as to avoid any irritation of the brain. The following is a case in which only a few muscles remained paralysed after the stroke, and in which a considerable amelioration was produced by faradisation.

CASE 10.—Jane S., aged 35, was in July, 1857, admitted into Carlisle ward, St. Mary's Hospital, under the care of Dr. Alderson. From the somewhat confused statement of the patient, whose intellect and memory are below the average, it appears that she had an apoplectic seizure fifteen months ago, in which she lost consciousness and the use of the left arm and leg. The leg appears to have soon recovered; at least when I first saw her on July 20, she could walk with ease, but several muscles of the left arm were paralysed, viz. the deltoid, the extensor of the forefinger, and all the muscles of the thumb. She could raise the humerus, this movement being produced by the concurrent action of the trapezius, serratus magnus, and deltoid, but she was not able to lift the arm to a right angle with her body, and when she held the hand on the lower part of the spine, she could not move it upwards. The forefinger was slightly contracted, and could not be extended; the thumb was held against the forefinger, and was totally powerless. All the affected muscles were flabby and wasted. The patient was not able to use her needle or do any other work. When I directed the faradic current to the paralysed muscles, they showed much less excitability to it than the corresponding muscles of the other side. The deltoid was much improved after five applications, but the muscles of the forefinger and thumb recovered only after a month's treatment, in which faradisation was used about twenty times. The patient then left the hospital, being again able to use her needle, and to accept a situation as cook.

The following is another case of this description, in which the loss of power was more general:—

CASE 11.—B. W., a gentleman aged 68, of gouty constitution, first came under my care in June, 1866. He was then suffering a good deal from gravel, and excess of uric acid in the urine, and digestion and assimilation had been imperfect for five or six years. In December, 1866, while dressing for dinner, he had an apoplectic seizure, accompanied with loss of consciousness and paralysis of the left side of the body. For a week he was in a very precarious condition, and I believe his life was only saved by large doses of ammonia and chloric ether, which I ordered to be given at short intervals. He gradually, however, recovered his consciousness and intellect; the face resumed its normal appearance, and the muscles of the arm also improved. Four months after the attack, he was in the following condition:—His memory and speech were unaffected, and there were no distressing sensations in the head. The skin of the left arm and leg was cold and flabby, and the pulse weaker in the left than in the right side. There was a feeling of numbness, and a certain degree of anæsthesia, in the left arm and leg. The muscles were relaxed and somewhat wasted, especially the extensors, but there was no rigidity either in the upper or in the lower extremity. Feeding, dressing, and all other movements of the arm and hand were extremely difficult, although with a great amount of exertion they could be performed. The patient could walk comfortably for half a mile, but then began to feel fatigued, and was obliged to rest.

From these symptoms I concluded that the clot which had been formed in the right corpus striatum and thalamus opticus, and which had produced the paralysis, had, to a great extent, been absorbed. If, therefore, the original injury had been repaired, the seat of the paralysis was now not so much in the brain, as in the motor nerves and muscles, which had been weakened by their long disuse. Faradisation was therefore now resorted to, with the result that, after sixteen applications, the bulk of the muscles was increased, the circulation in the limbs was properly re-established, and the patient had almost entirely recovered his motive power.

It must, however, not be supposed that faradisation always produces such beneficial results as in the two cases just related; sometimes there is only a trifling improvement or none at all, of which the following is an instance:—

Case 12.—In May 1858, I was consulted in the case of a merchant, aged 60, married, who had been in tolerably good health until December 1857, when he was knocked down by a cab. With the exception of some bruises on the back and the leg, no apparent injury was caused by this accident, but the day after he was seized by an attack of hemiplegia, which affected the whole left side of the body. He did not lose his speech nor his consciousness. The face recovered rapidly, but the arm and leg remained completely useless. He could pull up his shoulder to some extent, but was unable to lift the hand to the forehead or put it on his back, or on the opposite shoulder; nor could he bend the elbow, or move the wrist in any direction. He had to be lifted into, and out of, his bed, and everything had to be done for him as for an infant. There were hardly any contractions in the muscles, which were flabby, and responded only little to the faradic current. His general health was tolerably good. Faradisation was used for six weeks, but with no perceptible effect, the condition of the patient remaining much the same as before. The muscles of the limbs which had been faradised, were better nourished and answered more readily to the current than before; but there was no return of voluntary power.

At that time the continuous current was not used in such cases; but it is likely that it would have produced better results in the preceding instance than faradisation.

In a certain number of cases of hemiplegia the nerves and muscles of the affected side are equally excitable to electricity as those of the healthy side. In these cases the continuous current is more valuable than faradisation, although this latter is by no means ineffective.

CASE 13.—A naval officer, aged 54, unmarried, came under my care in February, 1868. He had had an apoplectic seizure in June, 1866, in which he lost the use of the left side. Speech and consciousness had not been impaired, but the arm and leg had been completely paralysed for about three months. Both extremities then began to recover their motive power to some extent; but as they were still very weak about twelve months after the stroke, the patient was faradised in the country, with satisfactory results. The leg became very much stronger, so that he was soon enabled to walk without a stick, for two or three miles at a time. The arm also improved, but not nearly as much as the leg, and the treatment was discontinued after three months, as it did not seem to produce any further effect. The patient then came to town to consult me, and as faradisation had already had a fair trial, I recommended galvanisation of the right cerebral hemisphere, and of the motor nerves and muscles of the arm. Within three weeks the patient had so far recovered the use of the hand as to be able to do everything for himself, although it was not yet quite as strong as the right hand.

There are few cases of hemiplegia where there is not a slight amount of rigidity in some of the paralysed muscles; but in some instances the rigidity is so severe as to form the most prominent symptom. Twitchings of the fingers and toes are often connected with it; they occur especially at night, and seriously interfere with sleep. In such cases the continuous current should be used in preference to faradisation, which latter may however be employed where an effective apparatus furnishing a continuous current is not procurable. The following case shows that faradisation of the antagonists of the rigid muscles may do a certain amount of good in such conditions :—

CASE 14.—In December, 1858, a man of the name of Marsh was under the care of Dr. Todd, in King's College Hospital. Four years ago he had an attack of paralysis of the right side. The paralysed muscles had then soon assumed a state of rigidity, which had not undergone any considerable change since that time. When I first saw the patient he could with some difficulty walk, but the right arm was perfectly useless, owing to rigidity of a number of muscles; viz. of the coracobrachial muscle, whereby the arm was adducted to the side, and of the biceps, by which the fore-arm was bent upon the arm. If forcible extension of the fore-arm was attempted, the biceps resisted the movement, but no pain was experienced during such forcible extension. The triceps was rigid, although much less so than the biceps; it was shown to be so when complete flexion of the fore-arm was attempted, so as to place the fingers on the acromion of the same side. The flexor muscles of the wrist and of the fingers were completely rigid; the hand was strongly flexed upon the fore-arm, and the fingers pressed against the palm of the hand, so that the patient was obliged to cut his nails very short, in order to prevent the skin from being irritated by them. The tendons of the flexors projected like tight strings beneath the skin. The patient, however, felt no pain if a forcible extension of the wrist and of the fingers was attempted. The muscles were not much wasted, but faradic excitability was very trifling in the extensors, while the flexors of the fore-arm contracted readily under the influence of a gentle current. The muscles of the lower extremity were not nearly so rigid as those of the arm; some degree of contraction however existed in the hamstring muscles and the flexors of the toes; and in walking the patient was seen to drag the paralysed leg.

I thought that in this case it might be possible by faradisation to correct to some extent the disturbance in the equilibrium between the different sets of muscles of the upper extremity; and this view was confirmed by the result of the treatment; for after I had faradised the extensors of the fore-arm for some time, the tendons of the flexors, which had before projected like tight strings beneath the skin, became soft and flexible; and the patient was able to open his hand and stretch his fingers; but having been some time afterwards exposed to a violent cold draught, the flexors again assumed a certain degree of rigidity. Unfortunately there was at that time no battery in King's College Hospital furnishing a continuous current, which I should have wished to apply to the rigid flexors, or the patient's condition might have been much more ameliorated. By further faradisation he again improved, but he left the hospital before a permanent relief was afforded.

In such cases there is always a certain degree of subacute or chronic inflammatory irritation of that hemisphere of the brain which is opposite to the paralysed side; and in a certain proportion of them the continuous current applied to the head of the opposite side, to the sympathetic, and finally as cord-nerve current, produces more benefit than any other remedy. From a very large number of such cases which have been under my care, I select the following:—

CASE 15.—Mrs. D., aged 53, came under my care at the Infirmary for Epilepsy and Paralysis, in June, 1866. She had been in good health until two years ago, when her husband being thrown out of employment, she had to undergo a good deal of anxiety and trouble, together with bad living. Two months ago she was seized with a paralytic stroke, which affected the left side, and left her entirely helpless. When I first saw her, she had recovered the use of the leg so far that she could just drag herself along with the aid of another person's arm, for a short time, but the left arm was quite powerless. On examining the limbs I found that the arm as well as the leg were warmer than those of the healthy side, and that there was rigidity of most of the flexor muscles of the arm and forearm, and of the hamstring muscles of the thigh. The forearm, hand and leg, appeared contracted, and on my trying to extend them the patient complained of excessive pain, which rendered further endeavours to that end useless. I applied faradisation to both arms for the purpose of diagnosis, and found that the paralysed muscles contracted in the most violent manner as soon as the conductors were applied to them, while the muscles of the healthy limb did not answer to the feeble current used, but contracted in the ordinary and regular way, as soon as the power of the current was somewhat increased. This made it evident to me that considerable intracranial irritation existed, and that faradisation could not be of much use. I prescribed atropine with bromide of potassium, and applied a current of twenty cells of the continuous battery to the right temple, the upper cervical ganglion of the sympathetic, and as cord-nerve current from the cervical portion of the spinal cord to the median, ulnar, and sciatic nerves, systematic use being made of voltaic alternatives in order to increase the therapeutical effect. This application had a most remarkable effect in loosening the muscular tightness, and the patient was, a short time after the application, able to stretch the arm and to open the hand. She had also somewhat less difficulty in walking. The improvement, however, lasted only for a few hours, and when I saw her again, three days afterwards, she was in much the same condition as before. The continuous current was now applied regularly twice a week, in the manner described above, with progressive improvement in all the symptoms; and at the end of six weeks the patient could walk by herself without assistance, and had also to a great extent recovered the use of the arm. This was now quite flexible, the muscular rigidity and the pain having entirely disappeared, but the power in the arm, as well as the leg, was still somewhat less than it had been before the attack.

In cases of this kind, galvanisation of the injured hemisphere appears to attack the seat of the disease, and if not able to restore any destroyed brain-matter to its previous healthy condition, yet does good in this way, that it not only seems to check the inflammatory irritation, and to promote the absorption of effusions which have taken place, but also restores their energy to the neighbouring parts of brain-tissue which have not been destroyed as far as their texture is concerned, but merely deprived of their vital force, either by the pressure of the effusion, or by the shock experienced during the apoplectic attack. The presence of early muscular rigidity is therefore no longer a thoroughly bad symptom in these cases; but if, in addition to the rigidity, spasms and convulsions are present in the paralysed side, the prognosis is, generally speaking, more unfavourable.

The results of galvanisation are not always so immediate as in the case just described; yet it is pleasant to see how, even in the apparently worst cases of hemiplegia with rigidity, perseverance in treatment is rewarded by success. Private patients are apt to lose hope if there is not a quick improvement; but from what I have seen in the out-patients of the hospital, where I have been able to keep such cases under observation for twelve or eighteen months consecutively or even longer, I have come to the conclusion that no case, however bad, is utterly hopeless. The anatomical alterations which Messrs. Charcot and Cornil * have described as occurring in the motor nerves under these circumstances, are therefore probably not constant, or if they are, it must be supposed that they gradually yield to the influence of galvanisation.

Where hemiplegia is combined with total loss of language (aphasia) the prognosis is decidedly unfavourable. A slight impediment of speech (thickness, huskiness, etc.) often yields to treatment, but aphasia never.

In paralysis owing to tumour or abscess of the brain, or any other severe structural lesion, no form of electricity can do good. But where it seems to occur in consequence of exhaustion and slight effusion, the continuous current is the best remedy. The effect is generally immediate and almost magical. The following case is one of this class:—

Case 16.—*Paralysis of the right arm in consequence of sudden loss of cerebral energy.*

A merchant, aged 52, married, had been in a low state of health for some years past in consequence of much anxiety and trouble, but had not suffered from any serious

* Comptes rendus de la Société de Biologie. Paris: 1863.

illness. He was sitting quietly at home, on July 20, 1867, writing a letter, when he suddenly felt faint and giddy, the pen dropped out of his hand, and he completely lost the use of the right arm. He did not lose his speech and consciousness, nor the use of the leg, nor was the face distorted. A friend who happened to be present advised him to put his hand into boiling water, which he did, and blistered it most severely with it. (The same barbarous treatment which, of course, cannot do the least good, has been adopted in at least a dozen cases of paralysis which have been under my care.) As the scalding of the arm and hand produced no effect, a cold douche was next applied to it, and the wrist was then a good deal knocked about, in order to get the life back into it. As none of these violent measures had the least effect, the patient consulted me two days afterwards, when I found complete paralysis of the forearm and hand, and nearly complete anæsthesia of the hand and fingers. I applied a current of twenty cells to the left hemisphere for one minute, after which the patient lifted his wrist and moved the fingers to a slight extent. I did not use any peripheral galvanisation. Two days afterwards he came again, when I found that the improvement had continued, but not made further progress. I then again resorted to cerebral galvanisation, with the effect that a little more action in the hand became manifest. But as it was still very weak, I now combined peripheral galvanisation of the radial and median nerve with it. The effect of this was apparently even greater than that of the cerebral application, as the patient could grasp my hand firmly afterwards, and dress himself without assistance. Another application of galvanism on the following day completely restored the use of the hand and fingers.

Concerning the pathology of this case I would remark that evidently no rupture of a blood-vessel could have taken place in the left hemisphere, as then the effects of the continuous current, applied so shortly after the seizure, could not have been so great. The paralysis probably arose from exhaustion of that portion of the brain which is the centre for the motor nerves of the upper extremity, and was probably accompanied with slight serous effusion.

The beneficial effects produced by peripheral galvanisation in this case do not clash with this view, for no absolutely peripheral galvanisation is possible, since a portion of the galvanic current used probably always travels towards the centres of the nervous system. A proof of this amongst others, is the sensation of taste which is frequently perceived by patients, while their hands or legs are galvanised; and which was the case with the patient just mentioned. That slight serous effusions may be very rapidly absorbed by the passage of the continuous current through such parts, is likewise shown by the instantaneous effects of the current in cases of muscular rheumatism, of which more hereafter.

Most cases of paralysis which occur during convalescence from acute diseases have the same pathology as the case just described, and should therefore be treated by the same means. In these conditions the induced current is not nearly as useful as the continuous, because its effects are only peripheral, while the disease is of central origin. Cases of this kind occur after measles, scarlet fever, small-pox, erysipelas, typhoid fever, pneumonia, dysentery, cholera, and puerperal fever. Diphtheritic paralysis has a somewhat different pathology, as it is due partly to the local effects of the poison on the pharynx, and partly to its general effects on the blood. In this form of paralysis the pharynx is always first affected, and sometimes remains the only part which is paralysed; while in other instances the muscles of the eyes, the lower extremities, the upper extremities, the muscles of the trunk, and the respiratory muscles become affected in the succession in which they have just been mentioned. Anæsthesia often precedes diphtheritic paralysis, and farado-muscular and galvano-muscular excitability is generally normal. In all such cases no time should be lost in employing galvanisation, as the probability of cure is in inverse ratio to the length of time which has elapsed since the commencement of the affection.

Where paralysis after acute diseases takes the form of complete hemiplegia, which is on the whole rare, the disease is more apt to resist the galvanic treatment than where it is either more localised or more general. There is probably in such cases actual hæmorrhage into the brain, and not merely exhaustion and serous effusion.

2. *Spinal Paralysis.*—By this is meant real paralysis of motion, and not want of co-ordination of movements, which latter occurs in tabes dorsalis or ataxy. Spinal paralysis is generally due to meningitis or myelitis, or to tumours pressing on the cord. If the paralysing lesion is seated in the lumbar portion of the cord, there is paralysis of the lower

extremities (paraplegia), and of the muscles of the pelvis. If the dorsal portion is affected, the abdominal and lumbar muscles suffer likewise, respiration is impeded, and there may be tympanites, priapism and paralysis of the sphincters. Finally, if the cervical portion is diseased, the upper extremities are also paralysed, respiration suffers more considerably, and deglutition becomes imperfect; but the intellect and the nerves of special sense remain in their normal condition. In cases of this kind the excitability of the muscles is diminished in exact proportion to the degree in which their nutrition is impaired; and it may at last entirely disappear. Anæsthesia is more complete and permanent in spinal than in cerebral paralysis; nutrition is therefore more seriously impaired, and there is great disposition to decubitus. Hemiplegia is very rare as a consequence of disease of the spinal cord; but there is no doubt that it occasionally occurs. In such instances only one-half of the spinal cord is diseased. The chief sign whereby we may distinguish spinal from cerebral hemiplegia, is the movement of the umbilicus, which, in the former is, by every inspiration, drawn towards the sound side.

Whether galvanisation is likely to do good or not in spinal paralysis, depends chiefly upon the cause and duration of the disease, and upon the age and constitution of the patient. If the paralysis is caused by tumours pressing on the spinal cord, or if there is scrofulous or other disease of the vertebræ, or if the substance of the cord is actually destroyed by inflammation and softening, the galvanic current may relieve certain symptoms of the affection, but cannot have any curative effects. On the contrary, if the paralysis is due to slight meningitis or myelitis, or to over-exertion and consequent exhaustion of nervous power, or to anæmia, much benefit may result from a judicious use of both galvanisation and faradisation. *Cœteris paribus*, young patients and recent cases are more likely to get well than the reverse.

CASE 17.—*Paraplegia due to disease of the spinal cord in the dorsal region.*

T. B., aged 35, a surveyor, had, with the exception of gonorrhœa, never been ill until six months ago, when he was unusually over-taxed with work, and was constantly exposed to the influence of damp and cold. So gradual was the loss of power that came over him, that he was not the first to notice it, but was told by his friends that he walked lame. Soon afterwards, however, he felt so weak that he could not walk without the aid of a stick. His feet used to perspire a good deal before he began to suffer in this way, but had not done so after he had become lame. In the region of the tenth dorsal vertebra, the back was painful to pressure, and hot sponges applied there, produced a peculiarly unpleasant sensation, different from that which was felt on other parts of the back. The patient had at first perceived 'pins and needles' in the lower extremities, which was, after a time, succeeded by a feeling of numbness, so that in walking he did not feel the ground. When standing in the dark, or with his eyes closed, he at once began to stagger. Going downstairs was very difficult for him. The skin was dry, cold, and flabby. I examined it by the aid of the æsthesiometer, and found a great diminution of sensibility all over the lower part of the back, the epigastrium, and the lower extremities; but there was no complete anæsthesia. The muscles of the abdomen and of the lower extremities were somewhat wasted, and sluggish in their response to the galvanic stimulus. The patient suffered from costiveness and a feeling of pressure and tightness in the epigastrium, and was obliged to use great exertions for relieving the bladder. The urine was apt to turn alkaline in a short time, but otherwise healthy. The patient had sometimes involuntary emissions of fæces and urine. He had taken much medicine, especially strychnia, bichloride of mercury, and iodide of potassium, but without any benefit.

The diagnosis was: chronic myelitis in the dorsal region, due to over-exertion and exposure; the treatment to consist of galvanisation of the back and the feet, and faradisation of the muscles of the abdomen and of the lower extremities. No medicine was given. The result was as follows:—The feet, to which a current of thirty cells of Bunsen's battery was administered, became warm and glowing after a short time, and the pain in the back, for which a current of twelve cells was used, was very much diminished. After a fortnight's treatment the patient felt a good deal better. He had more control over his legs, was better able to hold and pass his urine, and sensation was more distinct everywhere. He remained under my care for nearly six weeks, getting gradually stronger, and being again able to walk a short distance without the aid of a stick. The feet now perspired as much as they had ever done before. In this case, a longer treatment would probably have effected a complete cure, as the mischief in the cord had evidently not proceeded to destruction of nervous matter.

Case 18.—A commercial traveller, aged 38, consulted me in October, 1864, for weakness in the back, and loss of power in the lower extremities. He began to suffer in March of the same year, after unusually hard work and great fatigues; and had got gradually worse from that time. At first he felt a sensation of pins and needles in the feet, but this had now been succeeded by numbness. His gait was tottering, and he could only walk by the aid of two sticks. There was a high degree of anæsthesia in the back from the sixth dorsal vertebra downwards, and also in both thighs and legs, so that the application of an extremely powerful galvanic current was only just felt as a slight tingling sensation. The patient also suffered from costiveness and difficulty of micturition. There was no ataxy. I applied the continuous current twice a week for two months, at the end of which time the patient could walk without a stick, had lost the feeling of numbness in the feet, and the anæsthesia of the back had so far yielded that the application of forty cells of the battery was all he could comfortably bear, while at first the current of a hundred cells had appeared to him 'like nothing.' From beginning with the latter number, I gradually came down to fifteen cells, which were distinctly felt when I discontinued the galvanism. The patient being anxious to resume his avocations, I put him on a course of nitrate of silver, in order to guard him against a relapse; and I lately heard that he had remained in good working condition ever since.

The following case is of a different kind, as it was caused by mechanical violence:—

CASE 19.—R. M., a bricklayer, aged 37, was admitted as an out-patient at the Infirmary for Epilepsy and Paralysis, in October, 1866. Three months ago he had been run over by a cart, which had injured his back, and from that time he had lost power in the left thigh and leg. On examining the back, I found a considerable depression about the seventh dorsal vertebra, while the sixth vertebra was unusually prominent. There was great tenderness on pressure at these points, and incomplete anæsthesia of the left side of the back, and of the left thigh and leg. There was loss of power in all the muscles of the lower extremity, but no paralysis; the patient was able to move the thigh and leg, but any such exertion caused considerable pain and exhaustion. These symptoms I thought at first due to subacute inflammatory softening of part of the posterior arch of the sixth dorsal vertebra, whereby the dura and pia mater, and the left postero-lateral column of the cord, were compressed, but they were more probably owing to effusion, and subsequent partial muscular contraction and paralysis, whereby the position of the vertebræ became altered. In this case I used a cord-current of twenty cells. When I saw the patient again, three days afterwards, the tenderness on pressure and the anæsthesia were considerably less, but there was no more power in walking. The continuous current was repeated four times more, after which the depression of the seventh, and the prominence of the sixth dorsal vertebra, had very nearly disappeared, and there was neither tenderness nor anæsthesia. As the muscular power, however, did not return, I applied faradisation to the muscles of the thigh and leg, with the result that, after three such applications within ten days, the patient could be discharged cured.

An interesting case of imperfect spinal hemiplegia has been put on record by Benedict:—

A porter, aged 42, was admitted into Oppolzer's clinique, in the General Hospital of Vienna. Twelve months before admission he was accidentally pressed against the wall of a cellar by a large tub. He lost his consciousness, but soon returned to work. Ever since that time, however, he noticed progressive weakness in the whole of the right side, and lancinating pains in the right leg. On being ex-

* Canstatt's Jahresbericht, 1867, vol. i.

amined it was found that sensibility to pain as well as to touch was lost in the right arm and leg; that passive movements were not felt in the upper extremity, while on the hip-joint they caused pain. The patient could move his leg, but several muscles of the arm and shoulder were paralysed. Active and passive movements of the head were extremely difficult; there was great tension of the muscles, and pain and crepitation about the cervical vertebræ. The gait was that peculiar to hemiplegic patients. Headache in the occiput was complained of; there was no reflex action from tickling. Electro-muscular contractility was normal; electro-muscular and electro-cutaneous sensibility destroyed; sixth cervical vertebra strongly prominent, fifth much depressed. The vertebral column was strongly prominent towards the neck. Benedict pronounced the case to be one of affection of the spine, seated probably about the fifth cervical vertebra; the symptoms being due to compression of the right postero-lateral column of the cord. He applied the continuous current to the spine. The next day the patient felt passive movements, and the tension of the muscles of the arm was less. Four days afterwards the cutaneous sensibility in the foot and leg had returned, and the sensation in the arm was also normal. A fortnight afterwards the patient was discharged nearly well.

The following is one of Meyer's cases * :—

A Prussian officer, aged 38, who was much exposed to cold and heat alternately, being employed in the gun-factory at Spandau, first perceived in 1862 a sort of unsteadiness in his legs, which was followed by a feeling of cold and numbness in the whole left side of the body. These sensations gradually disappeared, but were succeeded by progressive weakness in the left thigh, reflectory movements in both legs, wasting of the left glutæi and muscles

* Die Elektricität, etc., p. 328.

of the left thigh, and a feeling of weight in the lumbar spine. The patient improved under treatment; but in October, 1867, on getting out of a cab, fell down, and could not get up by himself. From that time the lameness of the leg increased very much; going downstairs was very difficult, and the muscles of the thigh wasted away rapidly. There was pain on pressure on the lumbar spine. Meyer applied the positive pole to the painful spot of the spine, and the negative to the left crural plexus. After nine such applications the nutrition of the leg was improved, the lameness less, going upstairs and downstairs was easy, and the patient could walk for some miles without fatigue.

Dr. Hitzig * has cured a similar case :—

A sergeant-major of the Prussian Guards, aged 33, fell with his horse in March, 1865, and came down on the bottom of his back. He felt pain there, but was able to remain in active service until May, when he had pleurisy. He was convalescent in July, but from that time the pain in the back increased; there was also pain in the legs, and extreme sensibility to touch. He had 'pins and needles' in the feet, and felt the ground soft on walking. There were involuntary muscular twitches, and the patient got very lame; emissions of semen took place three or four times a week. He could neither walk nor stand with closed eyes, or in the dark, and was obliged, when he walked, to do so in a stooping position, as in walking erect he felt dizzy, and the pain in the back increased. Nitrate of silver and iodide of potassium had no effect. He slept badly, and had scarcely any appetite. After eight applications of the continuous current to the spine continuatively, he slept well; there was only little pain, and the legs felt easier. The crural nerves were now likewise galvanised intermittently, and with such good effect that the numbness in the feet disappeared, and he could stand with closed

* Virchow's Archiv, 1867, vol. xl.

eyes for fifteen seconds without staggering. After six weeks all symptoms had yielded to the galvanic treatment, with the exception of a slight pain in a few of the intervertebral spaces. The patient had two relapses, after considerable exertions and cold, but which yielded to the same treatment.

3. *Paralysis from Disease of the Cervical Sympathetic.*—Certain cases of paralysis can only be explained by assuming either pressure on, or disease of, the cervical sympathetic; and the diagnosis is confirmed if the paralysis is cured by galvanisation of the sympathetic, without any other treatment. One of the most interesting cases of this kind that have as yet been recorded, occurred a short time ago in the practice of Dr. Drissen, of Berlin:—

A sculptor, aged 35, served in the Prussian campaign of 1866. Ever since July of that year he had suffered a good deal in his arms. When he came under observation, both arms were wasted and as cold as ice; the hands were anæsthetic and anæmic, like those of a dead body; no blood flowed when a needle was deeply stuck into them and taken out; the movements were difficult and powerless. The lower extremities were in much the same condition, but not quite so bad. Diaphoretics of all kinds had been used for producing perspiration, but without success. Dr. Drissen directed the continuous current to the cervical sympathetic, and during the second application profuse perspiration occurred, more especially in the fingers, while the hands became red; diplegic contractions of the upper and lower extremities occurred at the same time. The temperature of the limbs rose considerably, and the motive power of the extremities was simultaneously increased. After twelve applications the patient had so far recovered that he could return to the active exercise of his profession. In this case no peripheral galvanisation had been used, nor had any medicine been given.

The following case occurred in the practice of the same observer :—

A youth, aged 18, perceived, after lifting a heavy weight, a sensation of heaviness and stiffness in the arms, which increased chiefly in the right side, and prevented him from writing. Neuralgic pains occurred in the sphere of the median and ulnar nerve. Peripheral galvanisation was resorted to for six weeks, but as the symptoms were rather aggravated than otherwise, the patient was taken to Dr. Drissen, who applied the positive pole to the left superior cervical ganglion, and the negative to the right transverse processes of the second to sixth dorsal vertebræ. The right arm felt warm after the first application; the second produced strong contractions in the biceps; and the third in the deltoid. After this treatment had been continued for two months, the patient was perfectly well.

Meyer* has had similarly good results in the following case, which was of a more severe kind :—

A butler, aged 46, had for some years past suffered from occasional spasmodic sensations in the throat, which rendered deglutition impossible; sensations of numbness and tightness in the legs, the spine, and the chest, were also complained of; sometimes there was general tremor and convulsive movements of the heels, knees, and the neck. Standing gradually became difficult, and walking impossible. The right side of the neck was much swollen, hard, and extremely sensitive, especially on the point corresponding to the superior cervical ganglion. Meyer thought that the tumour, by pressing on the cervical sympathetic,

* Loc. cit. p. 340.

caused all these symptoms, and therefore resorted to galvanisation of the same. No other treatment was used. Within six months the patient had so far recovered that he could walk several miles at a time. He was under treatment altogether for about eighteen months, the galvanism having been applied 270 times. In 1867 he was perfectly well.

The following instance of sympathetic paralysis occurred in my own practice:—

CASE 20.—A boy, aged 8, had within six months hooping-cough, scarlet fever, pneumonia, and chicken-pox. After the first two illnesses he remained comparatively well, but after the pneumonia he did not rally, and the chicken-pox seemed almost to finish him. He was in bed two months after the eruption had disappeared, and was excessively weak and thin. He gradually got somewhat better under restorative treatment, so that he was able to walk about a little, and take a certain amount of food. He was however frequently sick after his meals, and suffered at the same time from headache, dizziness, pain, and spasmodic contractions of the arms and legs. The upper extremities were so weak that he could hardly do anything for himself; they were cold and nearly anæsthetic, and much wasted. The lower extremities were affected in a much lesser degree. The intellect was acute. The little patient had a strong dislike to solid food, on account of mastication hurting him; and on examining the joint of the jaw, I found slight but highly sensitive swellings in both sub-auricular fossæ, more especially so in the right. I prescribed hypophosphite of soda, with small doses of iodide of potassium, and an ointment of iodide of potassium to be applied to the swelling about the jaw. After six weeks the boy was in the same condition as before, and I then resorted to galvanisation of the sympathetic, three times a week. From the first application there was a steady improvement, and after twenty-two applications the little patient had completely recovered his health.

4. *Hysterical Paralysis.*—This form of paralysis, which occurs generally in consequence of mental shock and painful emotions, in girls and women whose sensibility is unusually acute, may attack a few muscles only, or an entire limb, or the whole body. It is brought on either suddenly, or creeps on gradually and unawares. It frequently assumes the form of paraplegia, the recti of the thighs being most affected, but hysterical hemiplegia is by no means uncommon. Hysterical paralysis is altogether a functional disorder, and in no way connected with structural lesions in the nervous centres, the peripheral nerves, or the muscles. It is seldom the only symptom of hysteria in a patient, but is generally accompanied by globus, hysterical pains, anæsthesia of the skin, muscles and bones, cramps, and disturbance of the menstrual function. The course and termination of hysterical paralysis appears sometimes whimsical. Some cases get well in an almost incredibly short time, without any treatment, and such cases often make the fortune of quacks, while others resist for years a variety of energetic therapeutical efforts. On the whole, galvanisation of the spinal cord is the best treatment; but where no apparatus furnishing a continuous current can be procured, faradisation of the skin of the paralysed limbs by fine wire-brushes should be resorted to. The induced current applied by moistened conductors

to the paralysed muscles has usually only little effect, as it is chiefly upon sensibility, and not so much on contractility, that we have to act in this condition. Some cases are cured by the use of faradisation and galvanisation alternately.

CASE 21.—A girl, aged 19, living at Kilburn, became an out-patient at the Samaritan Free Hospital in September, 1864, and was sent to me by Dr. Savage. She had always been in indifferent health, and during the last three years had gradually lost the power over her arms and legs, to such an extent that she was scarcely able to walk even when supported, and entirely incapacitated from doing any work whatever. The cause of the affection was said to be due to 'some trouble' she had had. She first menstruated at 15 years of age, but was always irregular, the discharge being very pale and scanty. Sixteen months ago the catamenia ceased altogether, and from that time she became nearly idiotic. She was very listless when I first saw her, had a vacant look, and considerable dilatation of both pupils, more especially of the left one. The left iris was scarcely at all influenced even by strong light. The voice was almost entirely gone; she could only speak in a faint whisper. She was frequently troubled by pain in the head and the back. Her hands and feet were always quite cold. She complained of sickness in the morning, total want of appetite, and constipated bowels. She was always worse after emotions, and had frequently had hysterical fits. The muscles were very badly nourished, but contracted tolerably well under the influence of the electro-magnetic current. There was nearly complete anæsthesia of the whole left side, including the conjunctiva. On the right side the loss of sensation was not so marked as on the left; but the prick of a pin was only felt as if it were a touch by some blunt instrument. I applied an inverse continuous current of from 40 to 50 cells to the spine, continuatively, twice a week. After six weeks the patient was so much improved that she could walk three miles at a time without support; she could dress and feed herself; was able to do heavy work about the house, and had always warm hands and feet. The voice had returned, the bowels acted regularly, and she was cheerful, and took an interest in everything relating to her affairs. The pupils also gradually recovered their normal size; and the catamenia re-appeared on December 27, and continued from that time at regular intervals. The patient has several times called upon me within the last two or three years, and informed me that she has continued in perfect health ever since.

CASE 22.—A lady, aged 30, unmarried, was said to have suffered from congestion of the spine eighteen months before she came under my care (May, 1868). She had not been able to move from her bed or sofa since then, and had lost flesh to a great extent. When she endeavoured to sit up or walk, she felt so sick, that she was obliged to lie down again. There was a sensation of numbness in both lower extremities, and in the back from the sixth dorsal vertebra downwards, but no complete anæsthesia. Both legs were habitually cold; the appetite was excellent, but the bowels habitually confined, and the catamenia rather too abundant. The cause of the affection was a series of great mental emotions the patient had undergone. Faradisation and galvanisation were alternately used with the effect that after six weeks' treatment she could walk half-a-mile, without feeling sick or tired. The treatment was continued in the country, and when I last heard of her (April, 1869) she was again quite strong and well.

CASE 23.—*Hysterical Paralysis, Neuralgia, and Loss of Voice.*

M. K., aged 40, a needlewoman of feeble constitution, had for a long time suffered from neuralgia in the right arm, and also from want of power in the muscles, so that she was entirely unable to work. The cause of the affection was trouble and anxiety. She became an out-patient at the Samaritan Free Hospital, under the care Dr. Henry G. Wright, who sent her to me. After four operations, in which I directed an extra-current to the weakened muscles, and a primary current to the skin, she was greatly improved; but when she came to me next time, she had entirely lost her voice. I thereupon directed the faradic stimulus to the recurrent nerve, with the effect that the voice returned at once. By further treatment the patient was entirely cured.

5. *Lead Palsy.*—In this disease, which affects chiefly painters and compositors, but may also be caused by drinking water, beer or wine, which has become impregnated with lead, or by taking snuff which has been packed in lead-foil, or by using cosmetics containing lead, and in various other manners, the internal administration of iodide of potassium is the best means of removing the lead from the system; but this alone is seldom sufficient for curing the disease, the most frequent symptoms of which are dropping of the wrists, colicky pains in the abdomen, anæsthesia and neuralgia, obstinate constipation, weakness, or even loss of sight, and spasm of the eyelids.

For these symptoms galvanisation of the optic, sympathetic, and the cord, and faradisation or galvanisation of the paralysed muscles, is the most satisfactory method of cure.

Lead palsy attacks with preference the upper extremities. M. Tanquerel des Planches saw amongst

113 cases of this affection, 93 cases of palsy of the arms, 14 of the lower extremities, and 6 of general paralysis. Certain sets of muscles are more liable than others. The extensors of the right forearm are the first to suffer; the wrist drops and cannot be extended; the power of extension of the first phalanges of the fingers is also gone; but the motion of the two last phalanges is not impaired, as the interossei scarcely, if ever, participate in the disease. The muscles generally soon become atrophied, the back of the forearm appears concave, the thenar eminence flattened, and the triceps and deltoid more or less wasted. The electric contractility of these muscles is either totally gone, or considerably diminished; but the sensibility is generally preserved.

M. Eulenburg has related a case in which faradic contractility was completely lost, but galvanic excitability preserved and even increased; and a good therapeutical effect was obtained, without restoration of faradic, or diminution of galvanic, contractility. In such cases, whether we use extra- or intra-muscular excitation, a portion of the current will travel to the unaffected antagonists of the paralysed nerves and muscles. Eulenburg has, however, seen after a galvanic treatment, not only recovery of voluntary power, but also of faradic contractility. In one case he observed diplegic contractions, not only with the arrangement mentioned by Remak (p. 322), but also in crossed or unilateral arrangement of the electrodes, on any part of the trunk, with continuative or intermittent application of from 10 to 20 cells. These contractions appeared almost immediately on closing the circuit; where the poles were crossed they were stronger, and came on more rapidly in the arm corresponding to the negative pole; but on increasing the power of the current, they appeared in the other arm, and even in the face, and one or both lower extremities. They commenced with movements of extension and abduction of the fingers, elevation and adduction of the hand and the forearm, and finally the whole arm was elevated and adducted towards the thorax. Where the current acted continuatively, these movements partook rather of the character of a gradually increasing tetanic contraction; while if it was intermittent the contractions were jerking and convulsive.

6. *Paralysis from Disease of the Urinary Organs.*—Inflammation and abscess of the kidneys, renal calculus, inflammation of the mucous membrane of the bladder, chronic inflammation and enlargement of the prostate, stricture of the urethra, and other diseases of these parts, may produce incomplete paralysis of the lower extremities. In such cases the discharge of the urine is more or less impeded; the sphincter ani is weak, the digestion deranged, the limbs shaky, and the muscular sense nearly lost. The degree of weakness in the legs varies with the state of the urinary organs. In most of these cases a constitutional treatment is absolutely necessary for the cure of the affection, since the mere application of galvanism to the paralysed limbs cannot remove the cause of the disorder. In some cases the paralysis disappears after the cause has been removed; but if it still persists after that, a faradic treatment is generally required. In some such patients, faradisation may even remove the cause, and thus cure the disorder.

CASE 24.—A gentleman, aged 36, consulted me in December, 1866, for general debility and want of power in walking. He was not actually paralysed, but very weak in his legs, which was partly due to malnutrition of the muscles, and partly to pain in the thighs, which increased on walking. This pain seemed to radiate from the perinæum, and was worse after emptying the bladder and taking exercise. As the perinæum was very tender to touch, I made a rectal examination of the prostate, and discovered that the organ was very sensitive and considerably enlarged. The patient then told me that he had had gonorrhœal inflammation in 1862, and again in 1865, which was evidently the cause of the chronic inflammation of the prostate. The urine was neutral, and contained a good deal of muco-pus. The patient had already taken iodide of potassium, iron, and strychnia, without benefit. I prescribed small doses of liquor arsenicalis for improving the secretion of the urine, and applied faradisation to the prostate, for reducing the enlargement of that organ. The first application gave immediate relief, as the tenderness in the perinæum was diminished, and the patient could walk with more ease afterwards; nor was micturition so painful as it had been before. The urine was slightly acid after the arsenic had been taken for five days, and in about a fortnight it was perfectly healthy. After twenty-one faradic applications, the size of the prostate had become normal, with proportionate improvement in all the symptoms. The muscles of the thighs and legs were now galvanised several times, and within six weeks the patient was quite recovered.

7. *Rheumatic Paralysis.*—Paralysis of certain muscles or sets of muscles is not unfrequently induced by rheumatism. The angler, the huntsman, and others who by pleasure or necessity are much exposed to damp and cold, are chiefly liable to this kind of palsy, which affects with preference the muscles of the *lower extremities*, thus giving rise to incomplete

paraplegia, which is frequently mistaken for a symptom of disease of the spinal cord. The extensor muscles of the forearm, which are animated by the *radial nerve,* are also often subjected to rheumatic paralysis. Next in frequency ranks paralysis of the muscles of the eyes, the portio dura, and the *deltoid* and *trapezius.* The *interossei* and *lumbrical* muscles are also liable to rheumatic palsy. I have observed this latter affection chiefly in young women suffering from anæmia and defective circulation, especially in the extremities. The first symptom is a feeling of numbness and pain in the fingers, and the movements become difficult and troublesome. On faradising the interossei, their excitability generally appears impaired. In such cases it is easy to arrest the disease by a short faradic treatment; but if nothing be done for it, the muscles may in time become atrophied; the interosseous spaces then appear hollow, the circulation becomes impaired, the hand thin and cold, the fingers can be but slightly removed from one another, and the extension of the two last phalanges is impossible; numbness and stiffness increase, and at last the hand becomes quite useless. Paralysis of the *portio dura* will be considered under a separate heading.

The invasion of rheumatic paralysis is sometimes sudden, in other cases gradual. It is sometimes the consequence of rheumatic fever. It may begin with pain in a set of muscles, whereby motion is rendered difficult or impossible; and when the pain is gone, the immobility still continues; in other cases no pain, but only numbness is complained of, which is especially great in the toes, if the seat of the paralysis is in the lower extremities. If the invasion has been sudden, and pain is felt in the paralysed muscles, the electric excitation of the muscles is likewise painful; but when the disease has come on gradually, galvanism excites very little sensation.

There is no kind of paralysis in which the therapeutical effects of faradisation are so striking as in rheumatic paralysis, in which affection it cannot be replaced by any purely medicinal treatment. This applies also to protracted and severe cases which have resisted a variety of energetic therapeutical measures. M. Guitard has related the case of a patient who had suffered for three years from rheumatic paralysis; there was general emaciation and immobility; the head drooped on to the chest, the thighs were flexed upon the abdomen, the legs upon the thighs. Faradisation was used for a month, and after that time the head could be held erect, and the legs be moved into and out of bed. The faradic treatment was then discontinued for some time, whereupon the patient relapsed into nearly his previous state; it was then recommenced, and at the end of six weeks an almost total recovery had taken place.

I am convinced that every case of rheumatic paralysis can be cured by faradisation, provided that the muscular tissue has not yet been destroyed, and the treatment is not too soon discontinued. In cases of muscular atrophy resulting from rheumatic paralysis, faradisation is likewise of great service.

CASE 25.—*Rheumatic Paralysis of the Forearm and Hand.*

Mrs. G., aged 51, was sent to me by Dr. Hyde Salter, in January, 1862. Three months before, she had suffered from a severe attack of rheumatic fever, nearly all the joints having been affected. As soon as she was able to move about again, she went into the country, where her general health much improved. Her right arm and hand, however, remained painful and useless, and she was therefore advised to try faradisation. On examining the forearm and the hand with the æsthesiometer, I found that the sense of touch was considerably impaired. Moreover, the muscles were considerably wasted, more especially the flexors and the interossei and lumbricals; and on applying the faradic current to these muscles individually, it appeared that their sensibility, as well as their contractile power, were very nearly gone. The hand had lost its natural shape, and resembled a bird's claw; a configuration of the hand which is always associated with loss of power in the interossei and lumbrical muscles, and renders it entirely useless. The pain was greatest at night, and chiefly felt in the fingers. The general health of the patient was tolerably good, but she was very thin, and suffered greatly from despondency. I used faradisation of the skin for the cure of the pain, and of the suffering muscles for restoring them to their normal nutrition and function. After two operations the motor power of the fingers was much increased: the muscles responded more readily to the faradic stimulus, and the æsthesiometer showed an improvement in the sense of touch. The pain, although not entirely gone, was much diminished. After a fortnight's treatment, the patient attending every other day, she was able to cut her own meat, and to do some housework, and in a month she could do needlework for three hours consecutively without feeling pain or fatigue. There was then no longer any difference in the sense of touch in the right and left arm, the bulk of the muscles was much increased, and the hand had resumed its normal shape. This result was all the more satisfactory, as the age and general weakness of the patient were not in favour of a rapid cure.

In these cases galvanisation is equally effective as faradisation, and sometimes even more rapid in its action.

8. *Reflex Paralysis.*—This form of paralysis, which is due to an irritation proceeding from a sensitive nerve, and thence transmitted to the spinal cord, often disappears spontaneously as soon as the irritation is removed; in many cases, however, even after the cessation of the cause, the paralysis remains; and then faradisation or galvanisation are by far the best therapeutical measures to be used. Again, in many cases, faradisation or galvanisation may remove the irritation, and thus exercise a curative action. These propositions will be best understood, if illustrated by a few cases.

CASE 26.—*Reflex Paralysis of the Hand after Amputation of a Finger.*

Mrs. D., aged 42, pricked the forefinger of her left hand with a needle. This induced considerable pain, of which she did not at first take much notice; but as the finger soon became much inflamed, she applied for medical advice. Notwithstanding the treatment she underwent, the inflammation increased, gangrene ensued, and at last amputation of the finger became necessary. This operation was performed by Mr. Spencer Wells, on December 23, 1858. Three months elapsed before the stump was healed, as at first the pus was of a very bad character; and the secretion only improved after repeated cauterisations with nitrate of silver. When the cicatrix had at last been formed, it appeared that the patient had entirely lost the use of her hand, and Mr. Wells then sent her to me. When I first saw her, the fingers were extended and quite stiff; flexion and lateral movements were impossible. The forearm could only with difficulty be bent, and every movement of it was painful. Numbness was felt in all the fingers, and pain in the elbow was complained of. The stump, which had a livid colour, was extremely sensitive, and at the slightest touch of it the patient almost fainted. Besides this, she had that peculiar symptom which is by no means rare in persons who have undergone an amputation; that is, she felt pain in the removed part, which increased towards evening. Otherwise she was in fair health, with the exception, however, that she had three years before, after a difficult labour, lost the catamenia, and, in consequence of this, she suffered from headache for a few days every month. I directed a primary faradic current to the left arm, the positive pole being alternately applied to the trunks of the median and ulnar nerves. Intra-muscular faradisation of the interossei and lumbricals was also performed. Immediately after the first application, the patient was able to bend the second and third phalanges of the fingers; and after three more applications, she was no longer troubled with pain in the removed finger. After the ninth operation, the catamenia reappeared. The restoration of the mobility of the first phalanges of the fingers required a somewhat longer treatment, as in them the affection was very obstinate; but after some weeks this was also attained. At the same time the stump had assumed a much healthier colour; it was firmer, and not so sensitive to touch as before. The catamenia continued afterwards at regular intervals.

CASE 27.—*Reflex Paralysis and Neuralgia of the Forearm after Fracture.*

M. W., a married woman, aged 46, suffered a fracture of the lower end of the radius of the right arm, in consequence of a fall. She became an out-patient at the Middlesex Hospital, where a bandage was applied; but by the carelessness of the patient, this got out of order, and the bone healed crookedly in consequence. It was then again fractured by a surgeon, and put straight; but the cure was now protracted over ten months; and when the bone was at last healed, the arm remained painful and entirely useless. She became, some time afterwards, an out-patient at the Samaritan Free Hospital, and was sent to me by Dr. Henry G. Wright. Faradisation of the median and ulnar nerves was twice performed, when the pain was entirely gone, and the arm could be used as before.

CASE 28.—A gentleman, aged 46, when on a shooting excursion, in October, 1867, accidentally shot the thumb of his right hand right off at the metacarpal joint. The wound took nearly six weeks to heal, and it was then found that the hand was completely paralysed. Strychnia and stimulating embrocations were used, but without any effect; and the hand was totally useless when the patient consulted me in April, 1868. One application of the continuous current restored the mobility of the hand; but as it was still weaker than the left hand, the current was applied three times more, after which the hand was as useful as it could be *minus* a thumb.

CASE 29.—A young lady, aged 15, of scrofulous habits, suffered from an abscess on the right side of the neck which had to be opened, and was rather slow to heal. When the wound was quite closed, it was found that there was complete loss of power in the left trapezius and other muscles which execute the lateral movement of the head, so that the patient was unable to turn the head to the left side, while she could turn it to the right. I was consulted some time afterwards (July, 1869), and applied the continuous current intermittently to the suffering muscles. After the current had acted for about ten seconds, I desired the patient to make an effort to move her head to the left, when it was found that she could do it, although not easily. A few more applications completely restored the power in the muscles which had been paralysed.

9. *Peripheral Paralysis from Injury to the Nerves* (*Traumatic Paralysis*).—The pathology of these affections has already been discussed on p. 400. They occur chiefly in consequence of accidents, or by surgical operations unskilfully performed; for instance, where the ulnar nerve is divided in resection of the elbow-joint, etc. Pressure by tumours or effusions (syphilitic or gouty) may cause the same phenomena. The degree of functional disturbance is always directly proportional to the extent of the lesion. Where all the fibres of the nerve are totally destroyed, the properties of the muscles animated by it are totally lost; in other cases, where the continuity of the nervous fibres has only been more or less damaged, but not entirely destroyed, the muscles become weak, and their sensibility and excitability to the faradic stimulus diminished.

On the whole it cannot be said that the results of treatment in cases of this kind are very brilliant.

We have seen that the conductivity of the paralysed nerves does not reappear before at least two or three months have elapsed after the commencement of the disease, and that four, six, or even more months are necessary for recovery. Whether an electric treatment has much influence on these conditions is at present doubtful. Of course, where faradisation or galvanisation are employed shortly before the conductivity is re-established, as was done, for instance, in Bayerlacher's and Eulenburg's cases (p. 409), the results will apparently be excellent; but where the treatment is commenced in the beginning of the disease, the effect has generally not been quite so satisfactory. Nevertheless, electricity is the most rational remedy in peripheral palsy. It is still doubtful whether the continuous current does, by its catalytic effects, assist in removing the effusions of blood or serum which have taken place at the seat of the injury (Erb); but it seems rational to use it for that purpose in the earliest stages of the disease, the application being continuative, at the seat of the injury. At the same time we may galvanise the cervical sympathetic, and the sympathetic branches which accompany the vertebral artery. Local abstractions of blood, blisters, and iodide of potassium may be used at the same time.

Whether the regeneration of the nerve, and therefore the re-establishment of its conductivity, may be promoted or accelerated by the use of any form of electricity, is as yet unknown. It is, however, certain that when the regeneration of the nerve has taken place, and this does nevertheless not regain its function, electricity is the most effective means to restore its obedience to the orders of volition.

Electricity may also be of service by preventing muscular atrophy. We have already seen (p. 216) that muscles which are frequently caused to contract will preserve their nutrition longer and more thoroughly than those which remain quiescent. In paralysis from injury to a nerve, the continuous current should be used for this purpose, because this is the only form of electricity by which contractions can be produced. Faradisation employed soon or immediately after the commencement of the affection, is useless, and does not even prevent atrophy of the muscles deprived of their connection with the cord, because it is unable to cause them to contract. On the contrary, if resorted to from about eight to twelve months after the accident, when regeneration of the nervous tissue has taken place but the will does not reach the muscles, faradisation may be used with advantage.

CASE 30.—A porter, aged 32, suffered compound fracture of the right arm and other injuries from being run over by a van, in December, 1860. After three months the fracture was healed, but the arm remained useless. He came to me in May, 1861, when I found complete anæsthesia, paralysis, atrophy, and loss of electric contractility of the muscles, from the acromion downwards. I recommended him to do nothing for three months, and then to present himself again. This he did in the October following, when he appeared to be much in the same condition as when I first saw him. I then commenced the faradic treatment, and after four months he had to a great extent recovered the use of the arm, although it was still weaker than previous to the accident.

Case 31.—An unmarried lady, aged 30, of delicate constitution and sedentary habits, was sent to me by Dr. Thorowgood in June, 1868. She had had a railway accident, near Basle, in Switzerland, in September, 1867, when the carriage in which she was seated fell down a steep bank, and was upset. She was stunned for a time, but soon recovered herself. Her right collar-bone however was broken, and the skin and subjacent parts on the lower half of the right forearm were severely lacerated. For a fortnight after the accident, she felt pins and needles in her arms and legs, but had not done so lately. The fracture of the collar-bone healed within two months, and the injury to the soft parts of the forearm likewise. Three deep scars are to be seen on the front of the latter. There were all the symptoms of certain branches of the motor nerves of the arm having considerably suffered. Cutaneous sensibility in the lower part of the forearm, the hand, and the fingers was considerably diminished; the third finger being the worst in this respect. Concerning the sense of touch, it was found that the two points of the æsthesiometer were felt at the proper distance in the first, second, and little finger, but not in the third, where only one point was felt. Electro-cutaneous sensibility, both from faradisation and galvanisation, was likewise impaired, more especially in the third finger. The interossei and lumbrical muscles of the right hand were weak and wasted; the intra-metacarpal spaces being hollow, and the bones protruding. Farado-muscular contractility was much diminished, but nowhere completely lost; galvano-muscular contractility was somewhat increased. The patient experienced much difficulty in carving, dressing, writing, and buttoning her sleeves and gloves; but she could do all these things with an effort. She was able to bend the first phalanges, but not the second and third. There was no difference of temperature in the two hands. The lower portion of the forearm was emaciated, there being a difference of seven-eighths of an inch between the two arms; for, while the left arm measured fully seven inches, the right measured only six and one-eighth. The general health of the patient was satisfactory. I applied the positive pole of twenty cells to the cicatrices, in order to promote, if possible, the regeneration of nervous fibres; and also acted intermittently on the suffering muscles. After four such applications the patient felt a good deal stronger in the arm and wrist; she could hold things better, did not feel so stiff in writing, and her hand and arm did not ache after writing as they used to do. She also found carving and dressing easier, and had succeeded in turning a key in a lock, which she could not do before. After a few more applications, the third finger, which had formerly appeared as a 'dead log,' recovered its sensibility, and she felt the prick of a pin and the two points of the compasses quite distinctly. The metacarpal spaces became more filled up, and when she left town for change of air, a month after the commencement of the treatment, the arm and hand were much more useful than before, although not quite recovered.

Cases of paralysis from continued pressure, especially from the head resting on the arm, which occurs frequently during intoxication by alcohol, or in patients who are under the influence of chloroform, are generally curable by faradisation or galvanisation.

Case 32.—A lady, aged 23, had her first confinement in November 1864, during which she was for some time under the influence of chloroform. While in this condition her head rested heavily on the left arm, and pressed so much on the brachial plexus that a number of muscles, animated by the latter, became completely paralysed, there being also anæsthesia of the left arm. She was sent to me in January, 1865, by Mr. Paget. The affection was most severe in the muscles of the forearm, the patient being quite unable to lift the wrist, which was much swollen and had to be bound up with a splint. As she also complained of great weakness in the other limbs and the back, I combined a cord-current of fifty cells with faradisation of the left shoulder and arm. After six weeks of this treatment, the patient had entirely recovered the use of the left arm, and felt much stronger generally.

CASE 33.—Count Z., aged 63, had, about twenty years ago, suffered from a rupture of the capsular ligament of the hip-joint in consequence of an accident, and had never quite recovered from the effects of it. He complained of great numbness and stiffness in the right leg, the muscles of which were not nearly so well developed as those of the left, so that he had much difficulty in walking. The affection was evidently due to pressure from effusion and extravasation of blood. Sir James Clark, whom he had consulted in June, 1857, believed that faradisation would be the best means to restore him, and sent him to me. The patient was considerably improved by a short treatment, but as he left town soon afterwards to return to Russia, the cure was not complete.

10. *Infantile Paralysis.*—The pathology of this affection is still somewhat obscure. Infantile paralysis comes on frequently after convulsive fits, owing to irritation of the brain; but sometimes it appears suddenly, without any premonitory symptoms, in a child which is otherwise perfectly healthy. On examining the paralysed limbs in such cases, we generally find that electro-muscular contractility is much

diminished, or even entirely lost, in all the paralysed muscles; there is atrophy of the muscles and bones, the paralysed limb being shorter and thinner than the healthy one; and the temperature in the former is considerably lower than in the latter. The sensibility of the skin, the muscles, and the nerve-trunks is, however, not impaired, even in cases of very long standing. Benedict has found in some cases that in the commencement of the affection, the motor excitability to the continuous current was very much increased. I am unable to say whether this is the rule or not, as all cases which have been under my care had existed for some years before I was consulted.

Infantile paralysis resists all purely medicinal treatment, and only improves under the long-continued use of faradisation and galvanisation. Dr. Russell Reynolds,* who has written an excellent paper on this subject, recommends the alternate use of these two agents, and my experience entirely coincides with that of Dr. Reynolds. I generally advise a month's galvanisation, then a month's rest, and a month's faradisation, and so on. Gymnastic exercises, frictions with stimulating liniments, a meat diet, and the internal administration of phosphorus, may be combined with the electricity.

Case 34.—A boy, aged 11, came under my care in August, 1867. He was the eldest of three brothers, all of whom had suffered of nervous affections. This boy, when six months old, began to have convulsive fits, and was some-

* The Lancet, vol. i. 1868.

times screaming the whole night. After an unusually bad attack the right leg became paralysed, the little patient being then eleven months of age. He had subsequently whooping-cough and scarlet-fever, and had lost his hearing on the right side after the latter complaint. His general health was now tolerably good; the intellect keen, the appetite large, the bowels regular; he had not suffered from convulsions for the last five years. The right thigh measured eight inches and the left twelve, four inches above the patella; the right leg seven inches and the left nine and a half, three inches below the patella. The paralysed leg was about half-an-inch shorter than the healthy one, and he therefore wore a raised boot to correct the difference. The left leg was 2° Fahr. colder than the right, but there was no anæsthesia. Galvano-muscular and farado-muscular excitability were both considerably diminished. I advised the parents to let the boy have a course of faradisation and galvanisation occasionally for a month; when no electricity was used, friction of the leg with linim. camph. co., a liberal diet, plenty of fresh air and exercise, and $\frac{1}{40}$ gr. of phosphorus. The boy has been brought to me three times, and each time improved considerably. When I saw him last, in December, 1868, the difference between the left and right thigh, which was at first four inches, was only one and a half, and the difference between the right and left leg, which was at first two and a half inches was only one inch. The boy could walk for three or four miles, with a stick, without feeling much fatigue, but going upstairs, running, and jumping were difficult and tired him considerably. It is possible that within another year or two this boy may completely recover.

11. *Palsies of the Nerves and Muscles of the Eye.*— If the *third* nerve or motor oculi is paralysed, the upper eyelid droops down and cannot be raised, through loss of power in the levator palpebræ su-

perioris muscle (ptosis); the pupil is dilated and the eye cannot be moved in any direction except outwards, as the rectus externus, which is animated by the sixth nerve, retains its function. This muscle is, however, after a time generally affected by secondary contraction, which causes divergent squint and double vision.

Local palsy of the *fourth nerve* is of rare occurrence, and difficult to recognise. Professor A. von Graefe,* of Berlin, says that in this affection the pupil is turned a little upwards and inwards; when looking upwards, vision is not disturbed, but in looking at an object placed horizontally before the eye, the patient sees it double; and therefore, in order to avoid this, the head is generally turned towards the opposite side.

If the *sixth nerve* is paralysed, the patient squints inwards, and has double vision in certain directions; sometimes the inward deviation of the eye is so considerable, that the cornea may be entirely concealed at the inner angle of the orbit.

These palsies may be caused by cerebral affections; but are more frequently owing to rheumatic or syphilitic effusions, or to over-exertion of the eyes, or to pressure by tumours and exostoses. The patients are generally treated with iodide of potassium, and counter-irritation of the skin in the neighbourhood of the eye; and some recover by that treatment. Operative interference has often been attempted, but generally left the patient in a worse condition than

* Archiv für Ophthalmologie, vol. i. p. 1.

he was before the operation. Where the usual means do not improve the condition of the paralysed muscles, both faradisation and galvanisation may be employed. M. Meyer,* Mr. Soelberg Wells,† and myself, have seen very favourable results of the former; while Benedict ‡ expresses himself strongly in favour of the latter. When using faradisation, I generally place the positive pole below the ear, and a small moistened sponge connected with the negative pole to the skin of the closed eyelid, as near as possible to the paralysed muscle, sending the current through for two or three minutes. If galvanisation is used, it is not necessary to apply the current to the eye itself, as in this instance the effect takes place through the reflex action of the fifth pair of nerves. Benedict recommends to apply the positive pole to the forehead, and in ptosis, to draw the negative pole over the lid; in paralysis of the rectus externus, to put the negative pole to the cheekbone; and in paralysis of the rectus internus, to draw it over the skin of the side of the nose. He is quite correct in stating that an effect often takes place instantaneously, and that the application should be short and feeble; but he is wrong in denying the beneficial influence of faradisation in these cases. Only a short time ago I had a patient under my care who suffered from paralysis of the rectus internus muscle, and in whom the continuous

* Deutsche Klinik, 1856, no. 38.

† 'A Treatise on the Diseases of the Eye,' London, 1869, p. 568.

‡ Archiv für Ophthalmologie, vol. x. p. 1.

current was applied for a fortnight without any benefit whatever; I then resorted to faradisation, with the effect that the patient felt a great deal better after the first application, and rapidly recovered under a continuance of the faradic treatment. The rule should therefore be to apply either one or the other form of electricity, and not to continue one of them too long if no decided benefit is produced.

CASE 35.—A lady, aged 43, who had been in the habit of over-exerting her eyes, being very fond of painting in water-colours, was exposed to wet and cold in November, 1861, and suddenly noticed that she saw everything double. A blister was applied behind the ear, and she was freely purged, after which she was put on a course of iodide of potassium. As she did not get better, she was sent to me in February, 1862, when I found paralysis of the left rectus internus muscle, which was probably owing to rheumatic effusion. I used faradisation six times, after which the double vision existed only for objects at a great distance, but not for near things. The patient was then obliged to leave town, but returned in May of the same year, and had ten more applications, after which the muscle had quite recovered, and the double vision disappeared.

CASE 36.—A lady, aged 40, was sent to me by Mr. White Cooper, in October, 1862. She had for some time suffered from mydriasis of the right eye, which considerably interfered with sight. She was otherwise in good health, and unable to account for this affection. I applied a gentle current for a short time, which caused the iris to contract visibly. She was only able to stay in town for a few days, so that the treatment could not receive a full trial; but she was considerably improved even by the short treatment she had followed.

CASE 37.—A gentleman, aged 49, had for ten months suffered from ptosis of the left eyelid, for which he had undergone a variety of treatment without benefit, when he consulted me in December, 1864. There were many other symptoms, exciting the suspicion of cerebral disease. He had six applications of the continuous current to the eye in a fortnight, during which he recovered the power over the eyelid, although there was no improvement in the other symptoms.

Where both eyelids are drooping, we have to do with an incurable affection of the corpora quadrigemina; yet even in such cases the continuous current may prove of benefit, but which I fear is generally only temporary.

Mr. Carter * has lately recommended to combine faradisation of the paralysed muscle with tenotomy of the contracted one, and appears to have been successful in carrying out this treatment. He proposes to apply the electrodes directly to the muscular substance, the eyelid being lifted and controlled by a retractor, and the current being directed to that portion of the conjunctiva which corresponds to the situation of the muscle. Such an application is much more painful than the one I have recommended, and it would therefore be better first to use the electricity externally, and only in case this should not answer, to apply it internally. The combination of tenotomy with faradisation, however, will probably prove successful in many cases where the use of either of these remedies singly might fail.

12. *Paralysis of the Portio Dura.*—Most cases of

* The Lancet, December 1868.

facial palsy are due to the influence of damp and cold. A rheumatic effusion takes place into the cellular tissue, by which the peripheral branches of the portio dura are compressed, and their function more or less inhibited. In such cases the lower portion of the face is generally more affected than the upper one. Cases which occur in children or young persons, and where the quantity of lymph effused is not very considerable, may get well spontaneously; but in adults, or where a large effusion has taken place, the palsy only yields to appropriate treatment. Where all the muscles of the face are equally affected, we must conclude that the nerve is compressed by an effusion in the fallopian canal. In slight cases of this kind the farado-muscular excitability is diminished, and in severe cases it is completely lost. Galvano-muscular excitability is sometimes increased, and sometimes normal, but only in exceptional cases it is diminished or lost.

The treatment generally employed for these cases consists of blistering, and the internal use of iodide of potassium or strychnia. Electricity is, however, much more rapidly successful, especially if the affection be of recent origin. A considerable proportion of these cases may be cured by faradisation; but where this fails, and likewise in those cases where it produces no muscular contractions at all, galvanisation is preferable. The faradic current should be applied to all the paralysed muscles individually; while galvanism is better applied to the nerve, the positive pole being placed to the cervical spine, and the negative one passed over the peripheral branches of the portio dura. Voltaic alternatives are decidedly useful. Where the external application does not produce much benefit, the negative pole may be applied to the mucous membrane of the cheek, which sometimes does good, after all other modes of applying the current have failed.

Cases of rheumatic paralysis of the portio dura generally yield to treatment even if they have existed for a very long time; thus Professor Oré has related a case of eight and a half years' duration, which was cured by faradic electricity, and Dr. Russell Reynolds succeeded by the same means in notably improving one of fourteen years' standing.

Facial palsy is also observed as a symptom of *hemiplegia*, but it then generally appears only in a few muscles of the face, the respiratory branches of the portio dura, which animate the levator alæ nasi et oris, and the buccinator muscle being chiefly affected. In such cases the electro-muscular contractility is either normal or increased to both kinds of current. As this form of facial palsy has a central origin, faradisation should not be used. The palsy frequently disappears spontaneously, but where it continues troublesome for several months after the attack, galvanisation may be resorted to, and generally proves successful.

In *tumours* of the corpus striatum and crus cerebri, and in disease of the pons, facial palsy appears combined with paralysis of the third and other cerebral nerves. In such conditions no form of electricity can be of decided or permanent use, although the continuous current cautiously applied may relieve certain symptoms of the affection.

If facial palsy ensues in the course of *locomotor ataxy,* it is generally an unfavourable sign, showing that the disease is gradually advancing towards the medulla oblongata, and the roots and nuclei of the cerebral nerves. The continuous current may, however, under these circumstances be employed with a fair chance of temporary benefit.

Where facial palsy is due to *injury*, the prognosis is not so favourable as in those cases which are owing to rheumatic effusions. The injury may be due to external violence, such as a blow, shot, cut, fracture of the petrous portion of the temporal bone, division of the nerve in surgical operations, pressure by the application of the forceps, &c.; or to some pathological process in the internal ear, as caries or necrosis of the petrous portion of the temporal bone, syphilitic exostoses, etc. In such cases the farado-muscular excitability is quite gone, while galvano-muscular excitability is increased, chiefly in the commencement of the affection. The prognosis here depends entirely upon the cause; and any form of electricity applied as long as the cause is still acting, can do no good. But if the cause has been removed, and the nerve yet refuses to obey the orders of volition, galvanisation is the best means of restoring its function.

From many cases of facial palsy which have come under my observation, I select the following :—

CASE 38.—*Paralysis of the Face.*

Mr. F., a barrister, aged 35, having been exposed to a draught of cold air at a railway station, became affected with paralysis of the left portio dura. The physiognomical expression had entirely vanished from that side of the face. The patient was not able to laugh, to frown, to whistle, or to shut his eye, which latter appeared staring and protruded. The angle of the mouth was depressed, and drawn towards the opposite side; that of the sound side being higher and drawn towards the ear. The cheek was flabby and loose; and eating and speaking was troublesome. The patient was sent to me by Dr. Todd, whom he had consulted six months after the commencement of the affection. Farado-muscular contractility was diminished. I directed the faradic stimulus to all the paralysed muscles individually, with the effect that the patient regained his normal physiognomical expression, after a fortnight's treatment.

CASE 39.—George W——, a shoemaker, aged 44, came under my care at the Infirmary for Epilepsy and Paralysis, on April 25, 1866. He had for the last ten weeks suffered from paralysis of the portio dura, which he ascribed to having got wet through, and been exposed to a cold draught in a doorway. He was unable to close his eye, to laugh, or to whistle, and could not pronounce the letter 'f.' The right nostril was 'shut up,' and he had great difficulty in masticating his food at the right side. He also complained of headache, and occasional attacks of vertigo; but was otherwise in good health. Faradisation produced no contraction in the muscles of the face, while the continuous current caused contractions both on closing and opening the circuit. A continuous current of twenty cells was now applied regularly twice a week, and after six weeks of this treatment the patient was quite well.

13. *Paralysis of the Vocal Cords: Aphonia and Dysphonia.*—The introduction of the laryngoscope into medical practice has greatly facilitated the diagnosis of diseases of the larynx; and therefore the treatment of these affections is now more easy, safe and successful than it could have been before. Where loss of voice is due to pressure by an internal aneurism or cancer on the recurrent nerve, no good can be done by electricity applied to the larynx; where it is owing to inflammation, ulceration, or morbid growths in the throat, a special local treatment by caustics, astringents, the *écraseur*, etc., together with constitutional remedies, has to be resorted to; but where the affection arises from mere loss of power in the muscles connected with the vocal cords, faradisation of the skin of the larynx, or of the suffering muscles, is the best treatment. Such loss of power is frequent in hysterical girls, but it also occurs after acute diseases, such as typhoid fever and diphtheria, after ague and rheumatism, in poisoning by arsenic and lead, in anæmia, from taking cold, through over-exertion of the voice, or a powerful impression upon the nervous centres, such as terror, fright, etc. In such cases the voice not unfrequently comes back after a time without any treatment having been resorted to; but there are numerous instances in which it does not return for years, and all treatment is unsuccessful, except the electric.

The first case of functional aphonia treated by galvanism has been recorded by Dr. Grapengiesser,* of Berlin, who applied the current of a single galvanic pair to the throat of a girl who had lost her voice for several years. He first vesicated each side of the larynx by blisters of the size of a shilling, and then applied the zinc pole to one of the excoriated spots, and the silver pole to the other. The circuit was kept up for a quarter of an hour, during which time the larynx heaved convulsively, and a great quantity of serous liquid flowed from the sores. The sobbing continued after the metals had been removed, much mucus was expectorated, and two hours afterwards the voice was much more audible and clear. After this process had been repeated several times, the voice was perfectly restored. Six months afterwards, however, it was suddenly lost again in consequence of a cold, and it did not again return, although the same process of galvanisation was repeated.

Since then all the different forms of electricity have been frequently used in the treatment of functional aphonia, and the results of the treatment have on the whole been very satisfactory.

An easy and successful method of applying electricity in these cases is faradisation of the skin of the larynx by fine wire-brushes. I have on several occasions restored the voice by one such application. The current used must be of high tension. There

* Versuche den Galvanismus zur Heilung einiger Krankheiten anzuwenden. Berlin, 1801.

are, however, cases in which this method produces no effect, and in these, internal faradisation of the glottis should be resorted to. This method, which has been described on p. 385, has yielded excellent results, chiefly in the hands of Dr. Morell Mackenzie and Professor Ziemssen of Erlangen.

Dr. Mackenzie * subdivides paralysis of the vocal cords into bilateral and unilateral paralysis of the adductor muscles, bilateral paralysis of the abductors, unilateral paralysis of one abductor, and paralysis of the tensors and of the laxors. Bilateral paralysis of the *adductors* of the vocal cords prevents approximation of the cords on attempted phonation, and consequently gives rise to loss of voice. Out of more than 200 cases of this affection which have been under Dr. Mackenzie's care, direct faradisation of the glottis has failed only in four, so that the proceeding seems to be almost a specific for the complaint. *Unilateral* paralysis of the adductors prevents the approach of one vocal cord to the median line, and gives rise to hoarseness or loss of voice. This is more difficult to cure, but also yields occasionally to faradisation. In paralysis of the *tensors* of the vocal cords, these are not properly stretched; the voice is lost or muffled, the higher notes more or less suppressed, and vocalisation is attended with a sense of fatigue or pain. In paralysis of the *laxors* of the vocal cords, the formation of the lower notes is

* Hoarseness, loss of voice, and stridulous breathing, in relation to nervo-muscular affections of the larynx. London, 1868.

interfered with, and the pitch of the voice is raised. Both tensors and laxors may be beneficially affected by faradisation, while in paralysis of the abductors electricity does no good. The following cases may serve to illustrate these different conditions :—

CASE 40.—*Bilateral Paralysis of the Adductors of the Vocal Cords.*

In May, 1862, I treated an interesting case of this kind, together with Professor Czermak, of Prague, who had just then introduced the use of the laryngoscope into this country. It was the case of a female patient, aged 30, who had lost her voice two months before, in consequence of a great emotion. An examination of her throat showed that the adductors of both vocal cords were perfectly motionless and paralysed. Faradisation of the skin of the larynx was resorted to, and after two such applications, the patient could speak again, although still in a hoarse tone only. It was then discovered, by another examination with the laryngoscope, that the right vocal cord had, to a great extent, recovered its motion, but there was as yet no improvement in the left. By further treatment, the left cord was also brought back to its normal condition, and the voice entirely restored.

Case of unilateral paralysis of the adductors :—

C. E., aged 19, came under Dr. Mackenzie's care in June, 1865. He had at the end of July, 1864, suffered from a severe attack of diphtheria, and on recovering from the acute stage, had experienced great difficulty in swallowing, and loss of voice. The power of swallowing was now, to a great extent, recovered, though he still had occasional attacks of coughing from 'things going the wrong way' whilst he was taking his meals. This was especially apt to occur in drinking. He had been taking iron, quinine, and strychnia, and for six weeks electricity had been daily applied to his throat externally. The voice, however, had not at all improved. A laryngoscopic examination showed slight paralysis of the adductors of the right vocal cord. Dr. Mackenzie applied faradisation of the affected muscle daily, from August 16 till September 10. By that time the patient was able to sound his voice, though he usually spoke in a whisper. Ten days later the *sound* of the voice was the rule rather than the exception, and by the middle of October the patient was able to speak in a strong, clear voice, which to strangers appeared perfectly natural, although he thought that 'it sounded differently to what it had done before his illness.' The action of the right cord now appeared perfectly normal.

Case of paralysis of the tensors of the vocal cords:—

G. S., aged 10, suffering from loss of voice, but otherwise healthy, was seen by Dr. Mackenzie in August, 1863. In March of that year the child had been suffering from an attack of bronchitis, in which the nervous symptoms predominated, and on recovery it was noticed that she had lost her voice. Various tonics were tried in vain, and change of air to Brighton likewise failed to restore the voice. Dr. Mackenzie applied electricity to the vocal cords, and the voice was at once perfectly restored.

Case of paralysis of the laxors of the right vocal cord:—

Madame C., aged 34, a professional singer, consulted Dr. Mackenzie in May, 1865, on account of a difficulty she had experienced during the last year in forming her lower notes. Her voice in the ordinary way extended from *a* below the lines to *d* above the lines. A year ago she first experienced a slight difficulty in forming the lower *a*, and in January she could not reach beyond *b*. During the last two months she had not been able to sing at all, even in private, but broke down directly she attempted even a few notes. She attributed this loss of power to a strain, for she had first noticed a difficulty after the performance of a long and trying cantata, which had been twice encored. At the time she had experienced a stinging sensation, extending from the right side of the throat towards the ear. She had been constantly under treatment since her voice first became affected. The only thing which had seemed to do her good was a solution of caustic applied to the throat with a piece of sponge. But although this gave her temporary relief, there was no permanent improvement. On making a laryngoscopic examination, the parallelism between the vocal cords was seen to be lost, the right cord curving away in the centre from the median line. Dr. Mackenzie now resorted to faradisation of the right vocal cord. At the end of six weeks there did not appear to be any improvement, but a fortnight later the patient was decidedly better. In order to test the voice, she was now allowed to sing a few notes once a week, but at no other time. At the end of three months the voice was much improved, and in the following autumn it had so far recovered that the lady was able to accept an engagement in Madrid.

14. *Difficulty of Deglutition.*—Where difficulty of swallowing is due to paralysis or spasm of the pharynx or œsophagus, faradisation and galvanisation are the best, and in many instances, the only means by which we can hope to cure this most troublesome and annoying affection.

CASE 41.—Major I., aged 42, consulted me in September, 1862, for loss of voice and difficulty of deglutition, brought on by an apoplectic attack which he had had in 1859, and which affected the entire left side of the body. For several months after this he had been in such a condition that his life was despaired of. He gradually, however, got better, and partially recovered the use of his arm and leg, while the voice and deglutition did not improve. The latter symptom even became worse as time went on, there being constant regurgitation, especially of fluids, which distressed the patient more than anything else. After a fortnight's faradisation the voice was so much improved that he could converse with ease, while the power of swallowing had not yet returned. I then applied a continuous current to the pharyngeal and œsophageal nerves, with the result that, after the second operation, a marked improvement was perceptible; and in a week the patient was able to swallow quite easily, without any regurgitation taking place.

CASE 42.—A gentleman, aged 34, had ague while travelling in Tuscany, in summer, 1862. Ever since that time he had felt difficulty in retaining his food, which generally returned in from five to ten minutes. As time went on, the interval between taking and returning the food increased, which was probably due to that portion of the œsophagus which was just above the seat of the paralysis having become dilated, and forming a pouch which would contain as much as half a pint of beef tea, and retain it for twenty minutes or half an hour; after which the greater part of it would be suddenly returned through the mouth and the nostrils. The only way in which this patient succeeded in obtaining the passage of food into the stomach was by eating very small quantities of food frequently. There was no stricture, as a probang introduced into the œsophagus did not encounter any resistance. The patient had already taken iron, quinine, strychnia, cod liver oil, and many other remedies without benefit, and he had become very much emaciated and reduced in strength. I applied faradisation by means of an insulated conductor, in the form of a probang, three times a week, and prescribed ol. morrh. and liquor arsenicalis. Within a month from beginning this treatment, the patient had recovered the faculty of œsophageal deglutition, and had gained nearly a stone in body-weight. He continued the constitutional remedies for another month, after which he was quite well.

M. Hiffelsheim * has recorded the case of a man, aged twenty-six, who had suffered from acne, which was cured by arsenic, but who had otherwise been in good health. He had such difficulty in retaining his food, that most of what he took was returned as soon as it came into the pharynx, the liquids being rejected through the nose. In this case the continuous current was applied to the pneumogastric nerve. After three applications, the patient could eat some roast meat and retain it; after five more he was quite well.

III. SPASMODIC DISEASES.

Spasmodic diseases are on the whole less amenable to electricity than paralytic affections; yet in certain kinds of spasm, electricity fully deserves a trial when other remedies have failed. It appears probable that our methods of applying electricity in spasmodic affections are still defective, and that with an improved method better results would be obtained than is now generally the case. The methods principally employed at the present time are faradisation of the skin, and galvanisation of the affected nerves. Static elec-

* Annales d'électricité médicale. 1862.

tricity was formerly much employed in these cases, and seems to act much in the same manner as faradisation of the skin. As regards galvanisation, I am inclined to think that a longer application than is generally resorted to for the treatment of paralysis is necessary for the cure of spasms.

1. *Chorea.*—This affection, which is generally brought on by terror, fright, rheumatism, or intestinal derangement, is frequently seen to disappear under the influence of cold affusions to the spine, strychnia, carbonate of iron, zinc, arsenic, &c., or even without any treatment. Labaume, Fabré-Palaprat, and Drs. Addison, Golding Bird, and Gull have treated cases of chorea by static electricity, and have been well satisfied with the result. Dr. Bird has reported thirty-seven cases, thirty of which were completely cured, five relieved, one refused to continue the treatment, and only one was not cured. He applied static electricity in the way described above (p. 289), and affirms that the rapidity with which the patients were relieved was nearly proportionate to the facility with which the peculiar papular eruption on the skin took place. Dr. Gull, whose experience agrees with that of Dr. Bird, believes that the benefit is the result of a direct stimulation of the blood-vessels of the nervous centres, producing a more tonic and vigorous circulation in them.

Faradisation of the skin and of the suffering muscles is likewise often beneficial in chorea. Children bear this operation remarkably well, as it is not necessary to employ a strong current, a gentle application being sufficient for most cases.

Benedict has recommended to apply an inverse current to the spine, for a minute or a minute and a half continuatively, while Meyer recommends the intermittent application of the current to the suffering limbs. In the practice of the Infirmary for Epilepsy and Paralysis, where cases of chorea occur frequently, I generally use galvanisation and faradisation of the limb alternately, together with gymnastic movements, whereby most cases recover in a short time.

2. *Scrivener's Palsy: Schreibekrampf.* — This troublesome affection may be caused by emotion and anxiety, rheumatism, over-exertion of the hand, and by neuritis of the radial or ulnar nerves. In some cases of scrivener's palsy reflectory spasms occur, as the fingers, and especially the thumb, are strongly flexed into the palm of the hand whenever the patient takes up a pen; in other cases there is a semi-paralytic condition of the extensors of the thumb and forefinger. Mr. Solly * has rendered it probable that the origin of the affection is not local, but that it is due to incipient granular disintegration of the 'vesicular neurine' of the upper portion of the spinal cord, and that entire rest from the occupation which has produced the disease is the best treatment. While doing full justice to the able

* Surgical Experiences: the subjects of clinical lectures, p. 205. London, 1865.

reasoning of Mr. Solly, I must say that the experience concerning the beneficial effects of galvanism in this disease is now sufficiently large to justify us in advising a galvanic treatment, especially in those cases where complete rest and change of scene appear impracticable.

The mode of applying electricity should vary according to the nature of the individual case. Where there is loss of the power in the muscles, faradisation; but where spasm is a prominent symptom, galvanisation appears preferable. In order to illustrate the treatment, I subjoin two of Meyer's* cases:—

A private secretary, aged 27, perceived eight or nine months before he came under treatment, a sort of pricking and contraction in the wrist, and which extended to the fingers, especially the thumb and forefinger. The thumb was flexed, and adducted to the index as soon as the patient began to write. On examination it was found that there was loss of power in the abductor pollicis brevis and extensores pollicis longus and brevis. Faradisation of these muscles was now performed, and five weeks after the commencement of this treatment the patient could write with ease for fourteen hours successively.

Another patient of Meyer's, likewise a private secretary, aged 48, had for twelve months suffered from spasm in the thumb and forefinger, which tightly grasped the pen as soon as any attempt at writing was made; at the same time the wrist was spasmodically flexed towards the forearm, and turned outwards, so that writing was quite impossible. Meyer discovered a painful swelling in the course

* Loc. cit. p. 309.

of the radial nerve immediately above the elbow-joint. The continuous current was used sixty-five times, after which the patient was quite well.

3. *Spasmodic Wry-neck: Torticollis, Caput obstipum.*—This affection occurs mostly in adults, and can therefore scarcely be considered as a form of chorea. It consists of a convulsive affection of the spinal accessory nerve of one side, whereby the sterno-cleido-mastoid and the trapezius muscles are thrown into commotion. Electricity of high tension as a counter-irritant, and induction currents methodically applied to the antagonists of the suffering muscles, have effected amelioration or cure; but as the current must be very powerful if it is to do good, the continuous current appears preferable, its application being far less unpleasant.

CASE 43.—*Wry-neck and Dysmenorrhœa.*

In November 1859, I was consulted by a lady, aged 34, who had for about eighteen months suffered from spasmodic contractions of the left trapezius and cleido-mastoid muscles. The first symptoms had come on after a violent emotion, caused by witnessing an accident in the street. At first the contractions were slight, and only occurred if the patient was excited, or suddenly spoken to; but the affection gradually became more troublesome. When she carried a fork, a spoon, or a cup to the mouth, the head at once turned away; at the same time a feeling of numbness, stiffness and fatigue was observed in the left side of the neck; but there was no pain, unless the contractions were unusually violent. She was at first treated by blisters to the neck, and purgatives, but without any avail. At a later period of her illness, she consulted Dr. Todd, who prescribed valerianate of zinc, which she thought had done her some good; but as, after having taken it regularly for two months, she was still a severe sufferer from her complaint, by the advice of Dr. Todd she came to me for faradisation. On examining the muscles of the neck, I found the left trapezius and cleido-mastoid somewhat rigid. The corresponding muscles of the right side were not wasted, but on applying the faradic currents to the two sets, the excitability of the fibres appeared greater on the left than on the right side; and the sensation excited by the application of the current was also more considerable on the left side. While I was examining the muscles, violent spasms occurred; the head was convulsively thrown towards the left side, and all the patient's endeavours to keep it straight were of no avail; but by faradisation of the antagonistic muscles, I succeeded in restoring the balance between the two sets, and calming the spasms. I afterwards used faradisation of the skin, which I had previously found to be of benefit in hysterical convulsions. The influence of emotion in exciting the spasms was most striking in this case. The patient suffered far less when she was alone, and if the room was darkened; but if she thought herself observed and the object of wonder or pity, she became much worse. She had, therefore, almost retired from society, and was only with difficulty induced to leave her rooms, from which she used to shut out the light. As eating was troublesome, she took as little food as possible, and, in consequence of this, and the melancholic turn of mind caused by her affection, her general health had become impaired, and the catamenia were very scanty. Faradisation was continued for three days, when the catamenia appeared before the time, and unusually abundant, so that the treatment had to be discontinued for a week. After that it was recommenced, and the patient gradually improved, so that after a month's treatment the spasms appeared to be completely subdued. The general health rapidly improved in consequence of the changed mode of life now adopted by the patient, and the catamenia again became normal.

Case 44.—In May, 1861, I was consulted by a brewer from Hampshire, aged 40, a strong healthy man, who, with the exception of what he described as bilious head-ache, from which he now and then suffered, had never been ill before the present affection came on. In February last, he first noticed that his head was inclined to fall towards the left side. He was unable to assign any exact cause for the complaint, but mentioned that some time before, while driving, his horse fell and broke his neck, which gave him a great shock. He had also had much anxiety lately, and had slept on a damp couch shortly before being attacked by the spasms. The latter affected the left side of his neck, and gradually became so much worse that he was constantly obliged to hold his head in the right position with the left hand, so that the latter became in a measure useless. He was no longer able to dress himself. His food had to be cut for him, as he could not hold the knife and fork. He was also disturbed at night; for if he attempted to sleep on the side as he had been accustomed to do, his head began to shake, so that he was obliged to lie straight on his back. He could then sleep well, and generally felt better in the morning than at other times of the day. The treatment at home consisted of laudanum, calomel, blisters, leeches, and cupping; but it had no beneficial effect whatever. He then came up to town to consult Dr. Lichtenberg, who prescribed a veratrine ointment to be applied to the nape of the neck, and sent him to me, that the suffering part might be subjected to faradisation. On examining the neck, the left trapezius and cleido-mastoid were found more strongly developed than the corresponding muscles of the right side, which were soft and flabby. After the first operation, the patient felt easier, and could hold his head straight for a short time without being obliged to support it with the hand. The improvement was so rapid that, after a few other applications, the patient could feed and dress himself without aid. He could again sleep on the side, without being disturbed by shaking of the head. I was therefore hopeful of a cure; but the patient, being anxious about his business, felt so unhappy in London, that he left town before he was quite cured, after having stayed here less than a week.

CASE 45.—A married lady, aged 38, who had had no children, consulted me in June 1867, for a spasmodic affection of the left side of the neck, from which she had suffered for the last six years. As a child she had had St. Vitus's dance, and had always been in delicate health; her mother was hysterical, and one of her sisters had likewise suffered from chorea. The symptoms of wry-neck were very similar to those in Case 43, with the exception, however, that there was also occasional spasm in the left arm. I employed galvanisation of the left sympathetic and the spinal accessory nerve three times a week for a month. The head was always perfectly quiet during the application, and much more steady for the after part of the day, but the affection had not quite yielded to the treatment when the patient was obliged to leave town. She had another course of galvanism in July 1868, and then she got quite well.

4. *Epilepsy.*—In certain forms of epilepsy which resist other modes of treatment, the continuous galvanic current may do a great deal of good. Faradisation is, as a rule, useless in this disease, as it has no effect on the nervous centres; indeed, the only cases of epilepsy in which it has ever been of service, have been those where the menstrual function was dormant or irregular, and where it proved valuable as an emmenagogue. The best mode of

applying the continuous current is to direct the electrodes to the mastoid processes, the cervical sympathetic, and those peripheral nerves in the domain of which an aura is repeatedly or occasionally experienced. Where the aura starts from a mucous membrane, the negative electrode should be applied to it; but where it starts from the epigastrium, the positive answers better.

CASE 46.—*Irregular attacks of Petit Mal. Galvanisation of both Hemispheres, and of Medulla Oblongata.*

John F., French polisher, aged 36, married, admitted in the Infirmary for Epilepsy and Paralysis, November 27, 1866, has for the last six years suffered from irregular attacks of petit mal, which come on in the following manner:—While he is at work, or at meals, and without any apparent cause, he suddenly feels severe pain at the back of the head, and a thrilling sensation seems to go through him, as if he were going to die. Sometimes it appears to him 'as if a vapour rose on his brain and muddled him.' This lasts only about a second, and he then quite loses his consciousness for about a minute. While he is in this condition, he generally does something odd—for instance, he scratches the plate with the knife, or tears up paper or his clothes, or pulls a handkerchief over his head, or, if in the street, puts mud on his clothes, &c. When he comes out of these attacks, he feels very confused, and sees double for two or three minutes. Within an hour or two he has quite recovered himself. These fits he has two or three times a week, generally only one in one day, and only very rarely two or three successively. He attributes his illness to a great deal of trouble and anxiety. He also had a great fright some years ago, when he was awoke by an alarm of the house being on fire. He has never drunk or smoked to excess. His mother was hysterical, and his father died of consumption. Digestion had been out of order lately, and he had lost flesh. Four years ago he was operated upon for fistula in ano. There was no tubercle in lungs, but general emaciation. Ordered ol. morrh. ℥ ss. bis die, and argenti nitr. gr. ss. bis.

January 8, 1867.—Digestion improved; has gained flesh; look much better; fits much the same. Continue ol. morrh.; argent. nitr. gr. j bis die.

February 5.—Is now in good general health, but petit mal no better. Discontinue ol. morrh. and argent. nitr.; ordered zinci sulph. gr. ij ter die.

March 19.—Zinc has gradually been increased to gr. xxx per diem, but has had no effect except to confine the bowels. Continue it for another fortnight, taking pil. coloc. co. for constipation.

April 2.—Petit mal the same. Ordered misturæ amaræ (consisting of extr. quass. gr. iij to the ounce of water), ℥j bis, and galvanisation of both hemispheres and medulla oblongata twice a week.

May 7.—Since galvanisation was commenced has had only one fit, in which he tore his waistcoat. Rep. mist. amar. and galvanism.

October 15.—Has had altogether fifteen applications of galvanism, and no fit during the last four months. Ceased attendance.

CASE 47.—*Epileptic Fits, with Aura starting from Epigastrium. Frequent Auræ without Fits. Galvanisation of the Solar Plexus.*

Harriet S., aged 26, unmarried, admitted in the Infirmary April 25, 1866. She is an eldest child, and works at a sewing machine. She had an aunt and a cousin who died of fits. When she was a child of about four years, they gave her a 'roundabout' at a fair, after which she was first taken.

When she was fifteen the fits became worse. She was only menstruated at eighteen, and the fits then began to occur chiefly about the menstrual period, although she was by no means quite free 'between times.' She has now generally a series of six or eight fits about the time of the catamenia, and two or three off and on between. The fit is the usual epileptic one, with biting of tongue, and convulsion for about five minutes. It is ushered in by an aura running up from the epigastrium to the head, lasting a minute or half a minute. She describes it as a sort of creeping or crawling, which gradually proceeds upwards, and she loses consciousness when the crawling arrives at the head. Auræ frequent without a fit—sometimes four or five in one day. She fears the auræ very much, as they leave her breathless and in a state of excessive alarm. She says that they are worse at full moon. She sleeps very badly, and is sometimes so restless at night that she is obliged to take a 'penn'orth of laudanum,' which makes her stupid the day after; dreams a good deal, generally of horrible things; is irritable and low-spirited; says that the least thing upsets her so, 'as if she had the palsy'; appetite ravenous; bowels costive. Ordered potass. brom. gr. xv ter die, with ♏x of tinct. hyoscyami; emplastr. lytt. to epigastrium.

May 23.—At last menstrual period had only two fits instead of six or eight as usual, and none 'between times.' Feels better in herself; auræ not diminished in frequency, although blister has been repeated three times. Ordered a lotion of equal parts of tincture of iodine and water to be freely applied to starting-point of aura. Continue bromide.

June 16.—Has had one fit since, but says that 'sensations have been dreadful.' Ordered pure tinct. iodi to be applied to the epigastrium.

June 30.—Iodine has blistered the skin; auræ no better. Positive pole of twenty cells, with large conductor, to solar plexus, negative to ganglion cervicale superius of cervical sympathetic, first at right, then at left side.

July 7.—Was five days without an aura after application of galvanism; had two yesterday, but they had not nearly the same effect upon her as usual. Rep. galvanism, continue bromide.

August 4.—Has had neither fit nor aura; mental health wonderfully improved.

October 9.—Has had altogether eleven applications of galvanism. Neither fit nor aura for three months. Ceased attendance.

CASE 48.—*Epileptic Attacks. Aura starting from the Mucous Membrane of the Nose. Galvanisation of the Olfactory Nerve.*

Richard S., aged 42, unmarried, a carpenter, was admitted, September 18, 1866. Twenty years ago he went to South America, where he had a sunstroke, and remained very ill for some time afterwards. Since then he has been, off and on, subject to epileptic fits. At first they came at very long intervals, but now he has generally one or two every week. They are preceded by the perception of an abominable smell, either of tainted meat or fish, or rancid fat. Sometimes there is an interval of six or eight hours between the first perception of the smell and the fit, while at other times the fit occurs close upon the smell becoming perceptible. Occasionally, however, he has a bad smell and a pain across the nose without a fit. The convulsions last two or three minutes. General health tolerable, but he cannot masticate very well, as all his teeth were knocked out by blows he got on board ship. Ordered calc. hypophosphitis gr. v ter die.

October 23.—No change, although the dose has been increased to gr. xxx per diem. Potass. bromidi gr. xv ter die.

November 27.—Feels clearer in head and sleeps better. No change in fits and auræ.

December 11.—Has had headache and palpitations of the heart. Fits the same. Potass. bromidi gr. xx ter die, with gr. v of ferri et quin. citr.

January 22.—Feels not so well; is rather weaker than usual. Fits the same. Ferri et quin. citr. gr. x, without potass. brom. An insulated sound with metallic top, and connected with the negative pole of fifteen cells, is introduced into the cavity of the nose, the positive pole being placed to the mastoid process of the same side, two minutes to the left, and the same to the right side.

29.—Has had no fit since and no bad smells. Rep. mist. et galvanism.

March 26.—Has had eight applications of galvanism, and only two fits since it was first used. Smells have become less annoying and strong.

July 9.—Has had altogether fifteen applications of galvanism. Smells have quite disappeared, and no fits during the last two months. Ceased attendance.

Such results as these are very encouraging, but it should be added that they are not always so satisfactory. It would appear, indeed, that in some cases which seem to be well suited for the application of galvanism, it nevertheless produces little or no benefit, while in two cases which have been under my care, the remedy seemed to disagree with the patients. The following is one of the latter kind:—

CASE 49.—Caroline B., aged 27, single, admitted March 2, 1868, had her first fit eight years ago after a violent storm. With the exception of an attack of 'inflammation of the bowels,' which she had ten years ago, has always been in tolerable health. No family history of nervous affections. The fit is ushered in by an aura starting from the epigastrium, similar to that in Case 47. Galvanism was used in her case three times. After the first application 'she had such curious sensations that she did not know what to do;' she felt reeling and giddy, as if she had been drinking. A second shorter application had the same effect, and after the third she had a bad headache and felt unable to do anything for a day or two. It was therefore given up. Such idiosyncrasies must, however, be very rare, as amongst sixty-four epileptics in which I have used galvanism, the application of it disagreed with only two. Further observations will show whether the immediate benefit which is perceptible in the large majority of cases will be permanent; but there is now sufficient experience to show that, in well-selected instances, a judicious use of the continuous galvanic current may be of essential service.

5. *Asthma.*—Dr. Hyde Salter,* in his able treatise on asthma, speaks strongly against the employment of galvanism in that disease, and condemns 'the passing galvanic shocks through the chest.' He says that he has known this to do great harm; to bring on an attack in a patient at the time free from asthma; that it has, to his knowledge, aggravated existing spasm, but never done any good. Dr. Salter is at a loss to imagine what idea could have suggested the use of galvanism in asthma; but as he has taken himself great pains to prove that asthma is a nervous affection, depending upon a morbid condition, either of the pneumogastric or the brain, and not upon structural disease of the heart or air-passages, I am surprised at Dr. Salter's reasoning. I could understand his anathema against galvanism in asthma, if that disease were due to bronchitis, emphysema, or heart-disease; but as he, with great acumen, has made it out to be owing to spastic contraction of the un-striped fibre-cells animated by the pneumogastric nerve, galvanisation of that nerve

* On Asthma: its pathology and treatment, p. 317. 2nd edit. 1868.

would appear to be a most rational mode of treatment. Of course we must not think of 'passing galvanic shocks through the chest.' This would be a foolish proceeding, which could in no case be expected to have any beneficial effect. The proper way to apply galvanism in a case of asthma would be, to pass a gentle continuous current through the pneumogastric nerve, where it is accessible to the electrodes, at the neck, in the proximity of the carotid artery (p. 324). The induced current applied anywhere, or any form of electricity applied to the chest, would be of no use whatever; but galvanisation of the vagus will, I trust, eventually prove a useful remedy in cases where other remedies have been found wanting. The applications should be very gentle, and continued for one or two minutes at a time. Long and strong applications only irritate the nerve, and might therefore excite an asthmatic attack. I have used the continuous current in the way just described in two cases of true spasmodic asthma, uncomplicated with emphysema or other structural lesions, with apparently excellent effects; but sufficient time has not yet elapsed to enable me to say whether the results may be considered permanent. Anyhow, galvanisation of the pneumogastric may be safely recommended as a mode of treating asthma which has no inherent drawback, and offers a fair chance of success.

6. *Shaking Palsy: Paralysis agitans.*—Trousseau speaks of paralysis agitans as an absolutely incurable

disease, and this, I believe, is even now true for cases which are of long standing, and in which all the limbs are affected ; but if the affection be confined to one or two limbs, and the case be one of comparatively recent standing, the continuous current applied to the nervous centres and as cord-nerve-current, may be of service.

CASE 50.—A gentleman, aged 42, who had indulged in smoking to an almost incredible extent, his usual allowance during the last twenty years having been between twenty and thirty full-flavoured cigars in the day, consulted me in April, 1866, for shaking palsy of the right arm, which had come on four months ago. The arm, which at first shook only when the patient was excited, or wished to do anything hurriedly, now shook continually, and this shaking was much more violent when he was in any way worried or excited. During the last fortnight, the left arm had also commenced to shake occasionally, but as a rule, it was quiescent. There was no pain either in the right or in the left arm. The patient's general health was tolerable, but his eyesight was extremely weak and dim, and he complained of obstinate constipation. I first made the patient promise to give up smoking altogether, and at once, which he did. I then carefully regulated his diet, and applied the continuous current to the optic, sympathetic, and as cord-nerve current, every other day for a fortnight. At the end of that time, the patient's sight was considerably improved, his bowels were regular, and the arms perfectly steady. Three months afterwards he wrote to say that he had had shaking in the right arm only on one occasion, after having had a considerable annoyance, but that it went off the next day, and that he felt quite well again afterwards.

Dr. Russell Reynolds* has placed on record a case of

* The Lancet, 1859. Vol. ii. p. 558.

paralysis agitans of the right arm, which had come on suddenly in a man aged 57, who had for two years before suffered from occasional tremor of the right arm and leg. He used the current of 120 links of Pulvermacher's chain battery to the arm, for half-an-hour or an hour each time. There was improvement after the first application, and after five the spontaneous jactitation completely ceased. It is true that in this instance the shaking palsy had only lasted a fortnight, and was confined to one limb, which would make the case a most favourable one for galvanic treatment.

I have treated a considerable number of cases of shaking palsy of long standing, and where all the limbs were affected, affording more or less relief in most of them; but I have never obtained a cure where both the upper and lower extremities were affected. In some cases, galvanisation combined with the subcutaneous injection of morphia and atropia, and large doses of iodide of potassium, is followed by much more improvement than by any of these remedial measures used singly.

7. *Tetanus.*—Many cures of tetanus by electricity have been published, but such observations have not been given with sufficient detail. It is obvious that if electricity is used in this formidable disease, only the continuous current should be employed.

The observations of Messrs. Nobili and Matteucci on this subject have already been noticed (p. 202). Ranke,* who has lately followed it up, found that frogs tetanised by strychnia became quiet as soon as a continuous current was sent through the cord.

* Zeitschrift für Biologie, vol. ii. p. 398.

The direction of the current seemed to have no influence, but the power required for subduing the spasms was only discovered by actual experiment. At a certain stage of the poisoning, and where a sufficiently powerful current was employed, the frog remained, during the passage of the stream, perfectly insensible to irritants which either before or afterwards caused violent reflex spasms; but the animal died all the same, even if the galvanism was continued for a considerable time. Ranke has likewise established the fact that we are able, by galvanising the cord of unpoisoned frogs, for the time being, to completely inhibit reflex action.

The only cases of tetanus successfully treated by the continuous current which have been given with sufficient detail, are two recently placed on record by Dr. Mendel * of Berlin.

One of these was the case of a girl, aged 4, who had been run over by a cart on May 17, 1868, in consequence of which she suffered comminutive fracture of both phalanges of the right thumb, and some minor injuries. The father of the child dressed the wound himself, and when, eight days afterwards, the crushed finger was only connected with the hand by a small bridge of skin, he cut this right through. The general condition of the child appeared then to be satisfactory. Six days afterwards, difficulty of swallowing came on, the teeth could not be separated from each other, and the muscles of the neck became rigid. A centigramme of opium was given every two hours, without any result; on the contrary tetanus declared itself decidedly, fresh sets of muscles being successively seized by clonic

* Berliner klinische Wochenschrift, Sept. 21, 1868.

contractions, while those previously affected remained in tonic contraction.

On June 12 the little patient had a pulse of 132, the temperature in the rectum being 103·5° Fahr. She was lying on her back, moaning and coughing alternately; could neither sit nor walk nor stand, and only sit up in bed with much trouble, and amidst convulsions. The head was strongly retroflexed; the face bluish-red and slightly œdematous; the pupils slightly dilated. The masseters and temporal muscles were tetanically contracted on both sides, so that only the handle of a spoon could with difficulty be inserted between the teeth; on the tip of the tongue there were some abrasions perceptible, probably from the impressions of the teeth. A few herpetic vesicles were noticed on the edge of the right side of the lower lip. The right thumb was absent; on the right hand there was, above the os metacarpi pollicis, which was preserved, a wound of the size of a bean, covered with abundant granulations. The hand was flexed at a right angle, and slightly supinated; the fingers were closed in the hand. Even on using considerable force, it was impossible to change the position of the hand or the fingers. The muscles of the forearm and arm appeared hard and stiff. The left arm was in its normal condition.

The trapezii, on both sides, but more especially the right one, were rigid and prominent; the head could not be moved to either side; the muscles of the back, more especially the right rhomboides major, were tonically contracted. The muscles of the abdomen were in their usual condition, but those of both thighs harder than usual; both feet, more especially the right, had assumed the highest degree of pes equinus. The muscles of the calf were as hard as a board; the position of the foot could not be altered by employing mechanical force. Whenever the body was somewhat strongly touched, the spasms increased, their character being chiefly that of opisthotonus.

An examination of the chest showed, to the right and posteriorly, moist sounds, which were more feebly perceptible anteriorly. The left lung was not affected. The urine, which was scanty and passed into bed, contained a large amount of urates, but neither albumen nor sugar. There was some constipation. The continuous galvanic current was now used, and all internal remedies were omitted. The positive electrode of a battery of eight cells of Krüger and Hirschmann (Daniell's) was applied to the external side of the right forearm, and the negative to the cervical spine. Almost immediately after closing the circuit it became possible to move the hand, which had until then been quite fixed, freely in all directions; the tetanus in the muscles of the forearm had in fact disappeared. The positive electrode, applied in the same manner to the muscles of the left calf, while the negative was applied to the lumbar spine, appeared to have no effect on the muscles, the foot-joint remaining fixed. The positive electrode was then applied to the anterior part of the leg, close above the joint, after which the tetanus of the gastrocnemii and the tibialis porticus muscle disappeared almost immediately; and the foot was easily movable in every direction. The same proceeding was repeated on the right leg. When the positive electrode was placed upon the tetanic muscles, no effect was produced, but on being applied to the front of the leg, the tetanus ceased at once. The muscles of the jaw did not yield so readily, although the positive pole was successively placed on various points of the face; and only when it was directed to the left infra-orbital nerve, the mouth could be opened a little further. The electrodes having afterwards been applied to the muscles of the neck, the tetanus ceased there likewise, and the head became movable in every direction.

The whole application lasted about fifteen minutes, and the muscles remained relaxed after the application. On the following day, the improvement continued, there was greater suppleness of all the muscles of the extremities; neither the flexors of the forearm, nor the gastrocnemii had returned to their previous rigidity; the position of the head and back was better, and the mouth was so far opened that a finger could be brought between the teeth. The joints were, however, somewhat stiffer than they had been immediately after the first application. The induced current was now used, in order to see whether this would have any effect, but the muscles remained in exactly the same condition as before, and the irritation produced fresh reflex spasms. The little patient was now again treated with the continuous current, as on the preceding day, and the same result, immediate relaxation of the rigid muscles, was obtained.

The day after (June 14), the pulse had gone down to 112, and the temperature to 99·3° Fahr. The child had slept at night, the cough and other symptoms of bronchitis were less; there was some appetite; the mouth was so much open as to allow the introduction of the thumb. There was still slight rigidity in the muscles of the right forearm, and both legs, but some little force was sufficient to overcome it. The position of the head and back was satisfactory. The continuous current was again used.

June 15.—The child had had a good night, had eaten a roll, could put her feet to the ground, and had walked a few steps on being supported.

June 16.—The general condition much improved.

June 17.—The head was freely movable in every direction; the tongue could be put out; the child could stand upright. The muscles of the back and the extremities were soft and flexible. There was some œdema round the ankles. General condition satisfactory. Galvanisation repeated.

June 18.—No convulsions during the last few days; sleep and appetite good; the fingers of the right hand are still slightly contracted, and closed into the hand. No trace of tetanus left; galvanisation repeated for curing the contraction of the fingers. Within a week this result was likewise obtained. In this case the relief caused by the application of the continuous current was so immediate and decided, that no doubt about the real efficacy of the remedy could be entertained.

Dr. Mendel has also recorded a case of idiopathic tetanus in a girl aged 11, in which the continuous current, within ten days, completely overcame the affection. In this case he found that if the positive pole was placed to the second or third lumbar vertebra, and the negative to the sternum, there was immediate relaxation of the abdominal muscles. He has drawn the following conclusions from his two cases: a gentle current should be locally applied to the affected muscles. If a strong current is directed to the cord, powerful convulsions are the consequence. The positive pole should be directed to the antagonists of the affected muscles, which agrees with Remak's experiment, in which galvano-tonic contractions of the extensors were produced by acting on the median, and contractions of the flexors by acting on the radial nerve (p. 195). The current thus applied seems to act rather on the sentient than on the motor nerves, for no contractions are visible, while the excessive irritability of the sentient nerves is subdued. Dr. Mendel thinks that the direction of the current is of no importance in these cases. His success appears to have been so marked as to encourage us to resort, in the treatment of tetanus, to galvanisation, rather than to any other remedy.

8. *Hydrophobia.*—Several Italian authors have, in the commencement of this century, published cases of hydrophobia said to have been cured by galvanism;

but these records are worthless, because the cases have not been sufficiently detailed. More recently Signor Schivardi * has published a case of this disease which was treated under the supervision of a committee of medical men in Milan appointed to study hydrophobia, and of which the following is an abstract:—

A girl, aged 9, was bitten by a suspicious dog on March 15, 1866. There were three wounds on her head, and one on the right hand, which were nôt cauterised, but merely treated with an ointment, and healed spontaneously. The first symptoms of hydrophobia came on on April 27. Two days afterwards she was received into the hospital. The committee agreed that the continuous current should be used, and the negative pole of twenty-two cells of Daniell's battery was applied to the forehead, while the positive was directed to the feet.

This current, which deflected the needle to an angle of 34°, was for four days uninterruptedly sent through the body of the patient. The result was that the pulse became more quiet, the patient slept, and the throat-spasms decreased so much that the patient could eat and drink again. On the sixth day of the disease, after eighty hours' galvanisation, the girl had lost every symptom of hydrophobia, and electricity seemed to have mastered the disease; but the patient was now in a state of great prostration and somnolence. The committee refused to administer stimulants. The weakness got worse during the next few days. The pulse became more frequent, there was profuse perspiration, no appetite, loss of consciousness, diminished quantity of urine, which was alkaline, and a rod with hydrochloric acid approached to the mouth of the patient was covered with white fumes. The patient died seven days and seven hours

* Gaz. med. ital. Lombard. No. 22. 1866.

after the first symptoms of hydrophobia had set in, of uræmic poisoning of the blood.

Signor Schivardi thinks that this patient might have recovered if stimulants had been given; but this, of course, is only an opinion. There seems to be no doubt that the *symptoms* of hydrophobia were relieved, but the poison killed the patient just as well as if no treatment had been adopted. This would be analogous to the case of Ranke's frogs, which, after being poisoned with strychnia, could be kept without convulsions by the use of the continuous current, but died nevertheless of the systemic effects of the poison.

9. *Stammering.*—The best mode of treating stammering is, systematically to educate the vocal organs; but where this is slow to act, or seems to fail, the continuous current may be of service in conjunction with it.

CASE 51.—An intelligent boy, aged 9, one of ten children, was sent to me in January 1868. His general health was tolerably good, but ever since his fourth year he had suffered from defective speech. He could only talk fluently when he was excited, but otherwise he stammered very much. He complained of headache and occasional dizziness, and the pupils were excessively large. Having some suspicion of masturbation, I examined the sexual organs, and found a very high degree of congenital phimosis which appeared to produce considerable irritation. I therefore, before resorting to any further treatment, sent him to Mr. Curling to be circumcised, which was done in February 1868. In consequence of this operation the general health improved, but the spasm in the throat was still as bad as ever. I therefore now applied the continuous current to the laryngeal nerves continuatively, giving at the same time directions for a gymnastic education of the voice. After two months' treatment, the patient attending twice a week, he was very much improved; and when I saw him again four months afterwards, he spoke as well as could be wished.

10. *Facial spasm: (histrionic spasm, tic convulsif).*— This affection, which is owing to irritation of one or several branches of the fifth pair of cerebral nerves, resists all purely medicinal treatment. Neurotomy of the portio dura, which has sometimes been performed for the cure of it, I should consider bad practice, as it produces paralysis instead of spasm, the former being a greater inconvenience than the latter. On the other hand, the excision of a small piece from that branch of the fifth nerve, the irritation of which produces the spasm, generally cures the complaint, without paralysing the muscles of the face. The ulterior consequences of neurotomy of branches of the fifth nerve in such cases are not yet well known; but as it is almost always either the supra-orbital or the infra-orbital nerve which has to be divided, it is to be feared that the nutrition of the eye may suffer in consequence of such operations. It would therefore be very desirable to have a less severe mode of treatment at our disposal.

The continuous galvanic current, applied to the branches of the fifth nerve, generally improves the spasm; but seems to cure cases only of recent standing. I have never yet succeeded in completely curing one of more than twelve months' duration; while

Remak * appears to have succeeded better. In some cases a continuative, and in others an intermittent, application answers best. The direction of the current should be frequently changed, and the length of the application should be from one to five minutes. Subcutaneous injections of morphia and atropia are useful in conjunction with galvanism.

11. *Muscular contractions.*—These occur chiefly after exposure to damp and cold, and in hysterical persons, and are almost always curable by galvanisation or faradisation. Contractions in consequence of disease of the nervous centres are always accompanied by other symptoms pointing to an irritative lesion of the brain or spinal cord, and are not nearly so amenable to electricity as those due to rheumatism or hysteria.

IV.—ANÆSTHESIA.

Anæsthesia may be due to disease of the brain, spinal cord, or peripheral nerves, and is either complete or partial. In some cases all the different kinds of sensations are lost, but in others only one or two of them are gone, while the others remain intact. Thus common sensation may be impaired or lost, while the senses of temperature and locality are as acute as ever, &c. In most forms of anæsthesia an electric treatment is of service. Where the affection is due to effusions compressing the nervous matter, the continuous current appears to be most effective;

* Berliner klinische Wochenschrift, No. 22. 1864.

but where it occurs in consequence of great torpidity of nervous power, more especially in hysteria, faradisation of the skin or static electricity, are likewise applicable.

1. *Anæsthesia of the Cerebral Nerves.*

a. *Loss of Smell* (*anosmia*).—Total loss of smell is rare, and its pathology still somewhat obscure. In some cases it appears to be due to cerebral disease, while in others the olfactory nerve is compressed by tumours, exostoses, and effusions. Bertholon has recorded a case of anosmia consequent upon rheumatism, and which was cured by static electricity. Kragenhoff obtained a similar good result in a case of hemiplegia, complicated with loss of smell. Duchenne mentions that he has frequently used faradisation of the mucous membrane of the nose for restoring the lost smell, and has generally been successful. Most smells being disagreeable, patients seem generally not to care very much to have that sense restored. I have seen a case in which anosmia came on through excessive snuff-taking, in a Portuguese merchant; I proposed to him an electric treatment, but he would not submit to it.

b. *Amblyopia; amaurosis; weakness of sight from imperfect nutrition of the optic nerve.*—Amaurosis was much more frequently diagnosed before the introduction of the eye-mirror into ophthalmic practice, than it is at present. Von Graefe * excludes from

* J. Soelberg Wells's Treatise on Diseases of the Eye, p. 396.

this denomination all disturbances of sight dependent upon material changes in the refractive media, in the internal tunics of the eye, and also neuro-retinitis and embolism of the central artery of the retina. He confines the term amaurosis to cases of blindness from primary or degenerative atrophy of the optic nerve, while he understands by 'amblyopia,' that impairment of vision, which is produced by irregularities in the circulation, and which may in the end lead to primary atrophy of the optic nerve.

The medicinal treatment of these affections generally yields little or no result. The various forms of electricity have often been used, and sometimes with satisfactory results. De Saussure obtained a cure of amaurosis by shocks of static electricity directed from the eye-ball to the neck; while Magendie and Person were successful with magneto-electricity. M. Lesueur * has recorded a case of complete amaurosis, but where the mobility of the iris had not suffered, and which was nearly cured by electro-magnetism. He applied one moistened conductor to the closed eye, and the other to the neighbourhood of the orbit, the neck, and the scalp. The operation lasted four minutes. The patient discontinued the treatment before she was quite cured, but at the end of it she could read a test-type three millimètres high. Unfortunately neither M. Lesueur nor any other observer has examined the eyes of such patients with the ophthalmoscope, so that we

* Journal des Connaiss. méd., mars 10, 1861.

have no accurate information on the nature of the disease.

Mr. Dunn,* of Crick, Derby, has recorded a case of loss of sight in a servant-girl, aged 15, free from symptoms of hysteria, who while engaged with her work, fell and struck her eye upon a round knob of the stair balusters. The eye became much swollen and inflamed. The patient could see imperfectly after the accident, but the following morning she was totally blind on the injured side. Mr. Dunn saw her three weeks afterwards, when the eye looked perfectly healthy, all traces of inflammation having disappeared. Supposing it to be a case of concussion and subsequent paralysis of the retina, he passed a gentle magneto-electric current through the eye, using his finger as electrode. An immediate improvement took place; the sight gradually returned, and in five minutes the girl read large capitals with the affected eye. Faradisation was twice repeated, and after the last application one eye was as good as the other. In this case also no ophthalmoscopic examination of the eye was made.

Duchenne recommends faradisation for amaurosis; but the continuous current would seem to be the best of all the different forms of electricity, on account of its powerful physiological action on the optic nerve (p. 157). The continuous current has not yet been fairly tried, and it appears, therefore, very desirable that a systematic use of it should be made in one of our numerous ophthalmic hospitals, in order to lead us to definite conclusions about its actual value. An examination of the eye by means of the ophthalmoscope should always

* The Lancet, November 1867.

precede the commencement of the galvanic treatment, so as to leave no doubt about the nature of the case. The applications should be intermittent, short, gentle, and frequently repeated. One electrode should be put to the cheek and forehead alternately, and the other to the tongue; and voltaic alternatives should be systematically employed.

In *weakness of sight*, without structural lesions, and which might perhaps merge into amblyopia or amaurosis if allowed to go on unchecked, the continuous current often produces excellent results. I have seen a number of cases of this kind, which were due either to over-exertion of the eyes in reading and drawing, or to the general malnutrition of advancing age, and in which a short galvanic treatment rapidly restored the eyesight to its normal strength. Some of these cases were complicated with photophobia, which yielded to the same remedy.

c. *Anæsthesia of the fifth Cerebral Nerve.*—An instance of this kind has already been described (p. 137). I now subjoin the result of the treatment in that case, which consisted of the systematic application of the continuous galvanic current to the several branches of the fifth nerve, the positive pole being placed to the nape of the neck, while the negative one was being gently passed along the peripheral ramifications of the nerve. No medicine was given.

After this treatment had been followed for about three months, with several interruptions due to extraneous circumstances, the following change had taken place in the patient's condition:—The symptom of photophobia had entirely disappeared. Indeed the patient was able to leave off wearing the eyeshade after the first few applications of the galvanic current. The tinnitus aurium was likewise almost entirely gone; it was only occasionally slightly perceived when the patient was lying down at bedtime. The opacity of the cornea was considerably less on the left side. The patient can now read No. 10 (pica) of Jäger's test-types with the left eye, while, when he first came to me, he could with great difficulty make out single letters of No. 20 (8-line Roman). On the right side the improvement was likewise satisfactory, as the patient could read single letters of No. 20 with that eye. When I first saw him he was obliged to be led by another person; but now he was able to guide himself in the streets, and to read the street names at the street corners and the signboards of shops. Common sensation had to a great extent returned in the left side of the forehead, the right cheek, and the chin. In the other parts of the face it was still considerably impaired. The sense of locality in both sides of the face was re-established, for the patient could tell distinctly where he was touched or pinched. The sense of temperature had come back to some extent, for the patient was able to distinguish between heat and cold, although not so keenly as previous to the affection. The sense of touch had returned in the left side of the forehead, the right cheek, and part of the chin, as shown by the proper perception of the two points of the æsthesiometer. The secretion of tears and saliva had partially returned, while the excessive secretion of mucus had been considerably checked. The lips were no longer covered with froth, but quite dry. The lateral motion of the muscles of mastication was nearly re-established. The patient has been advised to continue the galvanic treatment, and I believe that the function of the fifth pair will, in course of time, be completely restored by it. He is now quite able to follow a light occupation.

d. *Loss of Taste* is very rare, and would, if remediable at all, probably yield to the influence of the continuous current.

e. *Nervous Deafness.*—Cases not unfrequently occur in which there is a defect of the power of the brain or the auditory nerve to receive or appreciate sounds, without any physical alterations of the organ of hearing. Such may be properly called cases of 'nervous deafness.'

The affection is often accompanied by general debility, and seems to arise from causes which have a tendency to weaken the tone of the nervous centres, such as grief, anxiety, sleeplessness, over-exertion of mind or body, and exhaustive discharges. I have likewise seen it come on during convalescence from acute diseases. Nervous deafness often yields to galvanisation or faradisation.

The most striking effect on the auditory nerves is produced by applying the continuous current to the mastoid processes; but I generally do not resort to this mode of application, just on account of its influencing the brain in too powerful a manner, as made evident by a feeling of giddiness and faintness which it causes. I therefore prefer the application of one pole to the membrana tympani, and of the other to the ganglion cervicale superius. The application should be intermittent, systematic use being made of voltaic alternatives.

Case 52.—A married lady, aged 46, who had lived much in the tropics, consulted me in March 1867. Five years ago she had suffered from small-pox, and when she was convalescent her attendants noticed that she had become completely deaf in both ears. She gradually recovered her health, but not her hearing. She had consulted a number of eminent aurists, who had given their opinion that there was no discoverable lesion of the organ of hearing, but that the deafness was due to a torpid condition of the auditory nerves. A great variety of remedies had been used, both externally and internally, but without effect. I advised the use of the continuous current. Twenty cells produced no sounds, and only a very slight pricking sensation. Thirty cells produced a stronger sensation, but no sounds. Voltaic alternatives were employed. After a fortnight's treatment, the patient heard a slight sound, when the positive pole was in the water filling the meatus, at the moment that the current was broken, while, if the negative pole was used, there was a faint singing noise on making the circuit and the whole time that the circuit remained closed, but nothing on opening it. These phenomena were more distinct in the right than in the left ear. A week afterwards the patient could faintly distinguish the sound of a bell and the musical sound of the hammer of an induction machine with the right ear. After five weeks she could hear the ticking of a clock distinctly with the right ear, and faintly with the left, and could follow conversation if loudly spoken to. The treatment had now to be discontinued, as the patient was obliged to leave London. I heard from her six months afterwards, when she informed me that the right ear had continued to improve, and that she could now hear well with it, while the left ear had remained in the same condition as before.

On the whole, galvanisation is more useful in these cases than faradisation; but that the latter also may do good, is shown by the following case:—

CASE 53.—A married woman, of highly nervous constitution, aged 37, became deaf as far back as 1849, and the only cause she could assign for it was cold. She was always worse when she was excited or embarrassed. There had never been any inflammation of, nor discharge from, the ear; nor was anything pathological in the ear discoverable when Dr. Henry G. Wright examined her at the Samaritan Free Hospital (December 1860). My examination of the patient's organ of hearing had the same negative result, and the case was therefore put down as one of nervous deafness. Faradisation of the membrana tympani did good at once; the patient who, when she came to me, did not notice any questions I addressed to her, nor heard any sounds produced, heard, on leaving my house, a dog bark, and on turning into Oxford-street, she heard the whistle of an omnibus conductor. From that time she steadily improved, so that it soon became easy to converse with her. At the same time the catamenia, which had been very scanty, became more abundant and of a better character.

M. Bonnafont * has recommended electro-puncture of the membrana tympani for cases of nervous deafness. He illumines the membrane by means of a speculum, and then introduces a fine acupuncture needle towards the anterior part of it, until it meets with an impediment. A small piece of cotton-wool is then put into the meatus, in order to keep the needle in its proper position. After this, a silver canula is introduced into the eustachian tube, where it is fixed with a forceps; and a fine silver wire is then inserted into the canula, which is insulated everywhere except at its two ends, one of which serves as electrode, while the other receives one of

* Traité théorique et pratique des maladies de l'oreille et des organes de l'audition. Paris, 1860.

the conducting wires. Magneto-electric shocks are then sent through the electrodes. The proceeding looks very pretty on paper, but is probably not more effective than the ordinary application, which is a far readier one.

2. *Anæsthesia from imperfect Cerebral Nutrition.*

The following is an instance of central anæsthesia cured by the continuous current:—

CASE 54.—A gentleman, aged 64, widower, accustomed to generous living, suffered two years ago from a severe cold and indigestion, after which he was frequently troubled by an unpleasant sensation of numbness and coldness in the left thigh. Of late he had had the same feeling of cold, heaviness and numbness in the left side of the head, especially after a chill; and walking had become rather troublesome. The memory was good, and although the patient had given up active occupation, there was no deficiency in his power of application, whenever it seemed to be required. There was a well-marked arcus senilis, and the sense of smell was defective. My opinion on this case was requested by Dr. Allan, of Hyde Park Terrace, in July 1866. We agreed that the symptoms could only be due to want of cerebral power in the right hemisphere, and that the continuous current should be used. I applied fifteen cells to the head, and thirty to the thigh, with voltaic alternatives. After four such applications, the sensation of numbness, heaviness and cold about the head was gone, and two more also relieved the anæsthesia of the thigh.

3. *Hysterical Anæsthesia.*

Hysterical women often suffer from a sensation of numbness, which is sometimes fixed in a limb, or part of a limb, but in other instances migrates about the body. Cases of this kind are generally curable by faradisation. In November 1857, an hysterical woman, aged 36, was sent to me by Dr. Henry G. Wright; she complained of numbness in the nape of the neck, the dorsal spine, and both arms. I applied the induced current to the parts mentioned, and when I saw the patient the following day, she stated that she had nearly regained the normal feeling in them: three other applications effected a complete cure. In other instances, however, a longer treatment may be required.

CASE 55.—A. C., aged 28, married, was in July 1857 admitted into Carlisle ward, St. Mary's Hospital, under the care of Dr. Alderson. Three years ago she had suffered from rheumatism. Fifteen months ago the first symptoms of her present illness appeared; walking became difficult, she did not feel the ground, and suffered from a continual sensation of numbness in the back and the lower extremities. She had never had cramps or twitches in the leg. She had been treated by cuppings, leeches, and blisters along the spine, strychnia, calomel, and galvanism. When I first saw her, soon after her admission, the skin of the face, neck, and arms was duly sensitive, but on the back there was complete anæsthesia from the seventh cervical vertebra down to the sacrum, and the same was the case with the lower extremities. In walking she staggered, and the muscles of the lower extremities responded very little to the faradic stimulus. There were no symptoms of disease of the womb, bladder, and rectum. In order to restore the lost vitality to the sentient nerves, I faradised the skin of the back and of the lower extremities with wire-brushes. While in the normal state of the nerves the faradic stimulus is felt as soon as applied, this patient did not feel it until it had been applied from five to six seconds. Such was the case on the back as well as on the lower extremities; but in the soles of the feet no sensation could be produced even by a most powerful current. I continued faradisation, and after six applications the sensibility of the back had become nearly normal. The sentient nerves of the lower extremities were more deeply impaired than those of the back, and it took a longer treatment to effect an improvement in them. The patient walked much steadier when she left the hospital, although she had not quite recovered.

4. *Anæsthesia from Effusions, or Injury to Nerves.*

CASE 56.—A gentleman, aged 62, unmarried, came under my care in November 1867. Three months ago he had had a sharp attack of gout in the right foot, which subsided after six weeks' treatment, when he first began to walk about with the aid of a stick. He then found that he had almost entirely lost the feeling in the sole of the foot, the ankle, and the knee-joint. He used liniments, and the leg was rubbed and shampooed, but with no effect. He now complained of a sensation of complete numbness and loss of power in the leg. The prick of a pin was not felt between the foot and the knee-joint, and even in the thigh it was felt less than in the thigh of the other side. There was still some tenderness in the big toe and the ankle, but no waste of muscular tissue. The leg was colder than the left, and the sense of temperature was completely gone. The patient had six applications of the continuous current intermittently to the nerves and muscles of the thigh and leg, after which he had recovered the sensibility and the use of the extremity.

The following case, which was due to injury, occurred in Remak's practice:—

A woman had injured the second phalanx of her left thumb with a hatchet. After the wound was healed, the top of the thumb remained insensible and numb. Within a twelvemonth the numbness progressed from the cicatrix to the back of the arm, along the course of the radial nerve, and in front along the course of the median nerve to the elbow; and it gradually thence crept up to the neck and the left cheek. On these latter places and on the back of the arm it disappeared again after a time, but increased in the course of the median nerve, and especially in the tips of all the fingers. A current of from fifty to seventy cells of Daniell's battery was applied to the cicatrix only, and the sensation in the thumb and the other fingers was restored after four such operations.

5. *Asphyxia.*

Hufeland * appears to have been the first to propose electrifying the phrenic nerve in asphyxia of newly-born infants, by applying one pole to the cervical vertebræ, and the other to the pit of the stomach ('ut iter nervi phrenici sequamur'). The same proposal was made, sixty years later, by Dr. Marshall Hall; † but neither Hufeland nor Hall seem ever to have carried out their idea in practice. In 1848, Jobert de Lamballe and Ducros made a number of experiments on chickens, pigeons, and other animals, in which anæsthesia by ether or chloroform had been produced, and which were readily roused by the application of the induced current. Duchenne ‡ recommended, in 1855, localised fara-

* De usu viris electricæ in Asphyxia. Gottingæ, 1783.

† On the Diseases and Derangements of the Nervous System. London, 1841.

‡ De l'électrisation localisée, p. 738.

disation of the phrenic nerves for the cure of asphyxia; but Ziemssen * was the first who, in 1856, used this method successfully.

A servant-girl, aged 27, was found in her bed, early one morning, asphyxiated by charcoal-fumes. Counter-irritation of the skin proved unavailing in inducing respiration; and when Dr. Ziemssen was called in, the pulse and respiration had nearly disappeared; the skin was getting pale, the temperature of the extremities low, and the râles in the trachea more marked. As soon as the phrenic nerves were rhythmically faradised, the thorax was dilated, the girl began to cough, the cheeks showed a faint flush, and the extremities became warmer. Faradisation was continued, with short interruptions, for two hours, when respiration was fairly re-established. Eleven hours after the first commencement of faradisation, respiration was perfectly regular, and the patient was quite well the next day.

Friedberg † has recorded a case of asphyxia in a boy aged 4, who was placed under the influence of chloroform in order to have a cyst of the eyelid removed. After a few inhalations the pulse suddenly became very small, the face livid, the eye glassy, the limbs relaxed; one short râle was heard, after which respiration ceased. Cold water was rapidly thrown on the face and chest, ammonia held under the nose, and the larynx tickled with a small sponge. After this had been done for two or three minutes, the pulse disappeared completely, the complexion became pale, the lower jaw dropped, the expression of the face was cadaveric, and the pupils dilated. Artificial respiration by methodical compression of the abdomen was then resorted to for three minutes, but likewise without any result. Dr. Friedberg now faradised the diaphragm by putting one electrode to the phrenic on the neck, and the other into

* Die Electricität in der Medicin, 1st edition, 1857. p. 49.

† Virchow's Archiv, 1859, vol. xvi. p. 527.

the seventh intercostal space, for one second at a time. After ten such applications, the first inspiration took place; faradisation was then discontinued, and a second and third inspiration became perceptible. After the third, the radial pulse re-appeared, and further methodical compression of the abdomen was now sufficient for re-establishing respiration and the heart's action. After twenty minutes the child had fairly recovered. The operation was then performed, and the little patient slept for an hour; after which he appeared perfectly well, and no further effects of the chloroform were noticed.

Ziemssen* has recorded four other cases in which faradisation of the diaphragm was successfully used; the asphyxia being due to poisoning with carburetted hydrogen gas, charcoal-fumes, and to freezing after alcoholic intoxication. In five other cases which have been under the care of the same observer, no result was obtained. A case of opium-poisoning recorded by Oppenheimer † was also unsuccessful, although faradisation of the phrenic nerves had been continued for three hours. Mosler and Möller have likewise published unsuccessful cases. Pernice ‡ has used faradisation in five cases of apparent death in newly-born infants; in two of these no result was produced, while in three life was restored.

Ziemssen recommends to faradise not the phrenic nerves alone, but also the motor nerves of those muscles which act in combination with the diaphragm; that is, the branches which proceed from the cervical plexus to the trapezius, levator scapulæ, and scalenus medius muscles; the nervus thoracicus anterior, which animates the pectoralis major and minor; and

* Die Electricität etc., 3rd edition, p. 180.

† Lehrbuch der physicalischen Heilmittel, Heft i. p. 157.

‡ Greifswalder medicinische Beiträge, Band ii. p. 1.

the nervus thoracicus posterior and lateralis, which proceed from the brachial plexus to the scalenus medius, serratus anticus, and the rhomboidei. The electrodes should be placed there for about two seconds at the time, in order to produce a deep inspiration; after which expiration is effected by an assistant pressing the abdominal parietes from below upwards. It has been proposed to promote expiration by faradisation of the abdominal muscles, but Ziemssen is not in favour of this proceeding, because he thinks it impossible to produce such a powerful compression of the contents of the abdomen by faradisation as may be effected by mechanical pressure on the parietes, and by pushing the diaphragm upwards. The current should be powerful and rapidly-interrupted. If after the first few times no effect is produced, the intensity of the current must be further increased, as otherwise the excitability of the respiratory nerves might completely vanish.

Onimus and Legros * think the continuous current preferable to faradisation. They have experimented on rats, mice, rabbits, and dogs, with ether, chloroform, and nitrous oxide gas; and have found that after respiration had ceased, and the animals had been apparently dead for two or three minutes, a continuous current applied to the digestive tract restored them to life. They recommend to place the negative pole into the mouth, and the positive into the rectum, and to apply the current continuatively, until respira-

* Comptes rendus, etc., March 1869.

tion and the heart's action are quite re-established. A current of twenty cells would, according to them, be sufficient for man.

V.—HYPERÆSTHESIA.

Hyperæsthesia is due either to primary disease of some part of the nervous system, or to morbid conditions of remote organs which cause an irritation of the nerves; and it depends entirely upon the cause of the hyperæsthesia whether it is amenable to electricity or not. Where the cause cannot be removed by electricity, either no or only symptomatic relief can be afforded by the same; while a cure may result, where the cause of the hyperæsthesia yields to the electric influence. Thus, for instance, hyperæsthesia may be caused by inflammatory diseases of the uterus, ovaries, and kidneys, or by exostoses in the osseous canals through which the nerves pass in their course to the periphery, or to cancer, &c.; and in such cases we cannot, as a rule, expect electricity to do much good, as the irritation of the nerves, and consequently the hyperæsthesia, continue as long as the disease persists and progresses in those parts; yet even in such cases electricity sometimes produces temporary relief, where other anodynes have been used and failed. Professor Schwanda,* of Vienna, has recently related a case of cancer of the breast, in which, six weeks before death, the pain, spasms, and sleeplessness were so severe as to defy all the usual means for the

* Zeitschrift der Wiener Aerzte, March 1869.

relief of those symptoms. The patient could not rest in bed, but had for three nights and days been without sleep, and 'contracted with pain.' Professor Braun, under whose care the patient was, then advised the use of electricity, and after two applications of the continuous current the patient felt so much relieved that she could assume the horizontal position in bed; the use of the current was continued up to the time of her death, and was the only thing which at all relieved her sufferings. In many instances, however, hyperæsthesia is owing to impaired nutrition of nervous matter, unaccompanied with any severe structural lesions; and in such cases electricity may not only temporarily relieve, but permanently cure the complaint.

In the milder varieties of hyperæsthesia all the different forms of electricity may be usefully employed, but in the severer forms of it only the continuous current affords relief. Static electricity may be employed in the form of sparks and slight shocks. Induction currents may be used by means of the electric hand (p. 380), which is very useful in headache, or as an electric moxa, one wire-brush being pressed to the skin, while the other is held at a small distance from it, so as to cause sparks to pass from the skin to the wire-brush, or by means of moistened conductors applied to the trunk of the nerve. Whether electro-magnetism or magneto-electricity is used in such cases, appears to be indifferent. If the continuous current be used, the positive pole should be placed, by means of a large conductor, to the suffering nerve, and the negative in the neighbourhood, the application being continuative for from one to five minutes. Finally, in obstinate cases of hyperæsthesia which resist other means, galvano-puncture may be employed, which is a most effective, although unpleasant, mode of using electricity.

1. *Neuralgia of the Face* (*tic douloureux*).—There are two kinds of facial neuralgia, a mild one and a severe one. The former generally comes on after exposure to damp and cold, or after mental emotions, or is owing to caries of a tooth; it is not made worse by moving the face, and it occurs at all periods of life; while the latter occurs generally without any apparent cause, is almost entirely confined to advanced age, and is brought on or made worse by the least movement of the face. The former yields to many remedies, and amongst others to electricity; while the latter, as a rule, defies every medicinal treatment, and only appears to yield to neurectomy and the continuous galvanic current. The following case is one of the former kind, which readily yielded to faradisation:—

CASE 57.—A married lady, aged 28, had been in good health until May 1857, when, in consequence of having got wet through, she was seized by violent pains in the right side of the face, accompanied with fever and general indisposition. The latter symptoms soon subsided, but severe shooting pains continued to occur in paroxysms, at the end of which the patient was completely exhausted. For the first few weeks the attacks of pain came on irregularly, about four or five times in the course of the day; but they gradually assumed an intermittent character, only one attack occurring every other day, between four and five o'clock in the afternoon. Large doses of quinine and arsenic had been given, but without producing any effect; the patient had also been treated by calomel, bichloride of mercury, iodide of potassium, and blisters. Her general health had much suffered, and she had become nervous and irritable. She now (October 1857) always had a warning that an attack was coming on, viz., a kind of tickling in the epigastrium, followed by a sensation of pins and needles in the face. Soon afterwards the pain begins to shoot through the zygomatic bone, the lower eyelid, the cheek and chin, is less violent on the nape of the neck, and spares the forehead and temple. Such an attack usually lasts about half an hour, and then slowly subsides into a dull aching pain, which continues for three or four hours. The following day she is free from pain, but on the third day there is another paroxysm. Movements of the face do not increase the pain. On examination of the face, I found two *puncta dolorosa*, viz., on the zygomatic bone, where the temporo-malar, and on the infraorbital foramen, where the infra-orbital nerve emerges from the orbit: pressure on these two points caused a distinctly painful sensation in the free interval. I used faradisation, directing the electrodes alternately to these two points, by means of moistened conductors, conveying a rapidly-interrupted current to the suffering nerves. The first application made at the time when the attack had just commenced relieved the severity of the pain, but did not shorten the duration of the paroxysm. Two days after, another attack came on in due time, but was then much shortened by faradisation. On the third day after that, there were premonitory symptoms, as usual, but no attack. Next time a paroxysm came on which was subdued in five minutes. Faradisation was used five times more, after which the patient appeared to be free from the disease. I saw her again in the beginning of June 1858, when she told me that up to that time she had been perfectly well.

Cases of that severe form of facial neuralgia which Trousseau has appropriately termed *epileptiform neuralgia*, and which is also called *Fothergill's disease*, resist the influence of faradisation. They yield to excision of a piece of the suffering nerve, but are apt to return as soon as regeneration of the nerve has taken place; and even before that time the neuralgia often invades neighbouring branches of the trifacial, so that further surgical operations become necessary. I believe that in this affection the continuous current is preferable to neurectomy; in the first instance because it does not injure or destroy the nerves which are necessary for the proper nutrition of the face; and secondly, because it has the power of completely altering the nutrition of the affected nerves, owing to which it probably produces more permanent effects than neurectomy. The most important case of epileptiform neuralgia which has up to the present time been placed on record, is one which occurred recently in the practice of Professor Niemeyer, of Tübingen, and which has been published by Dr. Wiesner.* In this case surgery and electricity had both a fair trial.

The patient was a huntsman, aged 64, accustomed to live in the open air and to 'rough it.' Five years before he came under Prof. Niemeyer's care, he first felt a 'painless shock' through the left side of the head and face; and such shocks returned at frequent intervals. After this had gone

* Berliner klin. Wochenschrift, No. 17, 1868.

on for a twelvemonth, attacks of severe pain came on, which commenced at the angle of the left jaw, and proceeded through the zygomatic arch right into the skull. Such attacks occurred at first about once in three weeks, and were generally owing to some exciting cause, such as smoking, masticating, speaking, wiping the mouth, &c. Pressure neither increased nor diminished the pain, the fits of which gradually became more frequent. The shocks lasted only one or two seconds, but recurred twenty or thirty times in the course of the day in the third year of the disease. In 1864 the patient consulted Prof. Billroth, of Zurich, with the view of undergoing a surgical operation. The pain at that time never came on without touching or moving the left side of the face, and it never occurred during sleep; it affected the left cheek, the upper lip, the upper jaw, and the teeth. A few decayed teeth were now extracted, but this gave no relief whatever. A number of remedies, such as quinine, iron, arsenic, iodine, and veratrine, were then given, with the same result; and it was only the subcutaneous injections of morphine which produced temporary benefit. By the advice of the late Prof. Griesinger, four leeches were now put to the diseased side; and this was repeated a week after, but the condition of the patient remained exactly the same. Prof. Billroth then excised a piece of the infraorbital nerve, one and a quarter inch long, from the infraorbital canal. The piece of the nerve which had been excised was carefully examined with the microscope, but it appeared perfectly healthy. The patient only remained free from pain for a few days, after which the attacks reappeared, although not quite so frequently nor so severely. At that time the attacks were brought on by pressure on the left upper jaw; and the parts animated by the infraorbital nerve remained free from pain. The paroxysms, however, getting continually worse, Prof. Griesinger advised the removal of the painful parts of the alveolar process of the jaw by means of raspatories. The patient was not put under the influence of chloroform for this operation, as he had to state which parts of the bone were painful. The operation was excessively painful, but had a favourable result; the patient was discharged on May 27, 1864, being then quite free from pain.

He was again admitted in February 1866, and reported that for some time he had been quite well, but that the attacks soon returned, and gradually became more frequent and severe. The patient urgently demanded a 'radical operation.' The left cheek was now free from pain, but all the other parts which are animated by the second branch of the fifth nerve were affected. Prof. Billroth then resorted to the osteo-plastic resection of the upper jaw, as practised by Von Langenbeck. He broke off the posterior wall of the antrum, and the posterior part of the lower portion of the orbit, dissected away the second branch of the fifth nerve up to the foramen ovale, and divided the nerve close to the foramen rotundum. The zygomatic and superior alveolar branches were then drawn out as far as possible, and likewise removed, and the infraorbital nerve was entirely taken away. The operation was not followed by any bad symptoms, and the wound of the jaw healed well together. A careful microscopic examination of the nerve again showed no alteration whatever.

This operation was successful for a time, but towards the end of March of the same year fresh paroxysms of pain occurred on touching the left upper lip. They soon became so severe, that Prof. Billroth excised on April 6, 1866, the buccinatorius nerve which branches off from the third ramus of the fifth. This operation was rendered difficult by the numerous cicatrices consequent upon previous operations; the ductus Stenonianus was injured close to its point of exit from the gland, and erysipelas set in afterwards, but yielded rapidly to treatment. The pain was now quite gone, but a salivary fistula remained. In May the tic was again as bad as ever in the left side of the palate and the chin. On May 9, therefore, Prof. Billroth cut away from the cavum oris through the lateral wall of the antrum, in order to excise the posterior dental nerves, and resected at the same time the mental nerve at its exit from the inframaxillary canal. On May 21 the salivary fistula was operated for, the anterior portion of the gland being removed, and the skin united by sutures. The parts did not heal, but suppuration set in, and the whole gland gradually sloughed away. In July 1866 the patient left the hospital free from pain, and also cured of the fistula.

He did not, however, long continue in good condition. In December 1866 the attacks were again very frequent. He was readmitted in July 1867, when the pain was excessively severe; it then proceeded from the dental process of the upper jaw, and radiated towards the nose, the lower eyelid, ear, and temple, from where it penetrated into the cavity of the skull. Prof. Billroth then advised the use of the continuous galvanic current; but as the patient believed that he could only be cured by a surgical operation, the Professor, on the urgent entreaties of the patient to do something for him, tied the left common carotid artery, just below the omohyoid muscle. During the first few days after this operation, a few feeble shoots of pain came on, but they soon ceased, and on the seventeenth day the patient left the hospital apparently well. But again the improvement was only temporary, and as Prof. Billroth had, in the meantime, left Zurich for Vienna, the patient went to Tübingen to consult Prof. Niemeyer concerning the applicability of galvanism.

He was admitted into the hospital in December 1867. At that time he used every day eight grains of morphine for subcutaneous injections, this being divided into three doses. The shoots of pain came on twenty or thirty times during the day; their starting-point being the articulation of the jaw, whence the pain spread to the anterior side of the ear, and the left parietal bone. It came on chiefly on touching the left upper lip. The continuous galvanic current was now used, and with such beneficial effect that the patient was soon enabled to discontinue the subcutaneous injection of morphine. After three months' treatment, the current having been applied nearly every day, the patient left the hospital apparently cured. Whether the effect of the galvanism will be more permanent than that of the surgical operations, remains to be seen; but it is to be expected that, if a relapse should occur, the same remedy would again produce the same effect. The current was applied, by moistened electrodes, to the affected nerves, no regard being had to the direction of the current, and for five minutes at a time; sometimes both electrodes were directed to the skin, at other times one was directed to the skin and the other to the mucous membrane.

Dr. Wiesner has recorded another case of a similar kind which occurred in a patient, aged 74 at the time he came under treatment, when he had already been a sufferer from the neuralgia for twenty-nine years. In this case a host of external and internal remedies had been used without effect; M. Nélaton had refused to perform an operation, and so had Prof. Bruns, of Tübingen. The induced current had been used as 'electric moxa,' but without producing any benefit. In July 1867, Prof. Niemeyer used the continuous current, connecting the positive pole with a moistened conductor, and the negative with a wire-brush. After twenty such applications, the pain was gone, and only a slight increase of sensibility remained in the upper lip. Some months afterwards there was a relapse; but it yielded rapidly to galvanisation.

The following case, which occurred seven years ago in my practice, is interesting on account of the disease occurring in a comparatively young patient, and yielding in a very short time to the influence of the continuous current, although it had lasted many years:—

CASE 58.—A married lady, aged 41, came under my care in August 1862. She had, for the last twenty-five years, with few intermissions, suffered from Fothergill's disease, which attacked the left side of the face, and more especially the temple, cheek, and chin. The pain was most violent between six o'clock in the evening and two or three in the morning, and prevented sleep until then. It was worse in damp weather and when easterly winds prevailed, and was excited by the least movement of the face, especially the lips. Almost every narcotic had been used for relieving her, but generally with the effect that the pain was increased instead of diminished. This was chiefly the case with opiates, belladonna, and henbane: arsenic and quinine had also been given, but failed. I applied a continuous galvanic current of four cells of Bunsen's battery to the two inferior branches of the trigeminal nerve, and ordered at the same time the internal use of Spa water for improving the general health. Three operations, which were very pleasant to the patient, were sufficient to cure her of a disease which had for twenty-five years embittered her life; and up to December 1863, when I last heard from her, no relapse had taken place.

Patients who are more advanced in years generally require a much longer treatment, and if this is prematurely discontinued, the benefit already gained may be lost again, of which the following is an instance:—

CASE 59.—A merchant, aged 64, widower, living in a manufacturing district, had for eight years suffered from epileptiform neuralgia in the right side of the face, which had first come on after a fatiguing journey undertaken in winter, and under anxious circumstances. Since then the neuralgia left him only occasionally; and when he came under my care in January 1869, he was not free from attacks a single day. Shoots of pain came on after the slightest movements of the lips, chiefly during mastication, and in speaking, stooping, gaping, coughing, and sneezing. An intercurrent attack of dyspepsia, to which he was rather subject, always increased the severity of his sufferings. He was generally free from pain at night. The severity of the suffering was such as to drive him nearly mad; and he had not known any enjoyment of life during the last eight years. When an attack came on, he could not help calling out or screaming, and he had not been to church for a long time, because he had sometimes been obliged to call out in the middle of the service. His general health was tolerably good, except that there was atheromatous degeneration of the valves of the heart, which gave rise to occasional bad attacks of dyspnœa. No puncta dolorosa could be found in the course of the trifacial nerve, the only objective symptom being a swelling in the mucous membrane of the right cheek, which was the principal seat of the pain. Digestion was good, but the patient was obliged to take his food minced very fine, because otherwise the act of taking it hurt him 'awfully.' He was also obliged to avoid anything hot, as this caused severe pain. No part of the right side of the face was quite free from the neuralgia, but the worst points were the temple and the cheek. It is unnecessary to mention the various remedies which had been used for the relief of the pain, as nothing seemed to have had the slightest beneficial effect. I now used the continuous galvanic current, applying at first the positive pole externally to the cheek and the temple, and the negative pole to the superior cervical ganglion. As this application, however, produced no perceptible effect, I introduced the next day an insulated metallic sound connected with the negative pole into the mouth, and touched with it the painful swelling in the mucous membrane of the cheek, the positive pole being alternately placed to the temple and the external surface of the cheek, altogether for five minutes. A current of ten cells was used. Immediately after the application was over, the patient exclaimed: 'That has done good!' The next morning he was in high spirits, as he had been quite free from pain during the remainder of the day, and had been able to masticate and eat his dinner without any trouble. He had had a good night, and it was only at breakfast that the pain had to some extent returned, although it was not nearly as bad as before. Within the next few days the patient had a bad attack of diarrhœa; nevertheless the pain remained in abeyance on masticating as well as on stooping. After the current had been applied a few more times, the inside of the cheek had become rather sore, and the treatment was therefore discontinued for a few days. The diarrhœa did not yield to the remedies used for it, and the patient consequently got very much below par; under these circumstances, about a fortnight after the commencement of the treatment, the pain returned much in the same manner as before. The patient then had another internal application, after which he was again much better. The next day, however, he was unfortunately seized by a bad attack of influenza, and the pain returned. When he had recovered from the influenza, he went to the seaside for change of air, and it appears that the neuralgia has since then continued in much the same manner as before. In this case galvanism was certainly used 'under difficulties;' as the patient had, during the time he was under the influence of it, two acute affections which interfered considerably with his general health; and I consider it highly probable that, if the galvanic treatment could have been continued for some time longer, and under more favourable circumstances, a cure would have been effected.

2. *Neuritis of the trifacial Nerve.*—In neuralgia of the trifacial, whether it be mild or epileptiform, there are no structural alterations of the nerve or its sheath evident to our senses, even if these are aided by the

microscope. There are, however, cases in many respects resembling neuralgia, but which are really due to neuritis, and in which the galvanism should be somewhat differently applied. We may distinguish neuralgia from neuritis chiefly by the difference in the sensitiveness of the patient to the galvanic current. In true neuralgia the patients actually relish the application of the continuous current, while in neuritis they dislike it. This is on the whole the most reliable diagnostic guide; yet we generally find that in cases of neuritis there are other symptoms besides the pain, viz., anæsthesia of the skin, tremor of muscles, and also local paralysis of certain muscles. In such cases the current used should be so gentle as to be hardly perceptible, and the length of application should under no circumstances exceed a minute, as long and powerful applications aggravate the symptoms. In epileptiform neuralgia, on the contrary, the current has generally to be used for about five minutes each time, and should be plainly felt by the patient.

3. *Headaches.*—There are few headaches which resist faradisation by the electric hand, or a gentle continuous current; but we should at the same time enquire into any derangement of the stomach or other organs which may be present, and which are so frequently instrumental in producing headaches. Yet many cases occur where a judicious medicinal treatment entirely fails in relieving the headache, and where this is promptly cured by electricity. I

have seen a large number of such cases, in which either of the above-mentioned methods of applying galvanism proved successful.

A frequent and peculiar form of headache is the *sick headache* (hemicrania). This generally resists not only medicinal treatment, but also faradisation by the electric hand; it yields however to the continuous current, applied through the mastoid processes and the temples.

4. *Photophobia.*—This troublesome symptom frequently accompanies diseases of the cornea and conjunctiva, and obliges the patients to keep their eyes closed. It often resists the ordinary treatment, but yields readily to the continuous current. Mr. Hewson has placed on record thirty-two cases of photophobia due to scrofulous inflammation of the cornea in children, which were all cured by the application of the continuous current. These children were between one and six years of age. The induced current made them worse, while from one to three applications of the continuous current completely relieved the affection. He placed the negative electrode to the supra-orbital foramen, and the positive to some part of the face. Other observers have obtained equally beneficial results.

CASE 60.—A married lady, aged 37, had suffered from glaucomatous inflammation of the left eye in the autumn of 1865. The cause of the affection was believed to have been rheumatic. She was seen by many oculists and physicians, and underwent iridectomy, but without much benefit. When I first saw her, in May, 1868, I found her highly hysterical; she often suffered from convulsive attacks, dizziness, palpitations of the heart, and pain in the epigastrium, back, and side. The most troublesome symptom, however, was intense photophobia, so that she would not leave her room, which had always to be kept dark. She was with some difficulty persuaded to have a gentle continuous current applied to the eye. The positive pole was placed on the closed eyelid and the left to the superior cervical ganglion. She felt much better after the first application, and after three more the photophobia was quite gone.

5. *Tinnitus aurium — noises in the head.*—The pathology of noises in the head consists at present, according to Mr. Hinton, of a few scraps of positive knowledge, with a great deal of conjecture. Mr. Hinton believes that this symptom has not any precise pathology in the sense of having any uniform cause, but that its pathology is like that of neuralgia. It generally appears as age advances, and is probably due to impaired nutrition of the fifth or the auditory nerve. I have found that it frequently yields to galvanisation, even when it has existed for many years. The current should be applied to the membrana tympani, and the cervical sympathetic, intermittently, with voltaic alternatives.

6. *Cervico-occipital Neuralgia.*—This occurs in the sphere of the occipital nerves, which arise from the upper four cervical nerves, and has the same pathology as tic. It is curable by galvanisation, but great care is necessary in using the current, as it may do harm if the application is too long or too strong, or if the treatment is too long continued.

CASE 61.—A lady, aged 49, had suffered from cervico-occipital neuralgia for the last twenty years when she came under my care (July 1869). No medicine had ever done her the least good, and the only thing which had for a time removed the pain was the actual cautery, which was applied by Mr. Paget in 1868. The pain, however, returned some time afterwards, and was now as bad as ever. The least touch 'drove her nearly wild,' and it was an 'agony' to have her hair dressed. I applied the continuous current to the occipital nerves continuatively for two minutes, with the effect that the pain was very nearly gone after the application; 'it seemed to have hardened her head;' she had a comfortable day and night, and the hair had been dressed without causing inconvenience. The current was now used several times more; but after the third application there was a considerable increase in the severity of the pain, together with great restlessness, sleeplessness, and general nervous disturbance. The treatment was therefore given up. In this case I believe that a cure might have been effected if only one or two applications had taken place; and I now make it a rule not to apply the current again when the pain has completely disappeared. It appears probable that in such cases the neuralgia is due to a faulty (peripolar or dipolar) arrangement of the electrical molecules of the nerve, which may be set right by one or two applications of the continuous current, but may be again disturbed by further applications, more especially in persons of such highly sensitive constitution as the patient whose case has just been described.

7. *Other forms of Neuralgia.*—Cases of *pain in the back* and of *inframammary pain* are generally curable by electricity. Inframammary pain is in some instances dependent upon incipient lateral curvature of the spine, but more frequently exists without any apparent structural lesion. It is generally felt below

the left mamma and at the margin of the ribs. I have seen a number of cases of this affection, some associated with amenorrhœa, others not. In those patients who suffered from amenorrhœa, the return of the catamenia and the disappearance of the pain were simultaneous.

Intercostal neuralgia likewise often yields to galvanisation or faradisation.

In the neuralgic stomach-ache (gastrodynia), which is to be traced to a functional derangement of the solar plexus of nerves, and where the pain is frequently confined to a small place on a level with the central ganglion, the continuous current is one of the most useful remedies at our disposal. The effect is, in most cases, immediate, and if the treatment be persevered in for some time, permanent.

Sciatica.—In sciatica, faradisation as well as galvanisation generally prove successful. It is sometimes advisable to combine them with subcutaneous injections of morphia and atropia.

CASE 62.—A Scotch farmer, aged 35, came under my care in July 1857. He had never been in strong health, and suffered for a long time from acidity in the stomach. Eight years ago he had his left thigh amputated for tumor albus, and he wears now an artificial leg, which, being very heavy, exerts a great strain upon the left side of the pelvis. Three years ago, he first began to feel pain on the back of the right thigh, and the inside of the leg, down to the ankle. The pain was at first dull and heavy, but after a time became so acute that the patient was laid up by it. He thought it was brought on by his having taken too much exercise. He did not suffer from violent attacks of pain followed by free intervals, but had no rest whatever. He placed himself under the care of two of the most eminent practitioners of Edinburgh, and after some time was much relieved, the acuteness of the pain slowly but gradually subsiding. He then left Edinburgh ; but being still very bad, acupuncture was resorted to, from which he received immediate relief, but the pain never entirely left him, and was much about the same shortly after the operation. About two years afterwards he came to Town and consulted Sir James Clark, who sent him to me. The pain was 'a dull ache' at that time ; it increased much on walking, even for a short distance, and in the first part of the night. Pressure had no marked influence upon the pain ; but it rather relieved than increased it. The muscles of the leg twitched a good deal in the morning, but not much in the course of the day ; these twitches were quite painless, and no doubt due to mal-nutrition of the limb. I used faradisation of the skin, by wire brushes, but as two such applications produced no effect, I applied the next day moistened electrodes, placing the positive one to the tuberosity of the ischium, and the negative to the ankle for six minutes. Immediately after this application the pain was quite gone ; it returned three hours after the operation, but was not nearly so severe as it had been before, and the patient had a very good night's rest. I repeated the operation three times more ; after the second, the pain went away till the following morning ; and, after the fourth, it was only slightly felt in walking, but not while in a quiescent position. The patient was then obliged to leave Town, and six weeks afterwards I received a note from him stating, that since faradisation was used, the limb had been a good deal better. He was, however, not totally free from pain when he walked to any distance ; yet the pain went off sooner, was less severe, and not so liable to return as formerly. I therefore advised him to undergo another course of the same treatment. This the patient did some time afterwards. Faradisation was used six times more as above, and with such beneficial effects that he was no longer in pain, even when walking three or four miles at a time.

CASE 63.—A retired general officer, aged 50, came under my care in October 1867. With the exception of a bad attack of dysentery, which he had had in China about twenty years ago, he had always been in good health until about eighteen months ago, when he got wet through and was unable to change his clothes for some time. The next day a severe attack of sciatica came on in the left leg, which was treated by leeches and blue pill. About a month afterwards he was able to leave his bed, but the pain had continued ever since. It increased on walking, and was very troublesome at night. Both thigh and leg were considerably wasted, there being a difference of two inches in the thigh, and three-quarters of an inch in the leg, compared to that of the other side. His weight had also considerably diminished, being more than a stone less than before. There was incomplete anæsthesia of the skin from the hip downwards. The sense of temperature was considerably diminished, and there were fibrillary twitches in the muscles of the leg. Digestion was impaired and costiveness habitual. There was an excess of urates in the urine and the expulsive power of the bladder had become somewhat diminished. The patient often suffered from headache and restlessness at night. The pain was most severe about the incisura ischii and the knee-joint; but it was also bad in the calf of the leg, especially after attempting to walk. I prescribed Vichy water for correcting the excess of acidity and applied the positive pole of the continuous current of 30 cells continuatively, by means of a conductor of large surface (three inches' diameter) to those points of the nerve which were painful on pressure, the negative pole being placed in the neighbourhood. The wasted muscles were afterwards faradised. The pain was considerably less after the first application, and completely disappeared after six. The current was now employed intermittently for relieving the anæsthesia, and faradisation was continued. Within a month the thigh and leg had recovered their usual bulk; the patient was again able to take regular walking exercise, digestion was improved, and the excess of urates had disappeared from the urine. The patient called upon me in February 1869, and informed me that he had been quite well ever since.

I conclude this section with a case of diffuse neuralgia, which was remarkable for its cause and rapid cure.

CASE 64.—A merchant, aged 30, of vigorous constitution, and active habits, was a passenger by the Canadian steamer, which foundered at sea on the 4th of June, 1861, about 200 miles off the coast of Canada. Many of the passengers were drowned; but this gentleman, by means of a life-buoy, was enabled to float until, three-quarters of an hour afterwards, he was picked up by a boat which was passing. Life was then almost extinct. The water was at the time excessively cold, as large masses of ice were floating in it. The patient, however, soon rallied; but unfortunately he had to remain in his wet clothes for a considerable time; and, even when he landed, he could not at once obtain a change of dress. He did not at first experience any bad effects from this accident; but, after some time, he began to feel severe burning pain in the arms and legs; and when the pain subsided, he perceived numbness in the limbs and loss of muscular power. He soon afterwards returned to England, and was, during his passage, subjected to treatment by the ship-surgeon, who prescribed anodyne applications of opium and aconite to the arms, and general tonics; but he derived no benefit whatever from the remedies used. On his arrival in this country, he consulted Mr. Snape, of Bolton-le-Moors in Lancashire, who thought that faradisation would be the best means of restoring him, and sent him to me. On examination, I found the following morbid symptoms:—1st, as regards the sentient nerves: there was a burning neuralgic pain, especially in the fore-arms and thighs, which increased very much towards evening and in the night; so that the patient was prevented from sleeping, and in consequence became much exhausted in the morning. There was also anæsthesia, especially in the right hand and fore-arm, where the prick of a pin could not be felt; while, on other parts, it was only obtusely felt, and not as a prick, but as a mere touch. The sense of touch, especially in the right hand, was much diminished. Finally, there was a semi-paralytic condition of the arms; the patient could move them, but he had no power over the muscles; he could not grasp anything with force, and experienced great difficulty in writing. The contractility of the muscles was not diminished, as they answered readily to an electric current of moderate power, only the influence of volition over them had considerably decreased. The flexor muscles of the fore-arm were most affected. The general health of the patient was good, notwithstanding the loss of rest, and the wear and tear consequent upon great suffering. I used faradisation of the skin and the suffering muscles, with excellent results. The pain, which was very severe at the time the patient came to me, disappeared during the first application; and he slept soundly the following night. The pain returned in the morning, although in a less degree; and, after a few more applications it was entirely subdued. The anæsthesia also yielded rapidly to the means employed. After three operations, the patient was again able to feel distinctly, not only the prick of a pin, wherever I applied it, but also the mere touch of blunt instruments; and when he left town, after having been under my care for six days, he was quite free from pain, the anæsthesia was gone, the sense of touch was again normal, and the muscular power had returned. I have not seen him since; but Mr. Snape has written to me to say that the effects of the treatment have been permanent; and that the patient returned to Canada some time afterwards in perfect health.

VI.—PROGRESSIVE LOCOMOTOR ATAXY.

Sufficient evidence has now been brought together for enabling us to say that nitrate of silver, especially when given in combination with some preparation of phosphorus, has curative effects in many cases of progressive locomotor ataxy. But where these remedies should fail, or be slow in their action, galvanisation should be employed. Recent cases of the affection are often cured by the continuous current, while such of old standing only receive temporary benefit from its use. Galvanisation may be often usefully combined with a gentle hydrotherapeutic treatment.

The following case of ataxy occurred in Benedict's practice:—

An artisan, aged 39, who had exceeded in drinking and sexual intercourse, was, five years before he came under treatment, seized with lancinating pains, and soon afterwards with weakness in the legs. All four extremities were numb, and there were frequent involuntary evacuations of the urine and fæces. He had the feeling of a tight band round the stomach. He was admitted into Oppolzer's Clinique in February 1863. He could not then stand for one instant with his eyes closed without falling; on turning round he staggered. Going up and down stairs was very difficult. The memory was bad; there was double vision, owing to weakness of the right rectus externus muscle; the lower portion of the dorsal spine was sensitive to pressure; he suffered from spasms and vertigo.

The patient was treated with the cord- and cord-nerve-current, and was, three months after the commencement of the treatment, quite free from every symptom of ataxy.

Onimus,* who has likewise obtained good results from the galvanic treatment of ataxy, lays stress upon the necessity of using an inverse current to the spine, and to omit galvanisation of the extremities altogether. As the natural tendency of ataxy is to travel upwards in the spinal cord, the proposition of Onimus appears judicious. I have however found that where the affection is confined to the lower portion of the cord, the direct current answers equally well as the inverse, and in some cases even better.

VII.—SPINAL WEAKNESS.

Atony of the spinal cord not unfrequently occurs without any structural disease, and is often not recognised, because many medical practitioners look upon the complaints of these patients as the mere offspring of a disordered imagination, and, therefore, class them under the convenient name of hypochondriasis, in the male sex; and of hysteria, if occurring in women. The illness of such patients, however, is not imaginary, but real, and they suffer quite as much as if they were affected by some organic disease. One form of spinal weakness has, as chief symptoms, weakness and irritability of the nervous system (commonly called nervousness), together with

* Gazette des Hôpitaux, 1868. No. 116--118.

imperfect digestion, and increased elimination of urea by the urine. Of this form, which I have reason to believe to be very frequent, the following is a good example :—

Case 65.—F. S., aged 42, a gentleman actively engaged in speculative business, had to do unusually hard work, and to undergo considerable anxiety during the autumn of 1865. He had felt nervous and irritable for a long time previous to this; but the first symptom of real illness which supervened was sleeplessness, which commenced in November 1865, and gradually got worse until March 1866. He either did not go to sleep at all on getting into bed, or if he dropped asleep from utter weariness, he woke up again in about half an hour, and lay restless during the remainder of the night. Besides this he complained of a feeling of great exhaustion, total disinclination to work, and to bodily exercise of any kind; of weakness in the back, and pain at the nape of the neck. He was easily excited and worried by little things, and extremely intolerant of noise, or of being asked any questions. He was frequently troubled with a sense of vague alarm, and distressing sensations in the head. He disliked his meals, and generally suffered from heaviness on the chest, flatulence and acidity, which seemed to be quite independent upon the quality or quantity of the food taken, and which came on chiefly after mental emotions or excitement. He was also much inconvenienced by frequent calls to pass the urine, especially in the morning, after breakfast. The analysis of the urine showed at once the nature of the morbid condition, as I found it to contain a considerable excess of urea. I now examined the urine daily for some time, and found that this excess of urea was not accidental, but constant. The body-weight of the patient was eleven stone three pounds, and the daily quantity of urea excreted by him should therefore have been about 550 grains. It was, however, continually several hundred grains in excess of this, as shown in the following table :—

Date	Number of Fluid Ounces of Urine passed in 24 Hours	Specific Gravity of Urine	Quantity of Urea in Grains	Morbid Excess of Urea in Grains	Treatment
March					
17	58	1027	808	258	
18	not noted	not noted	not noted	not noted	
19	,,	,,	,,	,,	
20	56	1027	780	230	Galvanism
21	52	1027	724	174	
22	57½	1027	801	251	Galvanism
23	46	1026	638	88	
24	52	1026	721	171	
25	not noted	not noted	not noted	not noted	
26	57	1026	790	240	Galvanism
27	52	1025	718	168	
28	48	1025	662	112	Galvanism
29	47	1025	649	99	
30	49	1024	671	121	
31	44	1024	603	53	Galvanism
April					
1	not noted	not noted	not noted	not noted	
2	,,	,,	,,	,,	Galvanism
3	42	1023	557	7	
4	46	1023	611	61	Galvanism
5	43	1022	554	4	

This patient was treated with nothing but the application of the continuous galvanic current, as cord- and cord-nerve-root-current, with voltaic alternatives. The influence of each application in diminishing the excretion of urea is well shown in the table; and the improvement in the general health went *pari passu* with this. The patient had three hours' uninterrupted sleep after the first application of galvanism, and that most troublesome symptom, sleeplessness, which had resisted morphine, was soon entirely removed. After three weeks' treatment the patient felt like another man, being able to exert himself both mentally and bodily, to enjoy his meals, and to take an interest in the concerns of daily life.

The case just related, to which I might add many more, shows in a striking manner how much the functions of digestion and urinary secretion are under the influence of the nervous system. Patients of this class have no disease of the stomach or the kidneys, as they are often inclined to believe, but suffer from spinal weakness, a functional disorder of the spinal cord, which, in my opinion, consists chiefly of a deficiency or perversion of the current of animal electricity, which Professor Dubois-Reymond, of Berlin, has shown to pass through the cord in its normal condition. Dr. Ranke,* of Munich, has proved by experiments on frogs, that, if the current proper of the cord is deficient, these animals suffer from a morbid increase of reflex excitability, and are often in a miserable and wretched state of health. He also found that this morbid reflex excitability could be removed by the application to the cord of a continuous galvanic current. Even in healthy frogs, a sufficiently powerful current sent through the cord will, for the time being, completely inhibit reflex action, which is another proof of the fact that the mechanism of living ganglion cells is accessible to physical influences. The systemic current which, in the healthy animal, streams inversely through the cord, most probably constitutes a contrivance for the

* Zeitschrift für Biologie, 1867. Vol. ii. p. 398.

inhibition of reflex movements; and a pathological increase of reflex excitability is therefore probably dependent upon the diminution of the inverse current streaming through the cord.

I have observed that in patients suffering from nervousness, dyspepsia, and increased elimination of urea, the most effective treatment is the application of the cord- and cord-nerve-root-current. No doubt patients of this class often derive great benefit from rest, change of air, mineral acids, arsenic, nitrate of silver, and other nerve-tonics; yet in almost all cases which I have had under my care, some remedies of this kind had already been employed without much or any result; and I am satisfied that none of them equal in efficacy and quickness of effect, the continuous galvanic current. If applied in the manner described above, the current has no direct effect on the stomach, and yet it cures dyspepsia; it has no immediate action on the kidneys, and yet it checks the morbidly-increased elimination of urea; it has however a powerful influence on the molecular condition of the ganglion-cells of the spinal cord, and chiefly on the current of animal electricity to which I have just alluded. In strengthening this current, where it is weak; in correcting it where its direction may be perverted, it not only does away with the weakness and morbid excitability more immediately depending upon the pathological condition of the cord, but it also indirectly removes symptoms on the part of remote organs, such as the stomach and kidneys, which are due, not to a disease of their own structure, but to a perverted and diminished nervous supply, which prevents them from properly fulfilling their functions in the human economy.

Spinal weakness likewise occurs in young persons who have grown unusually fast; and is then generally associated with deficiency or imperfect assimilation of phosphorus in the system. It is, therefore, only natural that nervous and osseous matter, which cannot be properly formed without a plentiful supply and proper assimilation of phosphorus, should suffer under these circumstances. In the commencement of the complaint, I have found that an artificial supply of phosphorus is sufficient for a cure; but when the affection has lasted for some time, the continuous current should also be used, as it considerably accelerates recovery.

Case 66.—A young lady, aged 22, very tall and of sallow complexion, came under my care in February 1866. She had grown very rapidly, especially between her seventeenth and nineteenth year, and had been ailing ever since. All the symptoms were referable to imperfect nutrition of the spinal cord and osseous system, and had lately increased to such an extent as to cause her parents much uneasiness. Being of an impulsive and highly gifted nature, she would take a passionate interest in certain things, and devote many hours of hard work to mastering a subject which attracted her imagination; after which she would be completely exhausted and prostrated for days or weeks, and be unable to do anything whatever. She often suffered from excruciating pains in the lower part of the spine, especially on making a sudden movement. She was almost entirely incapacitated from taking any active exercise, partly by pain and partly by weakness. The bones were sore and tender, and there was an excess of phosphates in the urine. Her appetite was very fanciful, her digestion weak, and the bowels habitually costive. The catamenia were regular, but pale and scanty. She had already taken a great many medicines, amongst which was phosphoric acid in combination with iron. I prescribed phosphorus in the form of the hypophosphite of lime, and used the continuous current as cord- and cord-nerve-root-current three times a week for a month. The patient was, in about a fortnight from the commencement of the treatment, able to walk out and take active exercise. Her digestion gradually improved, the morbidly-increased elimination of phosphates by the urine was checked, the catamenia became of a healthy character, and the bones became less sensitive. She took the hypophosphite altogether for three months, after which she appeared perfectly well. She had become stouter, and could walk for miles without fatigue. The beneficial effects of galvanisation were very strikingly shown, inasmuch as at first the patient could only walk on those days when the galvanism had been applied, but not on the other days. The pain which she used to feel in the spine disappeared after two applications of the galvanism, a circumstance which could not be ascribed to the medicine she was taking, as this has a very slow and gradual action in the system, while the effect of galvanisation is generally immediate. This lady was married in June, 1867, and has continued in excellent health.

VIII.—BASEDOW'S DISEASE, EXOPHTHALMIC GOÎTRE, GRAVES'S DISEASE.

This disease, which occurs chiefly in female patients between twenty and thirty years of age, and the principal symptoms of which are palpitations of the heart, enlargement of the thyroid body, and exophthalmus, is probably always due to disease of the cervical sympathetic, resulting in granular disintegration of nervous matter, and proliferation of connective tissue. A purely medicinal treatment rarely does much good, and galvanisation of the sympathetic (p. 321) appears to be the most rational remedy for it. Dr. Wietfeld* and others have used it successfully in several cases, but a more extended trial of it appears requisite before we can form any definite notions about the actual value of the current in Basedow's disease.

IX.—PROGRESSIVE MUSCULAR ATROPHY, WASTING PALSY, CRUVEILHIER'S DISEASE.

The pathology of this affection is still unsettled, for while some physicians believe it to be a primary disease of the muscular substance, others look for its seat in the grey matter of the anterior columns of the cord, and some again accuse the cervical sympathetic. I hold the latter opinion, and therefore strongly advise to treat the complaint from the first by galvanisation of the cervical sympathetic.

There are two forms of this disease, the *partial* and the *general* form. The general form begins either in the upper or in the lower extremities, and, as it almost always spreads to the trunk, threatens life. The partial form is not usually fatal, but it may pass into the general form, and thus ultimately cause death; it begins either in the hand or in the shoulder, generally of the right side, and may

* Medical Times and Gazette, November 1868.

destroy many muscles of the upper extremity, while in the general form all the voluntary muscles throughout the body may suffer, with the exception only of those of the eyeball and of mastication.

When the disease begins in the hand, the muscles of the thumb are generally the first to become attacked; the thenar eminence becomes replaced by a flattened hollow space between the first and second metacarpal bones; afterwards the interossei and lumbricales and the hypothenar eminence become affected. From the hand the disease spreads to the fore-arm, the extensors of which are especially liable to become affected, so that the fingers are slightly bent; but the flexor muscles may also be destroyed, and in this case the two last phalanges cannot be bent, so that the patient is unable to grasp or seize anything with the hand. In other instances wasting palsy first invades the muscles of the shoulder, attacking with preference the trapezius, the serratus magnus, the rhomboidei, and other muscles which unite the scapula to the trunk; the scapula is consequently displaced and twisted round its axis, its upper angle is depressed by the weight of the arm, while its lower angle is raised, and projects one or two inches from the surface of the thorax. From the shoulder the disease spreads towards the arm, destroying the deltoid and biceps; owing to which the acromion and coracoid process become prominent under the skin, and serious functional disturbances follow. Although the patients generally learn in the course of time to manœuvre very cleverly, so as to compel muscles which have escaped destruction to do the work of those which are wasted, they are at last no longer able to raise the arm nor to bend the elbow-joint; they can neither dress nor feed themselves, and experience considerable difficulty in putting on a hat or drawing a handkerchief from the pocket. If the muscles of the lower extremities are attacked, walking becomes difficult; and at length paralysis follows. The muscles of the chest, chiefly the pectoralis major, become affected in their turn; the chest appears shrunk, especially beneath the collar-bones.

A certain sign that the disease will shortly prove fatal is destruction of the facial muscles; the physiognomy loses all expression; the saliva flows involuntarily; articulation becomes slow and difficult; and finally, the muscles of deglutition and the diaphragm lose their power. This generally closes the scene, as the slightest impediment to respiration which may supervene produces asphyxia.

No medicinal treatment appears to do the least good in progressive muscular atrophy, and it is exclusively to the continuous galvanic current that we have to look for the cure of the affection. Faradisation has been fairly tried during the last fifteen years by many observers, but has been found wanting, more especially in the general form of the disease; while, if the continuous current is used with perseverance, the patients may recover even after the disease has reduced them to utter helplessness. A local application of the current to the muscles is useless, and the cervical sympathetic only should be acted upon.

Dr. Neumann,* of Magdeburg, has published a most instructive case of this affection, which had proceeded to paralysis of all four extremities, and yet completely yielded to the use of the continuous current. The patient was a youth, aged 19, who had had the measles in July 1866, and, after recovering from them, had felt unable to do the same amount of physical work as before. He went on comparatively well, however, until he over-exerted himself considerably one day, after which symptoms of atrophy and paralysis supervened rapidly, the patient becoming completely paralysed within a month. He came under treatment in October 1866, when he could move neither his arms nor his legs. There were the usual fibrillary twitches, but no anæsthesia. The diagnosis was rendered certain by harpooning a piece of muscle, and ex-

* Berliner klinische Wochenschrift, September 14, 1868.

amining it microscopically, when the diameter of the muscular fibres appeared diminished; there were plenty of fat-globules of different size, and the transverse stripes were mostly gone. In December, 1866, the patient was not able to make any movement except to flex the fingers very slightly, to nod his head, to breathe, and to masticate and swallow his food. The expulsive power of the bladder and rectum remained normal. Electro-muscular contractility was considerably diminished, but the appetite, digestion, and sleep were excellent.

At first the induced current was applied to the muscles, but as the patient got worse under its use, the continuous current of twenty cells of Daniell's battery was directed to the sympathetic, the positive pole being on the neck, and the negative on the throat, five minutes to each side, for three months every day, and then the negative pole was applied to the upper cervical ganglion, and the positive to the lower ganglion, likewise for five minutes each time. After a week's treatment he felt more power in the extremities; and in a few weeks more a real increase of power could be ascertained, at first in the legs, and then in the arms. In May, 1867, he could walk, although still in an awkward manner. In September, 1867, the muscles were again examined, and still found in a state of fatty degeneration. In October, 1867, the patient could put a piece of bread in his mouth. From January, 1868, the improvement began to progress rapidly, and in April the galvanism was discontinued. In May the muscles were again examined; it was found that the transverse stripes had re-appeared, and that there were only very few oil-globules, but that the transverse stripes were not yet quite so distinct as they were in health. The intra-muscular nerves were found perfectly healthy.

This case was remarkable by its rapid progress, as the disease became fully developed in two and a half months, the paralysis being proportionate in degree to the atrophy, and both corresponding in extent to the degree of electro-muscular contractility. The fact that the peripheral nerves were found healthy, speaks against the origin of the disease in the brain, cord, or spinal nerves, while the result of the treatment supports the view that progressive muscular atrophy is a disease of the sympathetic system of nerves.

X.—DIABETES.

Whatever may be the nature and causation of diabetes, there can be no doubt that the parts forming the floor of the fourth ventricle, and more particularly the roots of the pneumogastric nerve, play a considerable part in its production and continuance. It is likewise certain that the continuous galvanic current, when applied to the pneumogastric, is transmitted to the floor of the fourth ventricle, and galvanisation of the vagus seems therefore to be a rational remedy for diabetes.

Signor Mariano Semmola* has found that electrisation of the vagus, both by the continuous and induced current, causes, in diabetic patients, constantly a diminution of the quantity of sugar excreted, and sometimes also of the quantity of the urine. The effects of the proceeding are either temporary or permanent, and may lead to a cure. In those cases in which the effects are permanent, he believes the diabetes to be an idiopathic neurosis; but where they are temporary he suspects the presence of structural lesions in the fourth ventricle.

* Comptes rendus, 1861. Vol. liii. p. 399.

XI.—RHEUMATISM AND SEROUS EFFUSIONS.

In acute and chronic rheumatism of the muscles, both faradisation and galvanisation, when properly employed, are invaluable remedies. I have frequently cured cases of very long standing, and in which the patients themselves had almost despaired of a cure, by one or two applications. Rheumatic effusions in the joints are likewise amenable to faradisation, which must in this instance be continued somewhat longer than is necessary for the relief of muscular rheumatism. If, however, the effusions are considerable, galvanisation is preferable to faradisation; and both remedies may be used together, if muscular contractions are present. These contractions, which frequently resist a purely medicinal treatment, are readily cured by a proper use of the continuous and induced current.

CASE 67.—T. C., a musician, aged 31, had, during a tour in Scotland, in the summer of 1859, contracted severe rheumatism in the right shoulder and arm, which prevented him from following his occupation. He had followed various courses of treatment, and taken large quantities of nitre, bicarbonate of soda, iodide of potassium, and guajac. The pain was relieved after a time, but it never entirely left him, and a considerable contraction of the flexor muscles, both of the arm and fore-arm, remained, for which all remedies proved useless. He consulted me in September, 1861, when I found the arm in the following condition:— There was a certain degree of anæsthesia in the arm, for the patient did not feel the prick of a pin, nor could he distinguish the two points of the æsthesiometer when held at the usual distance. He complained of a dull aching pain, which at times became acute, and was very severe when he got into bed. The fingers were very numb. The biceps and brachialis internus muscles were so contracted that the arm was flexed in an angle of about 65°, and could not be extended; the flexor digitorum communis was also rigid, although in a less considerable degree, and the interossei and lumbricals were so much wasted, that the hand was nearly useless. The bulk of both arm and fore-arm was considerably diminished, being only ten and a half inches at a point eight inches downwards from the acromion, and only nine inches at a point three inches downwards from the olecranon; the corresponding numbers for the left arm being thirteen and ten and a quarter. The general health of the patient was tolerably good, but the appetite was indifferent, and the urine was loaded with urates. I prescribed Vichy water to be taken internally, and faradisation and galvanisation of the right arm. The result of this treatment was most satisfactory. In the course of a week the pain disappeared. Soon afterwards, the rigidity of the muscles began to subside, sensation was re-established, and the right arm increased so much in bulk, that after three weeks it equalled the left. In the meantime the urine had, by the use of Vichy water, become quite clear, and the appetite was much better. The interossei and lumbrical muscles were most stubborn, and only showed signs of improvement at the end of the third week. They then rapidly regained power, and when the patient discontinued the treatment, after having been under my care for five weeks, he was in every respect in excellent health, and able to resume his avocation.

CASE 68.—*Rheumatism in the Shoulder.*

Dr. T., aged 47, had been a sufferer from rheumatism in the left shoulder for more than seven years, when he came under my care (1857). He had tried almost every means for the relief of the pain, which, especially in autumn and winter, became very troublesome; he had also used galvanism, applied in the old-fashioned way of sending the current through both arms, but without any beneficial effect. Faradisation of the skin was resorted to, and, after two operations, the pain was gone and has not since returned.

Case 69.—*Rheumatism in the Knee-joint.*

An officer, aged 34, came under my care in February 1867. He had been a long time in India, and had for the last three or four years severely suffered from rheumatism in the knee. Six months ago he had a course of the waters of Aix-la-Chapelle, which, however, did him no good; and a large number of other remedies both internal and external had been used and found wanting. The right knee-joint was somewhat enlarged, and there was incomplete anæsthesia in front of the joint. The positive pole of forty-five cells was applied to the knee for five minutes, the negative pole being placed alternately to the thigh and the leg. After the first application the pain went away completely for six hours, and after the second the patient remained free from pain for a whole day. The applications were continued every other day, and after the patient had been under my treatment for a month, he had completely recovered.

Rheumatic gout yields to the continuous current, but the treatment must be persevered with for a considerable time.

Hydrarthrosis.—M. Van Holzbeck has recorded two cases of dropsy of the knee-joint, which were cured by him with electro-puncture. He put two needles in the sac, connected them with the poles of an induction machine, and sent the current through the knee for a quarter of an hour. The effusion was at once diminished, and next morning the swelling had disappeared. He now put a bandage on, repeated the operation once more, and in a few days the cure was complete and permanent.

In mild cases the external application of the continuous current is sufficient; while in severe cases either farado-puncture or the electrolytic treatment is preferable. The magneto-electric current is, in this disease, more effective than the electro-magnetic.

M. Tripier * has published a case of hydrarthrosis of the knee, of six weeks' duration, in which there was considerable effusion in the joint. A continuous current of forty-four small cells of protosulphate of mercury was applied by large moistened electrodes to the sides of the knee, for twenty minutes. After two such applications the liquid had disappeared.

Dr. Lange † has recorded the following case of *œdematous swelling of the feet*, which was cured by the continuous current:—

A printer, aged 32, complained, after a long walk, of a burning sensation in both feet. Being obliged to work in a standing position, severe pain at last came on, and the joints became so swollen as to be twice their usual size. He used Russian baths, local vapour baths, blisters, colchicum, iron, quinine, and iodide of potassium, without much benefit. He could only walk by the aid of two sticks. He continued in this state for three years. The joints were then still double their normal size; they were tender and stiff. The general health was tolerably good. A continuous current of thirty cells was now sent for twenty

* Manuel d'Électrothérapie, p. 282. Paris, 1861.
† Deutsche Klinik, Mai 9, 1868.

minutes continuatively through the left foot. The next day the foot was less painful, and the patient could step out more easily. Each foot was now galvanised for fifteen minutes at a time, and intermittent galvanisation of the muscles of the leg combined with it. A rapid improvement followed. The pain and swelling diminished from day to day; after ten days the joints were freely movable. After three weeks the swelling and pain were entirely gone, and the patient could walk quite as well as before.

XII.—DISEASES OF THE EYE.

I have already spoken of the electric treatment of paralysis of the motor nerves and muscles of the eye (p. 492), of amblyopia, amaurosis, and weakness of sight (p. 534), and of photophobia (p. 562). A few words now remain to be said on the use of electricity in opacities of the cornea, and in cataract.

1. *Opacities of the cornea.*—The slighter kinds of opacities, which are termed *nebulæ*, yield readily to the application of the continuous current, while thick opacities (*leucoma*) are more obstinate. These are due to more or less severe inflammatory changes in the corneal and epithelial cells. Opacities which are due to cicatricial hardening are incurable. A host of local remedies has been recommended for the cure of opacities, and amongst them electricity. In 1844, Signor Isiglio, of Corfu, treated some cases successfully with it. Signor Quadri, of Naples, M. Willebrand, of Helsingfors, and Dr. Türck, of Strasbourg, followed in his steps, and Prof. A. Von Graefe states, that in a case where both corneæ were

opaque, he employed electricity on one eye, and nitrate of silver or laudanum on the other, and that electricity was more rapidly successful than the chemical irritants. Mr. Soelberg Wells * says that electricity was formerly in vogue for the cure of these affections, but has now fallen into disuse. No doubt there are many other means by which these opacities may be removed; but I am inclined to think that electricity is in some cases more useful than chemical or mechanical irritation. The treatment of opacities by the induced current is no doubt tedious, but the continuous current is more rapidly successful; and it is well known that oculists have not yet given a fair trial to the continuous current in this affection. It may be applied, either to the closed eyelid, by means of a moistened sponge, or by a blunt gilt or silver conductor directly to the cornea. In the latter instance a very gentle current should be used, and the application must be short. Where the current is applied externally, the operation may be longer and stronger.

CASE 70.—H. T., aged 19, received in May, 1862, a violent blow on the left temple from a cricket-ball. He was at first quite stunned, and felt great pain in the head for several days afterwards. The conjunctiva and cornea of the left eye then became inflamed, for which the patient was put on a course of mercury; but although his system was much affected by that drug, the eye did not get better. Mercury was therefore given up after a time, and other treatment resorted to. The inflammation gradually sub-

* Loc. cit. p. 126.

sided, but a considerable opacity remained, which covered the whole extent of the cornea, and was thickest in the lower portion of that membrane. Vision was almost entirely prevented by it. Mr. White Cooper, whom the patient consulted in July, 1862, thought that electricity would be the best means of promoting the absorption of the opacity, and sent him to me. I combined faradisation with galvanisation, the negative pole being directed to the closed eye, and the positive to the temple, so as to stimulate the influence of the first branch of the trigeminal nerve upon the nutritive processes in the eye. The patient quickly improved under this treatment; and when he discontinued it, after having had twenty-four applications, there only remained a very thin film on the cornea, which was but perceptible on close examination, and impeded vision scarcely at all. A complete cure would probably have resulted, if the patient, who did not live in Town, had been able to pursue the treatment a little longer.

2. *Cataract.*—Crussel and Lerche * have made some experiments on the dissolution of cataract by the aid of electricity. They found that if the zinc pole of a voltaic pile is applied to a lens, this is rendered opaque; and that the opacity disappears if the copper pole is afterwards directed to it. Hence they concluded that it might be possible to dissolve cataract by the application of the negative pole of the pile to the eye. Matteucci † asserts that cataract cannot be dissolved by electricity; but we have the authority of Dr. A. von Graefe ‡ for the contrary. A few cases of cataract have been treated by Crussel

* Medizinische Zeitung des Vereins etc. 1841.

† Cours d'Électrophysiologie. Paris, 1858.

‡ Deutsche Klinik, 1852, p. 445.

with galvano-puncture, but the operation was followed by inflammation of the chorioidea, iris, and retina, and destruction of the eyeball, and is therefore unjustifiable.

XIII.—DISEASES OF THE RESPIRATORY ORGANS.

1. *Ozæna.*—In cases of ozæna which resist a constitutional treatment, and washing out the cavity of the nose, a combination of electrolysis with faradisation may be usefully employed. By electrolysis the clots of congealed mucus which plug up the nostrils are melted and removed, while faradisation affords a healthy stimulus to the mucous membrane, and enables it to return to its normal condition. Constitutional remedies, however, should not be neglected while the electricity is being used.

2. *Pleuritic effusions and empyema.*—Serous effusions may, as a rule, be cured by anything that causes an alteration in the secernent function of the serous membranes. It may therefore be supposed that electrolysis (p. 334), which can effect such an alteration mechanically by the hydrogen which is developed, chemically by the free alkali which appears at the negative pole, and dynamically by its special action on the vasomotor nerves, will in course of time prove of the greatest value in obstinate pleuritic effusions. Whatever may be said by the supporters of the operation of paracentesis of the thorax for pleuritic effusions and empyema, it is certain that

the profession, as a whole, look with considerable distrust upon that proceeding. It cannot be denied that the sudden withdrawal of a large quantity of fluid sometimes induces collapse, and the introduction of air into the pleural cavity is also frequent enough. Moreover, suppuration generally takes place after the operation, and the patient may sink from exhaustion and pyæmia. I may perhaps be allowed to recall here the remarks made ten years ago on this operation by a great master, the late Dr. Addison,* who had, from the numerous cases seen every year at Guy's Hospital, come to the conclusion that paracentesis of the thorax was one of the worst and most deceiving operations in general practice. 'A serous cavity' (Dr. Addison said) 'is almost invariably changed into a cavity pouring out purulent matter by the first operation, and the thick leatherlike false membranes lining the pleura soon make the operation one of great difficulty and danger.' I therefore hope that the electrolytic treatment of these effusions will soon be carried into practice.

XIV.—DISEASES OF THE DIGESTIVE ORGANS.

I have already spoken of the galvanic treatment of loss of taste (p. 539), and difficulty of swallowing (p. 506); and now proceed to mention some other affections of the digestive tract in which an electric treatment may be of service.

* The Lancet, November 17, 1855.

1. *Stricture of the œsophagus.*—This disease has hitherto offered insuperable impediments to other remedies, and generally led its victims through a terrible series of sufferings to death from starvation. I hope that in such cases electrolysis may eventually prove successful. The instrument described on p. 389 should be introduced to the seat of the stricture, and be connected with the negative pole of the battery, while the positive electrode may be placed on the chest or the back. Five minutes would probably suffice to destroy a stricture of moderate size. From twenty to thirty cells should be used.

2. *Dyspepsia.*—In most forms of dyspepsia faradisation of the stomach and intestines, and galvanisation of the cervical sympathetic, are useful, but more especially in that form which is called 'nervous indigestion.' A special form of dyspepsia, which is connected with increased elimination of urea, has already been considered (p. 572).

A bad case of indigestion owing to over-eating, and successfully treated by faradisation, has been recorded by M. Bonnet:—

He was called to see a girl who had eaten an enormous quantity of figs, and became convulsed the night after. Her pupils were dilated, the pulse small and rapid, the jaws firmly clenched, the abdomen hard and full, and consciousness lost. Cold fomentations to the head and three purgative enemas had produced no effect. M. Bonnet then introduced the positive electrode of an induction apparatus into the rectum, and placed the negative on the abdomen. The muscles of the abdominal parietes immediately began to contract; after two or three minutes the positive electrode was hurled out of the rectum, together with an enormous quantity of undigested figs and fæcal matter. The girl at once recovered her consciousness, and was quite well on the following day.

3. *Vomiting.*—Obstinate vomiting, from whatever cause, is often promptly relieved by faradisation.

M. Popper * has published the case of a girl who had for a long time suffered from vomiting immediately after her meals, and was likewise troubled with meteorism. The abdomen was extremely sensitive to pressure, and the bowels habitually costive. After a great many remedies had been used without avail, M. Popper resorted to faradisation, placing both electrodes on the stomach, and keeping up the action for five minutes. The girl was then allowed to eat, and retained her food. Twelve more applications were made and a complete cure effected.

4. *Sea-sickness.*—Although sea-sickness is probably a disorder of the nervous system, it may find a place here, on account of its principal symptom being sickness and vomiting.

Dr. Dwinelle † has given an account of M. Le Coniat's mode of treating sea-sickness by faradisation of the stomach. He first applies a solution of sulphate of atropine (a grain to the ounce) over the skin of the stomach; but it is not said how this solution is applied, or how much of it is used. After this he puts the negative electrode of an induction apparatus terminating in a flat disc, over the skin corresponding to the pyloric end of the stomach; and he then passes the positive electrode terminating in a moist sponge,

* Oester. Zeitschrift für practische Heilkunde, 1865, p. 365.

† New York Medical Journal, 1869, p. 390.

across the skin from the cardiac to the pyloric orifice, when the muscles are seen to contract vigorously. The effects are soothing and refreshing, and generally accompanied with drowsiness, followed by refreshing sleep. M. Le Coniat claims to cure by this proceeding, at least ninety per cent. of the patients suffering from sea-sickness; and believes himself able to control the vomiting and sickness of pregnancy by the same. Dr. Dwinelle mentions the case of a lady, who crossed over from Brest to New York, and who suffered from the worst form of sickness, the vomiting and violent retching having, on the second day, been followed by convulsions and extreme prostration. By one application of atropine and electricity the sickness was completely arrested; the lady began to eat with a relish, and kept perfectly well until her arrival at New York. Most of the passengers by the same steamer suffered from sea-sickness, and were completely freed from it by one or two applications. M. Le Coniat's theory is, that sea-sickness is induced by electric disturbance throughout the system, and that faradisation reverses the abnormal condition, and restores the electric equilibrium. The atropine is probably quite ineffective, as no mention is made of subcutaneous injection, and the unbroken skin would not absorb the solution.

5. *Constipation.*—In cases of constipation caused by insufficient peristaltic motion of the contractile fibre-cells of the intestines, and by loss of power in the abdominal muscles, electricity may be very useful, especially if the affection occurs after protracted diarrhœa and the abuse of aperient medicines. In such cases a total abstinence of laxative medicines is generally imperative, and even simple enemata sometimes do mischief; on the contrary, by faradisation powerful peristaltic movements of the intestines may

be induced, and more tone be given to the mucous and muscular coat of the alimentary canal.

CASE 71.—An unmarried lady, age 43, tall, of sallow complexion and sedentary habits, consulted me in February, 1866, for a 'nervous affection,' from which she had suffered for many months past. She complained of a constant dull headache, of giddiness on rising in the morning, a wearying feeling of mental depression, and frequent flushings of the face and ears. Her hands and feet were habitually cold. Her sleep was unrefreshing, being disturbed by unpleasant dreams; and too short, for she slept on the average only two or three hours a night. Her intellect and memory were as good as ever, but she found it difficult to fix her attention on any subject, and felt a distressing sensation of pressure on the head after reading or writing. The latter circumstance annoyed her a good deal, as she had been a zealous supporter of various philanthropic undertakings which required a considerable amount of correspondence. She was sometimes troubled with palpitations of the heart: the heart's sounds were weak; the pulse small and feeble. The breath was generally short; the chest otherwise healthy. The tongue was dry, and covered with a yellowish white coat. The appetite was feeble, and digestion tedious and painful. For many years past the patient had suffered from obstinate constipation, for which she habitually took purgatives. If she attempted to do without any, she felt great pelvic distress, especially in walking and standing, and considerable increase of all the head symptoms. She had chiefly taken cremor tartari, aloes, nux vomica, colocynth, scammony, and podophyllin. The evacuations were hard and ill-formed. The urine was generally scanty and turbid, and she had often a scalding sensation in passing it. She had a small fibroid tumour of the uterus, for which she had consulted several obstetric physicians, who had advised that it should be let alone. At the time of the catamenia her sufferings increased very much indeed. Purgatives then seemed to augment the menstrual flow to an alarming extent; it often, in fact, amounted to true menorrhagia, which lasted for ten or twelve days. She therefore generally took much smaller doses of purgatives during that time; with the effect that the loss of blood was not so copious, while, on the other hand, the pain and discomfort about her head were so dreadful that she often thought she would lose her senses. Her habitual dose of purgatives was now two teaspoonfuls of cream of tartar twice a day, and ten grains of compound colocynth pill at bed-time.

As she had lived too exclusively on meat diet, I ordered her to take boiled fruit and saccharine vegetables; to discontinue the cream of tartar entirely; to take five grains of compound colocynth pill at bed-time, and a tumblerful of Marienbad water twice during the day; and finally to take as much exercise in the open air as possible without fatigue.

February 25*th.*—Has found great relief from the change in her diet, and from the Marienbad water. Last period was more comfortable than it had been for many months past. Has not been able to take much exercise, because it brought on palpitations of the heart. Ordered to go on as before, but to take the colocynth pill only every other night.

March 18*th.*—Has been worse for the last week or ten days. The Marienbad water seems to have lost its effect. Has been obliged to take ten grains of colocynth pill daily for the last few nights. Head most uncomfortable; extreme depression of spirits. I now substituted Friedrichshall for Marienbad water, and allowed her to take five grains of colocynth pill every night.

April 20*th.*—The last period was just as bad as ever. The Friedrichshall water only relieves constipation when taken in large doses, which she believes to be lowering, and is ineffectual as soon as the dose is reduced. I now proposed to the patient the application of galvanism for inducing a healthier action of the bowels; and as she consented at once, I sent a current of moderate power for fifteen minutes through the intestines. The patient did not complain of any pain or discomfort from the application, but said she felt more exhilarated and hopeful than she had done for a long time.

24th.—She came to me in high spirits, saying that since the faradisation was used she had every day had a better motion than for many months past. I ordered her now to discontinue the colocynth pill entirely, and merely to take a wineglassful of Friedrichshall water twice a day.

From that time forward the patient made an uninterrupted recovery. Faradisation was continued twice a week for a month, after which neither medicines nor mineral waters nor the galvanic stimulus were any longer required. The head symptoms disappeared gradually in proportion as the action of the bowels was restored; and when I last saw the patient (July 1867) she was perfectly well, excepting the somewhat too copious menstruation, which was now the only trouble she experienced from the fibroid tumour of the uterus.

Case 72.—A hard-working merchant, aged 38, first consulted me in June 1865, for a troublesome form of dyspepsia, from which he had suffered for many years past. He complained of a feeling of heaviness and oppression after meals, especially after breakfast, coupled with eructations and flatus, which latter gave rise to acute pain until they were discharged. The bowels had been habitually costive since a journey the patient had undertaken to the west coast of Africa, in 1857, where he had suffered from a bad form of dysentery. Ever since that time he had been obliged to 'assist the bowels' with purgatives. He had also used enemata of various kinds, but the rectum seemed to resent them, and the patient had taken a great dislike to their use. The tongue was dry and furred. The patient had lost flesh lately, in consequence of being compelled to restrict his food to the smallest possible quantity. The urine was clear; the motions dark, hard and ill-formed.

I carefully regulated the diet, and prescribed a tumblerful of Eger water night and morning, and five grains of carbonate of bismuth twice a day after meals. Digestion and defæcation soon improved under this treatment, so that the patient was able to take more food than before, and he felt and looked much healthier and stronger than he had done for a considerable time past. About two months after I first saw him, business obliged him to return to Africa, and I did not see him again till March 1866, when he was very much worse than he had ever been before. He had been obliged in the interval to take strong purgatives habitually, for ensuring a sufficient action of the bowels. Indigestion and costiveness were now more troublesome than ever. The patient was emaciated and exhausted to the last degree. He was unable to do any work or take any exercise, and refused all nourishing food, so that his family were extremely alarmed about his condition. Under these circumstances, an energetically tonic plan of treatment appeared indispensable. I prescribed liquor arsenicalis, with vinum ferri, a dose of pancreatic emulsion in rum and milk twice a day, a compound rhubarb pill, with the twenty-fourth part of a grain of strychnia at bedtime, and faradisation of the bowel twice a week. Under the influence of this treatment the patient rallied wonderfully. The beneficial effects of faradisation in inducing a healthy action of the mucous and muscular coat of the bowel were well shown by the circumstance, that there was always a very good motion in the evening after the application of the electricity, while on those days where it was not applied the action was rather sluggish. At the end of a month the aperient pill was discontinued; the arsenic was taken for another fortnight, and the emulsion for a month more. Faradisation was discontinued at the end of three months, when digestion and defæcation were normal. Ever since that time the patient has been in good health, and taken no medicine whatever.

6. *Tympanites and flatulency.—Tympanitic distension of the abdomen* is owing to intestinal atony, and loss of power in the abdominal muscles; the intestines therefore meet with no resistance, and become considerably distended. This condition is frequently observed in hysterical women; after partaking of indigestible food; in acute diseases, especially typhus, pneumonia, small-pox, puerperal fever, peritonitis, &c. If the tympanites is very severe, it threatens life, as it may produce asphyxia by paralysis of the diaphragm, and compression of the lungs. A purely medicinal treatment often fails to relieve it, and faradisation or galvanisation should therefore be employed if the tympanites does not yield readily to other remedies.

Various methods of applying electricity have been resorted to. M. Becquerel has tried the effect of the induced current, placing the positive electrode in the mouth, and the negative in the rectum; and has never seen any benefit from it. This method is therefore not to be employed, as it is both inconvenient and useless. Dr. Cumming has proposed placing one electrode on the spine, and the other on the abdominal parietes, but the best way is faradisation or galvanisation of the rectum (p. 327 and 383).

CASE 73.—*Extreme meteorism after ovariotomy.*

A married woman, aged 37, mother of one healthy child, twenty-two months old, came from Aberdeen to London, in

April 1863, in order to consult Mr. Spencer Wells for a large ovarian tumour, which had begun to form in July 1862, and had rapidly increased after August of the same year. The patient had a dark and rather sallow complexion, and had become much emaciated during the last two months. The tongue was clean, the appetite pretty good, the bowels were naturally open, but she complained of troublesome flatulence. The breathing was only slightly affected; there was no cough and no expectoration. The catamenia had ceased in September, 1862. The pulse was at 120. The girth at the umbilical level was forty-nine inches. She had been tapped seven times, but had always refilled rapidly. Mr. Wells performed ovariotomy upon her on April 29. There were strong and extensive parietal adhesions, both anteriorly and laterally; thirty-three pints of fluid were removed, and the cyst and solid matter taken away weighed thirteen pounds thirteen ounces. Without going further into the details of the case, I will only say that the patient went on fairly, excepting the immense distension of the stomach and bowels by gas, which was so great as to threaten life. After the most efficacious medicines had been taken without improvement, Mr. Wells believed that faradisation was necessary, and requested me to see the patient. I saw her on May 18, when the flatulent distension was so great that the left lung was almost entirely compressed, the heart being dislodged to the right side, and there being tympanitic sound in the second intercostal space. I performed faradisation, after which the patient had a considerable discharge of flatus. On May 19, I repeated the operation, and the patient then had two motions, one of them solid. I operated upon her four times more, after which the lung had again expanded to its normal volume, and the patient being nearly well, I discontinued the treatment. On May 26 she went on board the steamer which was to sail the day following for Dundee. The patient died at home in the commencement of August from malignant disease, which had very rapidly formed; but both Mr. Spencer Wells and Sir William Jenner, who had also seen her, were of opinion that if she had not been faradised, she would have died in London from the effects of the meteorism.

Habitual Flatulency.

CASE 74.—A gentleman, aged 46, had dysentery fifteen years ago, and had ever since suffered from flatulency, which was extremely troublesome. He was otherwise in good health, but the flatulency never left him even for one day, and was so bad after meals, that he was obliged to lie down for an hour or two afterwards. The examination of the abdomen showed no tumour or obstruction, but merely a considerable accumulation of gas in the large intestines. He had used a great many remedies without success, especially charcoal and belladonna. I galvanised the bowel with a current of twenty-five cells, the positive pole being in the rectum, and the negative electrode being passed over the abdominal parietes. The patient felt very comfortable for some hours after the first application, and the flatulency only returned in the afternoon. After four more operations he passed a whole day without feeling troubled with flatulence; and after three weeks he was quite free from it.

7. *Incarcerated hernia.*

M. Delaux, of Toulouse, has described the case of a woman suffering from femoral hernia, and which became incarcerated after a violent exertion. She refused to consent to an operation. After three days, when she was rapidly getting worse, he first faradised the hernia itself, and afterwards put one electrode into the rectum, and the other upon the hernia. The tumour now began to move, and disappeared in a very short time. Within a few days the patient was perfectly well.

8. *Ileus, stenosis, volvulus, invagination, intussusception.*—Dr. Mac Cormac, of Belfast, has kindly sent me the particulars of the following cases of ileus which have been under his care, and which I give in that gentleman's own words :—

'The first case was that of a brewer. He had been three days ill of ileus, and was sinking rapidly. The pain was great, there was feculent vomiting, and I had tried, in large successive doses, vainly, calomel, compound extract of colocynth, castor oil, opium, turpentine, and linseed oil injections. The pulse was wretched, the expression of the countenance miserable, and the sufferer had been three days without any sustenance. It then occurred to me to resort to galvanism, which I did with the least possible delay. I stripped the patient, and applied the moistened negative pole or conductor to the spine, while I promenaded the other pole here and there over the abdominal surface, but preferably in the lines of the great intestines. The patient, who was standing all the time, winced a good deal. But after the lapse of from about two to three minutes, a sound of flatus in motion could be heard in the course of the tract of the great arch of the colon. The patient called out for the close stool, when he had an enormous evacuation of feculent matters with prompt and permanent relief. He had been previously under my care for an attack of hepatitis, and was of very indifferent stamina. I have not the slightest doubt that galvanism, in this instance, brought about the resolution of the disease, and by stimulating into normal activity the peristaltic action of the bowels, saved the patient's life.

'The second case was that of a very much younger man, but was otherwise, although not of so long standing, equally severe as the preceding case. The usual means were resorted to, both by Dr. Archibald Dunlop, under whose charge the patient was before I was called in, and by myself, but in vain. There was this additional feature of severity, too, that large quantities of blood were passed by stool, which, coupled with the ileus, was rapidly exhausting the patient's strength. In this conjuncture of affairs, I proposed galvanism, to which my colleague at once assented. It was very effectively resorted to, and in the course of the afternoon, not so speedily as in the first instance, though not less effectively, the patient evacuated a large amount of fæces with speedy relief and a lasting recovery.'

Dr. Clemens,* of Frankfort, recommends that in these cases one or two tablespoonsful of metallic mercury should be given, and a continuous current then sent through the abdomen; the negative electrode by means of a large conductor to be applied to that part of the abdomen where the seat of the obstruction is supposed to be, while the positive is in the rectum. Voltaic alternatives should be used, and the current closed and opened three or four times in one minute. The mercury accumulates at the seat of the volvulus, where therefore the effect of the galvanic discharge is more thoroughly experienced than in other parts of the intestinal canal. Dr. Clemens says that he has cured a case of invagination by this means; but Dr. Mac Cormac's cases show that electricity alone, without the mercury, is able to overcome this affection.

9. *Ascites.* Signor Solfanelli has recorded the case of a man, aged 50, who suffered from cirrhosis of the liver, and ascites; many remedies were employed for the ascites, but without result; the urine was very

* Deutsche Klinik, March 3, 1866.

scanty and œdema of the legs at last set in. Faradisation of the abdomen was now used, and after four such applications the ascites had disappeared.

The electrolytic treatment would appear preferable to faradisation in cases of ascites, and might prove curative in cases where the ascites is owing to weakness or malarial cachexia, and not to incurable disease of the heart, liver, or kidneys.

XV.—DISEASES OF THE ORGANS OF CIRCULATION.

1. *Diseases of the heart.* Dr. Fliess, of Berlin, has used galvanisation of the sympathetic and pneumogastric, for affording symptomatic relief in cases of valvular disease of the heart, and has been to a great extent successful. I have already mentioned Eulenburg and Schmidt's experiments (p. 254), which have shown that by galvanisation of the sympathetic the heart's action is powerfully influenced; and the proceeding therefore may be resorted to in those numerous cases of heart disease where the usual remedies fail to give relief to the sufferings of the patient.

2. *Diseases of the arteries.* Aneurism has been frequently treated by galvano-puncture, but although some favourable results have thereby been obtained, the number of failures is much larger than that of the successes, so that at present the operation of galvano-puncture is, by the best authorities, proclaimed to be an unsafe and unreliable proceeding.

Sir William Fergusson, in his 'Manual of Surgery,' curiously enough ignores it altogether. Mr. Erichsen condemns it in unqualified terms. Professor Pirrie remarks that 'the operation is founded on the principle of the galvanic current having the power of coagulating the blood; and that this principle is not sound, as stratified fibre is the substance by which we desire to solidify an aneurism, and not coagulated blood; that the proceeding is also very painful, and not unattended with danger, and the results are not encouraging.' Mr. Ernest Hart, in his article on aneurism in Holmes's 'System of Surgery,' says (Vol. III. p. 432), that galvano-puncture is inherently uncertain, liable to cause relapse by the melting of the coagulum, or inflammation by its too sudden deposition, and that it appears at present to deserve to rank only as an exceptional expedient, when the surgeon is called upon to treat either aneurisms at the root of the neck, or internal aneurism which cannot be reached by digital or mechanical compression, and some forms of varicose and cirsoid aneurism seated superficially.

M. Broca, and many other eminent foreign surgeons, entirely coincide in this view, and it may be said, therefore, that the proceeding has not established a footing in surgery; nor ought we to be surprised at this fact, since it is evident that the mode of applying galvano-puncture for aneurism has hitherto been faulty. If anything is well established in the pathology of aneurism, it is the fact, that clots, which have been rapidly produced and made to block up the sac, can be easily discussed or washed away by the current of blood; that they often give rise to consecutive inflammation, suppuration, and gangrene, and are unstable in the highest degree. These clots are red and soft, like currant jelly; they consist of coagulated albumen, fibrine, and blood-globules; while active clots are firm, tough, more or less devoid of colour, and consist merely of lamellated fibrine, resembling so many layers of differently-coloured chamois-leather. It is quite true that in a few cases quick coagulation has been followed by permanent consolidation. Such cases have occurred in the practice of M. Pétrequin and other surgeons; but on analysing these observations, we can have no doubt that in the cases which have thus turned out successful, there existed a peculiar condition of the blood highly favourable to the deposition of lamellated fibrine, and that this is so exceptional a circumstance as only to prove the rule, which is, that passive clots are rather prejudicial than otherwise. *Immediate coagulation should therefore be entirely eschewed,* instead of which we should endeavour to obtain a slow deposition of layers of fibrine, whereby the sac may be permanently obliterated. For this purpose it is necessary that circulation should be merely diminished and retarded, but not altogether interrupted in the sac. As soon as any deposition of fibrine has taken place, this has the tendency to attract fresh fibrine from the blood, whereby its bulk is gradually increased, until the whole sac is filled up. The wall of the aneurism is thus strengthened, and it is enabled to resist the action of the heart, until the time when the cavity is finally obliterated.

That this can be accomplished by electrolysis I am convinced from experiments on rabbits, in which I have by that means gradually obliterated the femoral artery. But there is also a curious case recorded in a recent treatise on medical electricity, by Dr. Frommhold, of Pesth, which bears out my assertion. This author, whose acquaintance with the physical aspects of electricity is very limited, thought to do the right thing, when having a case of aneurism to operate upon, by putting the positive electrode into the sac, and the negative one outside, in order to produce coagulation; but not knowing which was the positive and which the negative, as is evident from the details of his description, he used the negative where he meant to use the positive; and the proceeding proved entirely successful. There was no immediate coagulation; but the tumour gradually became harder after the operation, and it seems that the sac was at last completely obliterated.

'Where ignorance is bliss, 'tis folly to be wise.'

Dr. Frommhold's case is, for all that, not the less interesting, because it is the first case of aneurism which has been (although accidentally) cured by the negative pole, and thus goes far to prove the correctness of my principle, that it is to the use of this pole that we have to look for the cure of aneurism.

The gas that is developed in the aneurismal sac by the electrolytic process cannot prove dangerous, as it is intimately mixed with liquid, and moreover appears in excessively small bubbles, some of which have only a diameter of 0·005 millimètre.

Many observers think it of importance to protect the textures perforated by needles from the action of the galvanism by an insulating layer, as, in their opinion, otherwise inflammation and fatal consequences might follow. But this fear is evidently exaggerated, as, unless the application is very prolonged and very powerful, no such effects ever seem to occur. The difficulty of insulating the needles is very great. Sealing wax is totally useless, as it becomes semi-liquid at the temperature of the body, and is, as it were, peeled off from the needle by the skin, at the moment of introduction. Drs. Duncan and Fraser* have constructed a needle insulated with vulcanite, and which may be employed by timid operators. I believe a slight action on the skin in cases of this kind rather useful than otherwise, because it promotes shrinking of the sac, and likewise prevents hæmorrhage on removing the needles.

The pain of galvano-puncture has generally been described as excruciating; and Dr. Duncan has therefore in one of his cases placed the patient under the influence of chloroform during the operation. This however is not necessary, for the pain may be almost completely avoided by introducing the tumour gradu-

* Edinburgh Medical Journal, 1868, p. 115.

ally into the galvanic circuit. An operator who commences with the full galvanic power he intends to use, causes unnecessary suffering. The proper way to proceed is, first to apply the ether spray to the skin, and then to introduce the needles into the tumour, connecting them afterwards with the lowest galvanic power that is at hand. If the patient does not feel any galvanic sensation, the next degree should be had recourse to; and so on, until the full power is gradually reached.

With regard to cirsoid aneurism, the following words of Dr. Duncan * may be aptly quoted :—'For cirsoid aneurism electrolysis seems to be the safest, simplest, and most certain method of treatment. Ligature of large arteries, like the carotid, is extremely dangerous and has been singularly unsuccessful. Out of eighteen cases seven died and only two were permanently cured. The perchloride of iron, though it has been successfully injected, is also liable to failure, and has, moreover, certain well-known risks attending it. Extirpation, ligature and incision have been tried, but hold out little inducement to repeat them. Galvanism, however, has been successful in the only two cases in which it has been used, and though several operations were required in each, not the slightest accident happened in either.'

I now subjoin some cases of aneurism in which the application of the positive pole, or of both poles together, has proved successful :—

Dr. Duncan has treated the case of a cirsoid aneurism on the left side of the head of a labourer, aged 21, having the shape and size of the half of a large Jersey pear, and which

* Loc. cit. p. 110.

was cured by four applications. Both poles were put into the sac, the application lasted for twenty minutes each time, and was made with four cells of Bunsen's battery. Each operation produced a hard core in the tumour, whereby the latter was gradually obliterated.

Meyer * has given the details of a case of a male patient, aged 52, who suffered from an aneurisma racemosum of the left knee, which had gradually come on after an accident; there was distinct pulsation at different points of the patella, and the temperature was considerably increased. He introduced three needles, connected with the positive pole of the battery, into those places where pulsation was most marked, while the negative conductor was applied to the thigh. Twenty cells were used, and the needles left in the tumour for fifteen minutes. The operation was nearly painless, and no bleeding took place when the needles were removed. A digital compression of the femoral artery was then resorted to for twenty-four hours after the operation, and galvanopuncture repeated four times more at intervals of six or eight days, compression being again resorted to after each application. The pulsation in the tumour gradually became less and the clots in the interior of the tumour became so hard, that at last it was found extremely difficult to introduce the needles. A small abscess of the cellular tissue was formed at the lower portion of the patella, which had to be opened, but which healed within a week. The tumour shrank very considerably and only a small portion remained. The abscess might have probably have been prevented if, instead of the positive pole, the negative had been used for internal application.

Ciniselli † has recorded a case of aneurism of the descending aorta cured by galvanopuncture. The patient, aged 46, had a round, pulsating tumour on the right side of

* Loc. cit. p. 398.

† Gazette des Hôpitaux, 1868, No. 134.

the sternum, in the third intercostal space; it was six centimètres wide and almost equally long, and was elevated about one and a half centimètres above the level of the walls of the thorax. Ciniselli believed it to be an aneurism of the lateral portion of the aorta descendens thoracica, and used for its cure, three steel needles one millimètre thick, which were introduced into the third intercostal space, one being about two centimètres distant from the other. The positive pole was first connected with one of the needles, and the negative with a spongeholder applied to the skin in the neighbourhood of the tumour. He then connected the positive pole with the second needle, and the negative with the first where the positive pole had already acted &c., until each needle had been in contact with both poles. The application lasted forty minutes; the skin had become reddened and swollen. After a few days these local symptoms abated; there was no general reaction. Sixty-six days after the operation the patient was completely cured.

A curious case of aneurism of the external iliac artery in which not the continuous, but the induced current was used, is recorded by Mr. Eyre.* There was a pulsating tumour in the left groin, of the size of a fowl's egg; the pulsation was very strong, and accompanied with a bruit which could be traced two inches above the tumour; the limb was swollen and painful. Needles connected with the poles of an induction apparatus were introduced into the sac, and a current sent through it for some time. Alarming signs of inflammation supervened, and it was not until seventeen days after the operation, that the tumour felt harder, and the pulsation became fainter. In this case electricity acted merely as an excitant, and the sac was closed in consequence of irritation and adhesive inflammation, but not by chemical action. As suppuration may easily supervene in such cases, the employment of induction

* The Lancet, July 1853.

currents for the cure of aneurisms is, generally speaking, not justifiable.

3. *Diseases of the veins.*—I have treated several cases of varicose veins of the extremities, and of varicocele, by electrolysis, with apparently good results; but sufficient time has not yet elapsed to enable me to say whether the results have been permanent.

XVI. DISEASES OF THE URINARY ORGANS.

1. *Stricture of the Urethra.*—Crussel and Wertheimber were the first to attempt the cure of this affection by galvanism, but to Messrs. Mallez and Tripier,* the merit is due of having proposed an intelligible method of applying it. They recommend electrolysis of the stricture, by introducing an insulated sound with a metallic point to the seat of the obstruction, and connecting it with the negative pole of twelve pairs of the bisulphate of mercury battery; the positive electrode, which should be well moistened, being fixed on the inner surface of the left thigh. As soon as the circuit is closed, the patient feels a slight pricking sensation, which, however, diminishes in proportion as the eschar is formed. The metallic point is then pushed forward, so as to cauterise the different parts of the stricture; and when the impediment is destroyed, the sound is pushed forward beyond the point of the wire. A catheter can then

* De la guérison durable des rétrécissements de l'urèthre par la galvanocaustique chimique. Paris, 1867. 2nd edition, 1870.

be easily introduced into the bladder, showing that the stricture has disappeared. Messrs. Mallez and Tripier have treated thirty-one cases by this method in a public dispensary, with satisfactory results. It is true that one of these patients died a week after the operation of urethral fever; but he had already once before nearly died of that after urethrotomy. The authors of the operation do not consider that their proceeding should be made responsible for this fatal result, as death has occasionally occurred after simple catheterism, in persons who were either in bad general health, or suffered from disease of the kidneys. In the patient alluded to, the immediate effects of the operation had been satisfactory. One operation is generally sufficient, and nothing further need be done; but the catheter is introduced from time to time, in order to see whether the result of the treatment has been permanent. A curious circumstance is, that the size of the urethral canal, instead of diminishing, increases for a week or two after the operation, which is probably due to the absorption of peri-urethral effusions, which have been brought under the influence of the negative pole. The following is one of Mallez and Tripier's cases:—

A custom-house officer, aged 62, had had gonorrhœa at the age of twenty, and passed his urine with difficulty for the last ten years. For the last eighteen months there had been incontinence, which obliged the patient to wear a urinal, and he was unable to follow his employment. On May 2, 1864, the urethra was explored with an elastic bougie, which encountered an obstacle at the end of the spongy portion of the urethra; and rectal examination showed the existence of hypertrophied prostate without deformity. For twenty minutes it was tried to introduce a bougie No. 3 into the bladder, which caused a few drops of blood to appear. On May 6, a bougie No. 3 was introduced after patient trials of three-quarters of an hour; and on May 9 the stricture was electrolysed to the extent of half an inch. The application lasted five minutes; immediately after the operation, a bougie No. 19 and 20 could be introduced without the least difficulty, and the patient passed his urine in a full stream. No fever supervened. The incontinence ceased, so that the patient was no longer obliged to use the urinal. He was seen several months afterwards, when he was in excellent health, and there was not the least return of the stricture.

In most cases operated upon by Messrs. Mallez and Tripier, one application of the continuous current was sufficient for the cure of the stricture; in a few others from two to five were necessary. In only one case did the patient complain of pain during the operation, and in a few only was there slight hæmorrhage afterwards. Some of these cases have remained under observation for more than three years, and have shown no relapse; so that the results of electrolysis for stricture seem to be superior to those of many other operative procedures.

2. *Paralysis and atony of the Bladder.*—Paralysis of the bladder occurs in consequence of an injury to the spine, and also as a symptom of certain diseases of the nervous centres, such as myelitis, atony, &c. In such cases, the local application of electricity to the bladder can have no beneficial effect; but galvani-

sation of the spinal cord often cures the affection of the bladder, along with the other symptoms of the principal disease, of which the affection of the bladder is merely a symptom. In other cases the muscular fibres of the bladder become atrophied, and lose their expulsive power, the bladder itself being a thin flaccid bag. This occurs when persons have been obliged to retain the urine for a long time, and is also a symptom of the general malnutrition of advancing age. In such cases, faradisation of the bladder (p. 383) is the best remedy, which has proved successful in the hands of Dr. Russell Reynolds, Dr. Fraser, and my own. Paralysis due to injury of the bladder not unfrequently comes on after labour, and has then the same pathology as paralysis of motor nerves from pressure (p. 489). In such cases, faradisation is likewise of the greatest service, as shown by the observations of Dr. Goodwin and Radford.

Mr. Ta   of Anerley, has recorded a case of paralysis of the female bladder after forceps delivery, and in which the ordinary remedies had been used without any effect. He then introduced an insulated electrode into the bladder after the organ had been emptied, and applied faradisation. As two such applications, however, produced only little effect, he next faradised the full bladder, when, under the influence of the electric current, the organ forced the urine out by the side of the instrument, and on the same day the patient was able to pass urine voluntarily. Faradisation was repeated once more, after which the patient had regained her full control over the bladder.

* The Lancet. Vol. i. Feb. 1868.

Difficulty of urination in consequence of chronic inflammation of the prostate, has already been discussed (p. 478). Where senile hypertrophy of the prostate is the cause of the impediment, probably no form of electricity would do much good, although the continuous current deserves a trial for the cure of this otherwise irremediable affection. In such cases the positive electrode may be placed in the rectum, and the negative in the prostatic portion of the urethra.

3.—*Dissolution of urinary calculi.*

As far back as 1801, M. Bouvier de Mortier proposed using galvanism for the dissolution of calculi. In 1803, Mongiardini and Lando, and in 1813, Gruithuisen again recommended it for such purposes, but it was only in 1823 that the first successful experiments on this subject were made, by Messrs Prévost and Dumas.* They thought it best to destroy the state of aggregation by which the molecules of the calculus are bound together; for they argued that if once it was made friable, it would easily pass out. They did not, therefore, subject the calculus to direct chemical action, but utilised the mechanical action of torrents of gases in order to alter its texture, and reduce it to a fine powder. They first submitted a fusible human calculus to the action of a voltaic pile of 120 pairs, for twelve hours consecutively. The pile was recharged every hour. Platinum wires serving as electrodes were placed at two opposite points of the calculus which was immersed in a vessel filled with water. After a time a fine powder was precipitated. At the commencement of the experiment the calculus weighed 92 grains, and at the end of it only 80 grains. After having been subjected once more to the

* Annales de Chimie et de Physique. Paris, 1823. Vol. xxiii. p. 202.

action of the pile for 16 hours, the calculus became so friable that the slightest pressure reduced it to small crystalline grains; the largest fragments were scarcely the size of a lentil, and the canal of the urethra would not therefore have opposed their exit. Prévost and Dumas made a similar experiment on a living bitch. A fusible calculus fixed upon a sound was introduced into the bladder of the animal, and the electrodes so arranged that they touched the calculus on opposite points. Warm water having been injected into the bladder, the electrodes were connected with the poles of the pile. The calculus was left for an hour in this state, and when taken out showed unequivocal signs of decomposition. The same process was repeated every morning and evening for an hour each time, on six successive days; after which the stone was so friable that the experiment could not be continued. A few days afterwards the bitch was killed and the bladder examined; it was then observed that its tissue had in no way been injured by the operation.

In 1835 M. Bonnet, of Lyons,* succeeded in dissolving calculi by the direct chemical action of the voltaic pile. He placed different calculi between platinum electrodes immersed in a solution of a drachm of nitrate of potash in four ounces of water, and dissolved them by directing a continuous current to their texture. Stones of oxalate of lime were the only ones which resisted the action of the galvanism, while calculi of every other description were dissolved more or less rapidly. The point established by the researches of M. Bonnet is, that we may convey to the stone acids and alkalies, merely by the electro-chemical decomposition of a saline solution, without these powerful substances being diffused in the urine contained in the bladder. Most urinary calculi are dissolved either by nitric acid or by potash; but these substances cannot be

* Bibliothèque universelle de Génève, 1835. Vol. lviii. p. 391.

introduced into the bladder without cauterising its tissue. If, however, a solution of a neutral salt, such as nitre, is injected into the bladder containing the calculus, and the electrodes connected with the poles of the pile are made to touch opposite surfaces of the stone, the solution of nitre is decomposed, nitric acid being attracted in very small quantities to the positive pole, and potash to the negative pole. One of the sides of the calculus will, therefore, be subjected to the action of nitric acid, and the other to that of caustic potash. If the stones be composed of phosphates, it will be dissolved on the acid side; while if it be composed of uric acid, or urate of ammonia, it will be dissolved on the alkaline side. But while this process of dissolution is going on, the calculus and the mucous membrane of the bladder are in contact with a neutral solution. If the action of the current be kept up, the electrode gradually penetrates to the interior of the stone, but always on one side only. In this way stones of phosphate of ammonia and magnesia, phosphate of lime, ammonia, and magnesia, urate of ammonia and uric acid, are capable of being dissolved. If the texture of the stone be very dense, the solution will be confined to the point touched by the electrode, but if the stone be formed of layers which are only feebly connected with each other (as is the case with such of urate of ammonia, and triple phosphates), or if it be porous, when formed of phosphate of ammonia and magnesia, the calculus will soon become friable, and the layers separated from each other. The dissolved part does not remain in solution in the liquid, but is precipitated in the bladder as a fine powder of subphosphate, or of uric acid.

In the course of his experiments, M. Bonnet several times changed the saline solution in which the calculi were immersed, using the phosphate, the hydrochlorate, and the borate of soda, and the fluate of potash, instead of nitre; but he found that none of these salts had such a general and powerful action as the nitrate of potash.

Similar experiments were made in 1853, by Dr. Bence Jones,* who confirmed nearly all the results previously obtained by M. Bonnet, but found that calculi of oxalate of lime, which had been pronounced indissoluble by M. Bonnet, could be dissolved, although only slowly.

The only author who affirms having dissolved calculi in the human bladder by galvanism, is Dr. Melicher,† of Vienna. But as he has not described the instruments used, nor given his cases in full detail, his statements are devoid of value.

The mechanical effect of electric discharges has also been recommended for disintegrating calculi. It is well known that electricity of high tension is able to destroy the molecular structure of imperfect conductors; thus lightning will break and pulverise stones, panes of glass, and other similar bodies which it cannot traverse without destroying them. Proceeding from these facts Mr. Robinson has endeavoured to reduce stones to a fine powder by discharging a Leyden jar through them, and has succeeded in pulverising phosphatic, mulberry, and lithic acid calculi, which were previously placed in a bladder or in vessels of glass or earthenware filled with water. No effect was produced if the surrounding medium was air. He recommends the introduction of two conducting wires by means of an elastic catheter into the bladder, the wires being connected separately with the inner and the outer coating of the jar, and their free extremities being separated in order to grasp the stone. However ingenious all these ideas and experiments may be, it is not likely that electricity or galvanism will ever supersede lithotrity for the treatment of small stones, nor lithotomy for that of large ones.

* Philosoph. Transactions, 1853, p. 201.

† Oesterreichische medicinische Jahrbücher, 1848, p. 153.

XVII.—DISEASES OF THE MALE ORGANS OF GENERATION.

1. *Impotency.*—Electricity has often been recommended and used for the cure of impotency. Dr. Westring,* a Swedish physician, has recorded the case of a man, aged 36, who had become impotent in consequence of debauchery; erection was imperfect, ejaculation took place too quickly, and without any pleasurable sensation. The patient was treated with the continuous current of a voltaic pile applied by means of metallic conductors, and had within a fortnight quite regained his virile power. M. Stacquez † cured a case of impotency by shocks from a Leyden jar; his patient was an officer aged 35, who had been completely impotent for several years. M. Duchenne ‡ has been successful with faradisation of the testicles and spermatic cord; and M. Schultz § and M. Roubaud || have likewise seen good results from the galvanic treatment of such cases.

Want of erectile power is a frequent cause of impotency, and curable by electricity, unless it is caused by malformation or other serious pathological changes in the male organ. In such cases faradisation of the ischio-cavernosus and bulbo-cavernosus muscles,

* Journal du galvanisme et de la vaccine, 1803. Vol. i. p. 297.

† Archives belges de médecine militaire, 1849.

‡ De l'électrisation localisée, etc., p. 764.

§ Wiener medizin. Wochenschrift, 1857. No. 10.

|| Traité de l'impuissance et de la stérilité chez l'homme et chez la femme. Paris, 1855. Vol. ii. p. 685.

which preside over erection, is useful. The same application may be resorted to in cases of sexual hypochondriasis, where patients, for some reason or another, imagine that they are impotent, but where virile power is not really impaired. In anæsthesia of the skin of the sexual organs, faradisation of the skin of the organs may be resorted to.

CASE 75.—In June 1858, Mr. Curling sent to me a gentleman, aged 26, who had completely lost his virile power after gonorrhœa, for the cure of which he had been advised to make caustic injections. Faradisation of the ischio-cavernosus and bulbo-cavernosus muscle, and of the penis, restored his energy in a short time. The power was subsequently lost again, but returned for good after a second course of faradisation, in August 1859.

Where impotency is caused by general malnutrition, diabetes, syphilis, lead-poisoning, or the habitual use of opium and hasheesh, excessive tea or coffee-drinking, by over-study and similar causes, a general treatment should be combined with the application of electricity. In such cases the continuous current, applied to the lumbar spine continuatively, and to the penis and testicles intermittently, is superior to faradisation. Where the virile power is lost from disease of the spinal cord, galvanisation of the cord frequently restores the sexual energy, without any local application to the sexual organs having been made.

2. *Sterility.*—Mr. Curling * has shown in an ex-

* A Practical Treatise on the Diseases of the Testes, and of the Spermatic Cord and Scrotum. London, 1866. Third edition, p. 433.

cellent paper on this subject, that there may be capacity for sexual intercourse, but at the same time inability to procreate; and that this inability in man arises from malposition of the testicles, obstruction in the excretory ducts of the testicle, impediments to the escape of the seminal fluid, and aspermatismus.

Whether deficient secretion of semen may be improved or cured by electricity is at present not known. It does not appear impossible that it should be so, for electricity has considerable effects in rousing the activity of the vaso-motor nerves in general. By electrifying the skin, we may produce erythema and papular eruptions; in cases of amenorrhœa electricity is often instrumental in promoting normal menstruation; in paralysed limbs which have been cold and flabby, animal heat may be restored by its use; a deficient secretion of cerumen may be improved, and lacteal secretion in women after parturition may be excited by it; and the secretion of tears, of nasal mucus, and of saliva, is stimulated by the application of electricity. It therefore appears, *à priori*, not unreasonable to expect that the secretion of semen may be restored or improved by galvanising the testicles; provided, of course, that the want of secretion is due to paralysis of the vaso-motor nerves of these organs, and not to the results of inflammation, cancer, tubercle, or other pathological processes which destroy the texture of the testicles, and therefore render any secretion of semen impossible. Observations on this point are as yet wanting, but in the absence of other remedies for the condition just mentioned, electricity, and more especially the continuous current, deserve a trial.

3. *Spermatorrhœa.*—Excessive spermatic discharges may occur both during sleep and in the day-time, and are generally the consequence 'of the passions being excited without an opportunity being afforded for their gratification.' * In nine cases out of ten, spermatorrhœa comes on after masturbation has been practised for some time, and constitutes a very troublesome complaint, which is generally attended by symptoms pointing to a profound disturbance of the central nervous system. Mr. Curling recommends the application of nitrate of silver to the prostatic portion of the urethra, in those cases which do not get well by a constitutional treatment, and the occasional introduction of bougies; and his success appears to have been very marked. Galvanisation of the prostatic portion of the urethra (p. 327) may likewise be employed. It has the advantage that it can be readily adapted to the special sensibility of each patient, and that it causes no distress during or after the application, if this be judiciously performed.

CASE 76.—A gentleman, aged 26, consulted me in January 1868. He had been in good health until he began to masturbate five years ago, which habit he had continued for three or four years. Within the last three years he had suffered from extremely frequent seminal emissions at night,

* Curling, loc. cit. p. 453.

in consequence of which he had become very much debilitated; at present not a single night passed without an emission, and there were sometimes three in one night. The memory was bad, the patient felt unable to work, and complained of heaviness about the head, great despondency, and pain and weakness in the back. I prescribed mineral acids, and applied the negative pole of fifteen cells for two minutes to the veru montanum by means of an insulated metallic conductor, the positive pole being placed to the perineum. The galvanism was afterwards applied to the parts externally, three times a week. The patient now had no emission for fifteen nights consecutively. He had one in the sixteenth night, and galvanisation of the urethra was then repeated. After this he went sixteen nights until he had another emission; and the one he had then was the last he had while he continued under my care (three months). His general health had at the same time become much better, and the despondency of mind had given place to his natural cheerfulness.

4. *Hydrocele.*—Dr. Ruschenberger, of the united States' Navy, Prof. Pétrequin and M. Scoutetten have cured obstinate cases of hydrocele by galvano-puncture, both electrodes being introduced into the sac. Dr. Lehmann and M. Tripier have used farado-puncture, and have also been satisfied with the result. Dr. Friedlaender of Vienna, and Mr. Powell of Dublin, have successfully used the method first recommended by me, viz. to direct the negative pole only to the liquid, and to place the positive outside. Two needles and fifteen or twenty cells appear to be generally sufficient. Care should be taken that the points of the needles should project into the fluid, as, if they were merely passed into the subcutaneous

cellular tissue, or the tunica dartos, the current would only act upon these membranes, but not upon the liquid accumulated in the sac of the tunica vaginalis. The operation should last for five or seven minutes, and at the same time gentle pressure be made upon the tumour. After the operation, the scrotum appears puffed, and the quantity of fluid in the sac is diminished. If electrolysis is used, one application is sufficient, while for farado-puncture three or four operations are generally required.

XVIII.—DISEASES OF THE FEMALE ORGANS OF GENERATION.

1. *Amenorrhœa.*—Electricity has been frequently employed for the cure of amenorrhœa, and generally with satisfactory results. Dr. Golding Bird * expresses his belief that electricity is the only really direct emmenagogue we possess, and that it always excites menstruation where the uterus is capable of performing this function. It appears indeed that every form of electricity has an almost specific stimulating influence upon the vasomotor nerves of the ovaries and the uterus. Dr. Bird has cured twenty out of twenty-four cases of amenorrhœa, by the application of static electricity. The mode in which he applied it was to transmit a dozen shocks from an electric jar holding about a pint, through the pelvis, one conductor being placed over the

* Lectures on Electricity and Galvanism in their Physiological and Therapeutical Relations. London Medical Gazette, 1847, p. 705.

lumbo-sacral region, and the other just above the pubes. Cases of amenorrhœa cured by the application of the continuous current have been recorded by Drs. Westring and de Molle; and Sir James Simpson has seen good results from the use of his *intra-uterine galvanic pessaries,* which are composed of copper and zinc. The induced current has proved beneficial in the hands of Duchenne, Schulz, Baierlacher, and my own. Even a lightning stroke has, according to Dr. Le Conte,* brought back the menstrual function in a negress seventy years of age, in a plantation in Georgia: in this person the period had ceased for more than twenty years; but after she had been struck by lightning, the menses were completely re-established, and continued with the utmost regularity for more than a year after the accident; at the same time the mammæ had become enlarged.

Electricity is especially valuable as an emmenagogue in young women, where the menstrual function has not yet been fully established in consequence of a torpid state of the vasomotor nerves of the ovaries and the uterus; and also when the catamenia have been lost, after labour, or in consequence of cold, shock, or mental anxiety. Where amenorrhœa is caused by structural diseases of the ovaries and the uterus, the prognosis is not so favourable.

I have taken some trouble to determine the most effectual way of administering electricity in amenorrhœa. Duchenne has recommended faradisation of

* New York Journal of Medicine, 1844.

the womb, which is certainly very effective, but not applicable to unmarried women. Experience has shown me that in many cases the catamenia are brought on, whatever part of the body may have been faradised; but that the most effectual way after faradisation of the womb, is to apply one electrode to the abdominal parietes, and the other to the lumbar spine. It has frequently happened in cases under my care that the catamenia appeared after one or a few applications, when the faradic treatment was employed for another complaint; thus, for instance, in a lady suffering from aphonia, I guided a mild current along the course of the recurrent nerve; a few hours afterwards the catamenia, which had not been expected for a week, appeared. In another lady I faradised the drum of the ear for nervous deafness and noises in the head; soon after the operation, the patient felt a general sensation throughout her body, and the courses, which had before been tardy in their appearance, had come on a week too soon.

I subjoin a case of amenorrhœa which presents some interest partly on account of the advanced age of the patient, and partly because electricity was not used with the intention of effecting a return of menstruation:—

Case 77.—A married woman, æt. 48, was admitted as an out-patient at the infirmary for epilepsy and paralysis, under my care, on May 5, 1866. Six years ago she had a paralytic stroke which took away the use of the left side.

She was then so ill for three months that her life was despaired of. She had had many miscarriages, and several children, but none of them were now living. Shortly before she had the attack, the courses stopped away, she being then 42 years old; when she first missed them, she had a great deal of pain in the back, and suffered from sick headaches. She had never seen a sign of them since. She had now nearly recovered the use of the arm, but there was almost complete anæsthesia of the left leg from the knee downwards, and walking was very troublesome. I resorted to faradisation of the skin of the anæsthetic leg; and after this had been done seven times, the patient informed me she had been very much astonished by the period having returned. It came twice more, at a month's interval each time, after which I lost sight of the patient.

2. *Chronic metritis.*—French surgeons frequently employ faradisation in inflammatory conditions of the womb; and to M. Tripier* great merit is due for having improved the method of applying electricity in such cases (p. 387). Messrs. Beau and Fano have been equally successful with the faradic treatment of uterine disease as M. Tripier. I have likewise had a few cases of it under my care, in which the results have been so satisfactory, that I feel justified in recommending a more extended use of faradisation to obstetric physicians.

The influence of faradisation in uterine disease is easily understood if we consider the minute anatomical structure of the womb and its appendages, and the pathological nature of the principal diseases to which this organ is liable. The substance of the uterus consists of three different layers of organic muscular fibre-cells, which are intimately con-

* Manuel d'Électrothérapie. Paris, 1861, p. 548.

nected with one another, and pervaded by a considerable mass of nucleated connective tissue, with which the muscular fibres are so interlaced that it is almost impossible to isolate the several structural elements. The broad ligaments by which the uterus is kept in its proper position, contain a continuation of these muscular fibres. Now, the chief morbid changes which occur in the tissue of the uterus and broad ligaments consist of atrophy of the contractile fibres, with effusions, and relative or absolute increase of connective tissue; and faradisation acts beneficially by inducing contractions of the muscular fibres and strengthening their tone, while at the same time it promotes the absorption of effusions, and checks the undue proliferation of connective tissue.

Chronic inflammation occurs after child-birth, repeated miscarriages, and mechanical injury to the parts, or from disturbances of the abdominal circulation, cold, mental emotions, sedentary habits, habitual constipation, and excessive sexual indulgence. Its chief anatomical feature consists, according to Scanzoni, of an excessive growth of connective tissue, which is formed by the organisation of the lymph effused between the muscular fibres of the womb, causing compression or even obliteration of the blood-vessels in some parts, and dilatation of the same in others.

Enlargement of the uterus without inflammation occurs after child-birth, in consequence of defective involution of that organ, and its symptoms are similar to those which are due to true chronic inflammation, viz., a sensation of weight, fulness, and dragging about the pelvis. Standing and walking are shunned, and if a little more exercise than usual is taken, severe pain is felt in the hypogastrium, the inguinal and sacral regions. The catamenia are mostly scanty, irregular, and painful; a leucorrhœal discharge is either permanently present, or occurs a few days previous to the period. Digestion is tardy and imperfect, there is frequently sickness, habitual constipation, and tenesmus about the bladder and the rectum, and anæmia and a weak and irritable condition of the nervous system follow in due course.

CASE 78.—A married lady, aged 36, had three children very quickly after one another, She had her last confinement four years ago, and directly after that began to feel very ill. Her medical attendant told her that she would most likely have no more children, as there had been inflammation of the womb after the confinement. She lost all energy, and felt unable to superintend her household. Even writing and reading were troublesome to her. The period was regular, but pale and scanty. Digestion was tedious, and the bowels habitually costive. Walking and standing were so painful that she passed her life chiefly in bed and on the sofa. Whenever she attempted to walk, she had a bearing-down sensation, as if the womb were going to be expelled. She habitually suffered from fulness and heaviness in the pelvis, and also from chills along her back, which came on every evening. These latter were so constant that she had been treated for ague, and taken quinine and arsenic, without any effect. She had, however, never had real ague. She had been subjected to a variety of local treatment, but nothing had seemed to have any beneficial influence on her condition.

The lips of the os were indurated and enlarged, the os dilated, and the body of the womb nearly twice its normal size. A somewhat copious secretion took place from the cervical canal, but there was no ulceration. Faradisation was now had recourse to (June 1867), and the first application of it did good, as the patient felt less heaviness and fulness in the pelvis, and could walk and stand without being so much troubled by bearing-down sensations. After six applications, the patient could walk a mile with comparative comfort. The uterus had then already considerably contracted, and the lips of the os had become softer and smaller. The period came on after the sixth application. It was of a better character, and not nearly so painful as before. The patient had fourteen more applications, and I then discontinued the treatment, as she had conceived, and further applications might possibly have led to abortion. The patient was, when I last heard of her, advanced in pregnancy, and had all the time been able to take active exercise. Her general health was very much better, and she had never been obliged to have recourse to opening medicines, since faradisation was first used.

Dr. G. Murray * has used Sir J. Simpson's galvanic pessaries for the relief and cure of sub-involution of the uterus, where the organ is heavy, larger than natural, and flabby to the touch; the os uteri open, or readily admitting the point of the forefinger; the anterior, posterior, or both lips thickened or elongated; and where there is an offensive discharge from the cavity of the womb, and an excess of menstrual flow. In one case of this kind, where the organ was also retroverted, and Hodge's pessary had failed to remedy the diseased condition, Dr. Murray succeeded, by the introduction of the galvanic pessary, in reducing, in the course of a fortnight, the large flabby uterus nearly to its normal and healthy condition.

3. *Displacements of the Womb.*—The treatment of displacements of the womb by the introduction of the uterine sound is often unsatisfactory, as the sound cannot always remain in the organ, and the moment it is withdrawn the body of the uterus falls back into its old position. The plan of introducing pessaries for rectifying the position of the uterus, was a considerable improvement, as they not merely give mechanical support, but also tend to

* The Lancet, vol. ii. 1868.

alter the tissue of the womb, so as to make it contract. Yet pessaries frequently give rise to great irritation and inflammation, which is chiefly due to the difficulty experienced in adapting a really well-fitting pessary to the individual case, and to the mischief which results if the pessary does not fit. The annoyance and inconvenience caused to the patient by wearing a pessary is also considerable; so that, if more extended experience should prove that faradisation is of substantial value in these conditions, a considerable therapeutical improvement would be effected.

a. Anteversion and Anteflexion of the uterus are generally owing to prolonged congestion, or the presence of a tumour, and connected with engorgement or hypertrophy of the anterior wall of the uterus. Such displacements are a very frequent cause of sterility, for in 250 cases of sterility observed by Dr. Marion Sims, no less than 103 patients had anteversion. If faradisation is used in such cases, we ought to act chiefly on the posterior portion of the womb, the positive electrode being introduced into the vagina, and the negative into the rectum. The latter should be moved about, during the application, so as to increase its exciting effect on the contractile substance of the womb.

b. Retroversion and Retroflexion occur chiefly after labour or miscarriages, when the uterus is large and lax, and its ligaments longer than usual, and it is, therefore, easily twisted and displaced. It may also occur where the menstruation has been unusually profuse, and the womb enlarged and congested from other causes. For these cases M. Tripier recommends

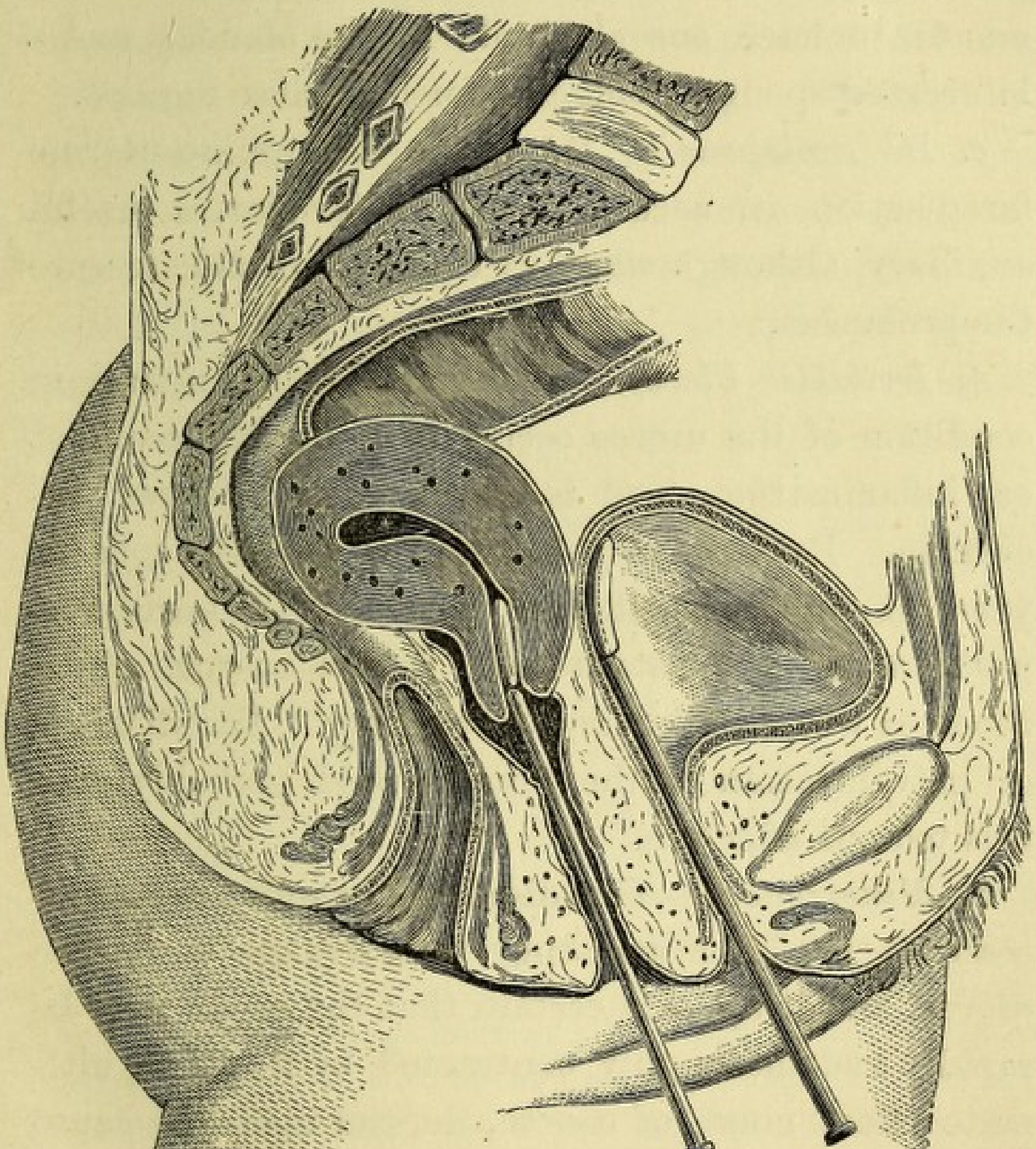


Fig. 62.

first to introduce an air-pessary into the rectum, in order to raise the fundus uteri, and then to put the negative pole to the os, and the positive into the bladder. Where it should not be convenient to introduce an electrode into the bladder, a moistened sponge-conductor may be placed to the abdominal parietes. In unmarried women, M. Tripier recommends to have one electrode in the bladder, and a bifurcated sponge-conductor for both iliac regions.

c. *In Prolapsus of the Womb*, bi-inguino-uterine faradisation is, according to M. Tripier, a useful auxiliary, although when used alone, not able to cure the prolapsus.

4. *Irritable Uterus.*—The irritable or neuralgic condition of the uterus occurs without displacement or inflammation, and is generally considered incurable. Patients of this kind live on their sofa for years, being compelled to assume the horizontal position by a constant pain in the uterus, which becomes worse on sitting or walking. Faradisation or galvanisation of the womb would probably cure this tedious affection.

5. *Menorrhagia.*—Faradisation has often been successfully used for arresting hæmorrhage from the uterus, and it appears certain that the organ may be rapidly and thoroughly contracted by it. The ultimate effect must, of course, depend upon the cause of the disease, which has to be treated according to the requirements of each individual case.

6. *Stoppage of the Lacteal Secretion.*—In women after parturition, where the secretion of milk is tardy, either from a sluggish state of the mammary nerves, or from malnutrition and atrophy of the glands; or

where the flow has been suppressed through fright or depressing mental emotions, faradisation of the mammæ with moistened conductors is useful. Messrs. Aubert and Becquerel were the first to put this treatment into practice. I have myself treated several cases of this kind with good results. Dr. Skinner,* of Liverpool, also thinks faradisation beneficial where the milk is absent from the effects of mammary inflammation or abscess, or where it has been inadvertently stopped by the administration of certain medicines. The following is one of Dr. Skinner's cases:—

In August, 1861, he was consulted by a lady, aged 36, on account of vaginal irritation and other morbid symptoms resulting from anæmia. The lady had been lately confined of her fifth child under the care of an experienced accoucheur, and she was at the time suckling her infant. She was ordered moderate doses of tincture of iron thrice daily, but this medication was followed, in a few days, by a complete stoppage of the milk in both breasts. The right breast had never been used for suckling since an attack of mammary abscess some years before, so that he only applied the current to the left breast. At the time of the application the patient told him that she felt a distinct sensation as of 'a rush of milk to the breast.' On the 16th, the patient reported, that within a few hours of the faradisation a copious supply of milk was permanently established in the left breast. He was then asked by the lady if he could do any good to the breast which had been so long useless as regards the function of lactation. He made the attempt, having little faith in the wished-for result, but

* The Galactagogue Properties of Faradisation, in Transactions of the Obstetrical Society of London, 1864.

was agreeably disappointed to find that, after two brief sittings of little more than five minutes each, the right breast became as well supplied with milk as the left.

XIX.—TUMOURS.

Four different methods of applying electricity have been recommended and used for the removal of tumours. These are faradisation by moistened conductors (Meyer); the galvanic cautery (Heider and Middeldorpff); the external application of galvanic chains (Maurice Collis) and electrolysis (the author).

a. Faradisation by moistened Conductors has, in the hands of Dr. Moritz Meyer,* succeeded in considerably reducing glandular tumours of large size, and in which surgical operations were inapplicable. The method is, however, excessively tedious, as hundreds of applications are required for powerfully influencing the nutrition of the tumour. It is possible that farado-puncture might be somewhat quicker in its action.

One of Meyer's cases was that of a young lady, aged 25, who suffered from a tumour on the right side of the neck, which had within four weeks of its first appearance increased so rapidly, that it had assumed the size of an adult's head. Various remedial measures were adopted, such as the internal and external use of iodine, the baths of Kreuznach, &c.; but as no effect was produced, and an operation was inadmissible, Professor Langenbeck advised the use of electricity. At

* Loc. cit. p. 407.

that time the tumour filled up the entire space between the lower jaw, the mastoid process and the linea semicircularis inferior of the occiput; then proceeded posteriorly towards the vertebral column, which was displaced to the left side, terminated anteriorly in the middle of the throat, and reached inferiorly below the shoulder blade, the movement of the latter towards the spine being considerably impeded. The tumour did not appear to adhere to the bones, but was excessively hard, especially in its lower portion. The circumference of the left side of the neck was six inches, and that of the right side fourteen inches. The right sterno-cleido-mastoid muscle could not be made out, and the clavicula was completely covered by the tumour, and the head turned towards the left side; the least lateral motion towards the right side being impossible. The induced current was now sent straight through the tumour by means of metal plates covered with moistened sponge, for an hour or an hour and a half each time. After fifty-six such applications the bulk of the tumour had been reduced to one half its previous size, and the upper part of it was much softer. After 144 applications the size of the tumour was only one third its original size. The circumference of the right side of the neck was then only ten and a half inches. The sterno-cleido-mastoid muscle could be plainly felt, the head was straight and could be turned slightly towards the right side, and the spine was no longer displaced towards the left. Altogether 273 applications were made. The improvement was steady but did not progress, when the treatment was interrupted. At the end of the treatment the difference in the circumference of the two sides of the neck was only two inches, and the head could be easily turned towards the right side.

b. The galvanic cautery is a most powerful agent, by means of which many forms of tumour may be rapidly removed. It is chiefly applicable to superficial tumours and polypi, but has the drawback of generally leaving unsightly scars. The following are a few cases which have been recently operated upon by Mr. Bryant* :—

Cutaneous nævus over chest.—Alice C——, aged four months; nævus involving the skin on the left side of the chest, the size of a crown-piece. On January 8, 1869, it was cauterised deeply with the porcelain cautery, brought to a white heat by a coil of platinum wire. The whole growth was completely destroyed, and in two weeks, when the eschar had separated, perfect cicatrisation had taken place.

Large epithelial cancer of the perineum removed by cautery; recovery.—Eliza L——, aged fifty-nine, was admitted into the hospital, under the care of Dr. Oldham and Mr. Bryant, with an epithelial cancer, the size of a crown-piece, occupying the perineum, and involving the anus and portion of the recto-vaginal septum. It had been growing for two years. On November 13, the patient being under the influence of chloroform, Mr. Bryant isolated the base of the growth by passing three large pins beneath it into the healthy tissues. He then passed round the base of the tumour beneath the pins a strong platinum wire, and fixed it to the ecraseur, screwing it home. Junction was then made with the galvanic battery, and with a few carefully applied screws of the instrument the growth was removed, no drop of blood showing itself. A white ash-coloured surface was left. Rapid recovery followed the operation, the patient leaving the hospital well on December 15.

Mr. Bryant remarked that this case illustrated very beautifully the use of the cautery, for the removal of a tumour so situated with the knife would have been very difficult, and must have been attended with severe and troublesome hæmorrhage.

* The Lancet, May 1, 1869.

Spreading lupus of the face, cured by the cautery.—Eliza T——, aged 30, came under Mr. Bryant's care with a spreading lupus, involving the whole of the nose and upper lip. It had existed for four years, and, in spite of all treatment, had steadily progressed. On November 6, 1868, it was freely cauterised. By the 19th the scab was coming away, a healing surface remaining. By the 26th the whole eschar had fallen off, and the wound was closing. By December 8 the woman was well. She was seen on April 10, when it was difficult to make out the seat of the former disease, the cicatrices being so indistinct, and the skin natural.

c. External application of Galvanic Chains.—The late Mr. Collis, of Dublin, has used small batteries of zinc and copper wire wound on cylinders or plates of wood covered with felt, and rendered active by immersions in a weak solution of sulphuric acid. The negative pole is brought into contact with a plate of zinc, copper, or silver foil, laid over the tumour, and the positive pole is connected with a plate of copper laid somewhere on the general surface, with a preference to the spinal region. He has succeeded, by a prolonged application of these chains, in removing or considerably reducing glandular and some other kinds of tumours.

d. Electrolysis.—The electrolytic treatment appears to be the most universally applicable method of electrisation for the cure of tumours, although it is not nearly so rapid as the galvanic cautery, especially where the tumours are large. Its effects are essentially slow in all tumours except those with serous contents; and it tends rather to a profound modification of the nutrition of the parts involved, than to a sudden destruction of the morbid growths. Electrolysis may therefore be described as a physiological rather than a mechanical remedy. The kinds of tumour in which electrolysis has hitherto proved chiefly successful, are nævus, bronchocele, sebaceous tumours, hydatid tumours of the liver, and cancer.

CASE 79.—*Nævus of the eye-lid; electrolysis; cure.*

In July, 1866, Mr. White Cooper requested me to see with him a lady, aged 28, who had a congenital nævus of the right lower eyelid, of the size of a pea, which it was thought desirable to remove. I gave the opinion that this might be safely done by electrolysis, without hæmorrhage, and without subsequent inflammation, suppuration, or sloughing; and we therefore met on July 23, in order to perform the operation. As the patient was of a highly sensitive constitution, chloroform was administered by Dr. Allan, of Hyde Park Terrace, the ordinary medical attendant of the lady. As soon as she was fairly under the influence of it, Mr. White Cooper introduced a needle connected with the negative pole of ten cells of the battery into the right half of the tumour, and I closed the circuit by placing a moistened electrode connected with the positive pole to the skin of the neck. The current was then allowed to pass for two minutes, after which the needle was withdrawn. Not a drop of blood was lost on withdrawing the needle. The patient recovered well from the chloroform, and said that she felt no pain in the part that had been operated upon, but merely a slight stiffness. The right half of the tumour appeared shrunk and shrivelled up, while the left half had not been altered in any way. This was an interesting circumstance, as it showed that even in so small a tumour as the one described, the action of the current could be limited to that portion of it which was in contact with the needle.

We met again on July 26, when the same operation was performed on the other half of the tumour; but this time the patient objected to the use of chloroform, and bore the trifling pain of the galvanism quite well without it. I have not seen the patient since; but received on October 13 a note from Dr. Allan, in which he expressed himself as follows:—'Mrs. —— is in the country, but last time I heard from her, she said that the nævus had disappeared. A dozen years ago I wished it to be removed; but no one would do it; and the able and esteemed oculist whom she then consulted, deprecated all interference. At length I persuaded her to have another opinion (that of Mr. White Cooper). The result was your employment of galvanism, with the happy effect of complete obliteration of the evil.'

CASE 80.—*Nævus of the orbit; Electrolysis; cure.*

A male child, aged 7 months, was sent to me by Dr. Schulhoff in December, 1867, with a congenital nævus at the angle of the right eye, part of it being intra-orbital. It had the size of an almond and was highly vascular. When the child was 5 weeks old, the tumour was on three different occasions cauterised with nitric acid. This (according to the parents) only took the colour out of it, but did not diminish the size of the tumour. At 2 months of age the child was vaccinated in the nævus, which for a time checked its growth; but it soon afterwards began to increase again. It was then twice more cauterised with nitric acid, but as this had no effect, Mr. Nunn, who was then consulted, advised the use of electrolysis. After five applications the tumour seemed entirely destroyed, and a scab was formed. which came off within two weeks. The tumour had a considerable tendency to reproduce itself, and it was therefore again electrolysed from time to time. When I last saw the child (October 1869), no trace of the tumour was left, but only a slight induration of the cellular tissue, for the removal of which I recommended the local application of the tincture of iodine.

CASE 81.—*Papillary Growth in the Arm-pit; Electrolysis; cure.*

A lady, aged 27, consulted me on November 21st, 1866, on account of a small papillary and highly vascular growth which had first appeared in the right axilla since the commencement of 1865, and had somewhat rapidly increased in size during the last few months. It was one-third of an inch long, and one-fourth of an inch wide in its widest part. I introduced a needle connected with fifteen cells of the battery into the base of the tumour, and allowed the current to pass for three minutes. No chloroform or ether spray was used. The current had not acted many seconds when a peculiar change was observed in the tumour, which lost its flesh-colour, and became quite white, as if it had been frozen. When the needle was withdrawn, circulation in the tumour had evidently quite ceased. There was scarcely any pain during the operation, and none at all afterwards, nor was any blood lost.

November 23.—Tumour entirely shrivelled up, looking like a thin brown leaf just adhering to the skin. The operation was therefore not repeated.

December 20.—The eschar fell off about a week after the operation. There is now no sign that there ever was a tumour; no scar nor even redness of the skin being perceptible.

CASE 82.—*Sebaceous Tumour of the Nose; Electrolysis; cure.*

A young lady, of considerable personal attractions, was sent to me by Mr. White Cooper, in April, 1867, for a sebaceous tumour, which she had on the right side of the nose, near the eye, and which had existed for the last three years. The tumour did not give rise to any inconvenience, but spoilt her appearance, and she was therefore anxious to have it removed. A gentle current was used four times within ten days, after which the tumour had disappeared. I saw this lady again in October, 1867, when not the slightest scar, or even redness of the skin, was perceptible on the place where the galvanism had been applied.

For *goître* (*bronchocele, Derbyshire neck*) the electrolytic treatment is also most valuable, because any other surgical interference with such tumours is so dangerous to life that few surgeons are willing to operate. In most of the cases which have been under my care, Mr. Prescott Hewett, Mr. Paget, Sir William Fergusson, Mr. Cæsar Hawkins, and other eminent surgeons, had been previously consulted, and pronounced any of the ordinary operations to be inadmissible. All these tumours were solid, and of very large size, and on that account required a long continuance of the treatment; but I believe that all cases of bronchocele, however large, may be cured by electrolysis, if the treatment be persevered in for a sufficient time. The cystic variety is, of course, much more rapidly curable with it than the solid.

Dr. Morell Mackenzie, to whom we are indebted for so much additional knowledge in the pathology and treatment of diseases of the throat, has kindly given me, in the following lines, his experience with electrolysis in cases of goître :—

'I have used electrolysis as recommended by Dr. Althaus in several cases of goître with a fair amount of success. In one instance in particular, the treatment was rapidly followed by most satisfactory results. The following are brief notes of the case.

'Adelina G., age 17, a native of Savoy, came under my care at the Hospital for Diseases of the Throat on June 14, 1867, on account of a goître which had been coming on for two years. The swelling affected both lobes; each of which appeared about as large as a moderate-sized orange. The hypertrophied tissue seemed to be of moderate density, uniformly distributed and not nodular. The neck measured eighteen inches round, when the tape was carried over the prominences of the thyroid gland.

Treatment by electrolysis was at once commenced, two needles being introduced into the enlarged lobes and kept in for about ten minutes. This operation was repeated on the 16th and again on the 19th, on which day there did not appear to be any change in the form or size of the thyroid glands. On the 22nd the patient was seen again, and as she stated that she was sure that the throat was much smaller, it was measured again and found to be reduced to seventeen inches. The reduction had principally taken place in the right lobe. A week later the left side was much smaller, the throat only measuring sixteen and a quarter inches. On July 5 it was reduced to fifteen and a half inches, and on July 11 it measured only fifteen inches. As there was now no apparent enlargement, the treatment, which had been carried out for less than one month, was discontinued. The patient had been previously treated by an English practitioner who had given her medicine and tincture of iodine to apply externally. Neither had done her any good, and when she came to the Hospital, treatment had been altogether suspended for three months. During the time that the electrolytic treatment was being carried out, no other remedies either external or internal were employed.

So remarkably successful was the treatment that an Italian gentleman well acquainted with the case called at the Hospital, some months afterwards, in order to procure a battery of the same kind for use in the village in Savoy, whence Adelina G. had come. Although he informed me that there were many other similar cases in the same village, I did not recommend him to use electrolysis except under the direction of a medical practitioner.

'In several other cases under my care, benefit resulted from electrolysis. In one very dense hypertrophy, the results were negative. I consider that electrolysis is very useful in cases of moderate duration—six months to two years—and of yielding consistence.'

I will only add to this statement, that in the solid variety a more powerful current is required than in the cystic (viz. from thirty to forty cells instead of ten or fifteen).

Hydatid tumours of the Liver.—Messrs. Durham and Cooper Forster* have, at Guy's Hospital, and the Royal Infirmary for Children, Waterloo Road, successfully electrolysed large hydatid tumours of the liver. In one patient, who was under the care of Dr. Hilton Fagge, and who was operated upon by Mr. Durham, in June 1868, the dulness in the hepatic region measured seven inches vertically, the ribs on that side were bulged, and the intercostal spaces prominent. Two needles were introduced into the most prominent part of the swelling, one piercing the space between the eighth and ninth costal cartilages, and the other about two inches behind it, between the ninth and tenth ribs. The needles were passed into a depth of two or three inches. One of them was then evidently free in fluid, for it could be moved about and rubbed against the other. The posterior needle doubtless passed through the diaphragm, as it was jerked about by the respiratory movement. Both needles were connected with the negative

* The Lancet, July 18, 1868.

pole of ten cells of the battery freshly charged. The positive pole, connected with a moistened conductor, was placed between and near the needles. The current was allowed to pass for twenty-five minutes, and during this time there was a crackling feeling under the finger, as of emphysema, owing to the development of hydrogen from the liquid of the cyst. After the operation there was some pain for four or five hours. In the evening the temperature was 100·9°, and the patient did not sleep well that night. Next day the temperature was 99·6°, and on the morning after it had risen to 101·2°. At this time the hypochondriacal tumour had greatly disappeared, and the man expressed himself as feeling quite well. On examining the right side of the chest, however, Dr. Fagge was a little startled at finding absolute dulness behind, up to the fourth or fifth dorsal vertebra; and over this extent of thorax there was loss of vocal vibration, marked tubular respiration, and ægophonic character of the voice, which afforded conclusive evidence of a large effusion of fluid. There was very slight pain about the points where the punctures had been made, but no pleuritic pain. The man lay on his back and felt quite comfortable. The liquid had evidently been squeezed through the puncture in the diaphragm into the pleural cavity. The man went on perfectly well, and the chest symptoms disappeared rapidly. Twenty days after all traces of the abdominal tumour had disappeared.

The ease with which this patient recovered from the accidental effusion of decomposed hydatid liquid into the pleural sac, adds one to the many instances which I have myself observed of the extraordinary tolerance of the system with regard to electrolytic operations in which only the negative pole is employed internally. If that needle which in Dr. Fagge's patient passed through the diaphragm, had been connected with the positive pole, the life of the patient might have been placed in great jeopardy, as it would have introduced irritant metal salts into the cavity of the pleura.

Mr. Durham has informed me that eight cases of hydatids of the liver have been successfully electrolysed at Guy's Hospital. At the Royal Infirmary for Children, Waterloo Road, Dr. Phillips and Mr. Cooper Forster have used the same treatment in a child, aged 13, which had one tumour in the epigastrium, and the other at the lower border of the liver —one electrolytic operation was sufficient to cure it. In this case there was quite a gradual diminution of the tumours, without any untoward symptoms. In about a week no margin could be felt; and in ten days the liver could be clearly made out.

Cancer.—In my paper 'on the electrolytic treatment of tumours and other surgical diseases' (1867), I expressed myself as follows concerning the value of electrolysis in cancer:—'A larger experience than I command at present is necessary to decide the question, whether the electrolytic treatment will eventually supersede the methods now in use for the removal of cancer. . . . Electrolysis, however, may be applied to every variety of cancer, and it seems to be of little consequence whether or not the tumour adheres to the bones; a circumstance which often renders removal by the knife difficult or impossible. I believe that in this disease the electrolytic method will be found generally useful, not merely by removing the present tumours, but also by so modifying the nutrition of the parts concerned, that no relapse is likely to take place there; and it may thus indirectly help towards the eradication of the cancerous diathesis. It is a curious fact that the peculiar lancinating pains of cancer generally seem to disappear, or at least to diminish considerably, soon after the commencement of the electrolytic treatment, and long before the whole tumour has disappeared.'

I have successfully electrolysed several cases of cancer; but as I do not wish to relate any cases in this section which have not been seen by at least two medical practitioners, I prefer to give the details of a bad case of cancer which has been recently put on record by Dr. Neftel,* of New York.

Dr. Neftel used in his case the 'serres-fines conductor,' described in my paper on the treatment of tumours by electrolysis, which appeared in the 'Medical Times and Gazette' for May 2, 1868 (vide p. 341 of the present treatise).

The patient was a member of the American Congress, and aged 56. In 1868 he consulted a number of eminent surgeons, both in London and Paris, who were unanimous in their opinion concerning the cancerous nature of the tumour, which occupied the left mammillary region. They all refused to operate, as the case was even then looked upon as one of general infection of the system with the cancerous poison, and it was therefore thought that a surgical operation would only accelerate the inevitably fatal result. The tumour was however eventually excised by

* Virchow's Archiv, November 1869, p. 521.

Dr. Marion Sims, in Paris. Soon after the wound had healed, the axillary glands of the left side began to enlarge and formed in January, 1869, a hard swelling of the size of a fist. The patient and Dr. Marion Sims were both at that time in New York, and the same surgeon again excised the tumour, which was exhibited at a meeting of the Pathological Society of New York, and microscopically examined by competent histologists, who pronounced it to be cancerous. Diffuse erysipelas set in after the second operation, with fever and severe constitutional disturbance; the temperature rose to 106°, and there were rigors and delirium. The patient rallied after a time, but the wound afterwards healed very slowly. Cicatrisation was hardly completed when a fresh tumour began to develop itself in the right mammillary region. This grew rapidly, and soon attained the size of an orange.

Further surgical procedures now appeared inadmissible, especially as the general health of the patient had given way. Dr. Neftel therefore proposed to employ the electrolytic treatment. He introduced on three several occasions, in April and May, 1869, at first two, then three, and at last four gilt needles separately into the tumour, and connected them, by means of the serres-fines conductor, with the negative pole of a Daniell's battery, the positive electrode being placed on the skin in the neighbourhood of the tumour. He began with a current of ten cells, which was gradually increased to thirty. The first operation lasted two, the second five, and the third ten minutes. The needles were removed without any hæmorrhage taking place. Immediately after the operation the tumour appeared considerably larger, from the hydrogen which had become evolved in it, but it was softer and more elastic to the touch. No fever or any other unpleasant symptoms supervened; on the contrary, the patient, who had been very feeble, anæmic and cachectic, became stronger from day to day, and the tumour gradually began to shrink. Two months after the first application, it had almost entirely disappeared; and three months after, no trace of it was left. The general health of the patient had improved *pari passu*, and was, when last seen, excellent. No fresh tumours had appeared anywhere.

Dr. Neftel is inclined to believe that electrolysis produces remote constitutional effects, by altering the condition of the protoplasm of the cells in which the poison of the cancer is contained, and by the propagation of which the disease becomes constitutional. As soon as the protoplasm has, by the electrolytic process, lost its specific contagious qualities, the cancer is prevented from reproducing itself, and gradually disappears through the process of absorption.

Lipoma.—Fat being a very imperfect conductor of electricity, lipomas offer more resistance to the electrolytic treatment than other tumours. They may, however, be completely removed by it in course of time. Free alkali being, by the action of the negative pole, developed from the bloodvessels and the connective tissue in which the fat is imbedded, the tumour is gradually changed into an emulsion, which is absorbed into the general circulation.

Slight bleeding may sometimes occur on removing the needles, if the tumour is highly vascular, the galvanic power employed very low, and the needle is too rapidly taken out; but it can always be stopped by again applying the negative pole to the puncture. As a rule, however, there is not the slightest appearance of blood, if the operation is carefully performed.

In leaving this subject I must lay stress on the importance of having a perfectly satisfactory action of the battery, as insufficient galvanic power has in such operations, to my knowledge, been a cause of disappointment. As regards the number of cells to be employed, we must be guided by the nature of the tumour. For cysts and tumours with soft contents less power is required than for hard swellings. *Solid bronchoceles and scirrhus will resist ten or fifteen cells, but yield to thirty or forty.*

XX.—WOUNDS AND ULCERS.

Faradisation is useful where ulcers are slow to heal; and after amputations, where the stump is in a bad condition. Some years ago, I treated by this means a patient upon whom Mr. Spencer Wells had performed amputation of the forefinger. Cicatrisation had been very tardy, and although the wound healed at last, the stump remained livid, very soft, was exceedingly sensitive to touch, and bled easily. Under the influence of faradisation, it became much firmer, acquired a healthier colour, was less sensitive to touch, and never bled again. Mr. Mitchell Henry has informed me that he has, in patients who were under his care in the Middlesex Hospital, found the same means very beneficial for improving the secretion of ulcers ; and Dr. Ruschenberger, of the United States' Navy, has successfully used the induced current for the cure of unmanageable decubitus. Mr. Nunn, of the Middlesex Hospital, has also adopted this mode of treatment for the sequelæ of mammary abscess, in sinus of the breast, and the painful œdema, which is so apt to remain after the more acute phenomena of inflammation have subsided. In several instances, Mr. Nunn has seen, after one application, the indolent edges of the fistulous opening assuming a healthy appearance, and the dull red colour of the infiltrated skin giving place to a tint peculiar to resolution. In all these cases, faradisation acts by stimulating the vasomotor nerves, in consequence of which the activity of the bloodvessels is increased, and the absorption of exudation-products is promoted.

The continuous current is likewise valuable in such cases. Mr. Spencer Wells,* who has used it a good deal, has come to the conclusion that there is no means so capable of producing a rapid growth of healthy granulations as the continuous current, and that often a very beneficial change is effected in the condition of ulcers within twenty-four hours. Mr. Wells found that if two slight excoriations, two ulcers or suppurating surfaces on a limb or any part of the body were subjected to the action of a single galvanic pair, the zinc being applied upon one and the silver upon the other, the surface beneath the silver rapidly cicatrised, while that beneath the zinc was in two days converted into a superficial eschar. To insure the passage of the current it is not necessary to denude, but only to moisten the cuticle. If the plates be still kept applied, the eschar extends to the subcutaneous cellular tissue, and presents all the

* Appendix to Dr. Golding Bird's Lectures on Electricity and Galvanism. London, 1849.

characters of a slough produced by caustic potash, except that the dead tissues are a little less compact. After the separation of these sloughs cicatrisation under ordinary applications is very tardy, but sets in at once if the silver plate be applied, zinc being fixed on some neighbouring part.

Professor Schwanda* has used static electricity for the treatment of primary syphilitic sores which did not heal under the usual applications, and seen them heal rapidly after the electricity had been used.

XXI.—DEFORMITIES.

1. *Club-foot.*—In some forms of club-foot, where the deformity is caused by a semi-paralytic condition of the tibial muscles, faradisation of the latter has done good. In pes planus, where the sole has lost its normal arch, M. Duchenne has recommended faradisation of the peronæus longus muscle.

2. *Curvature of the Spine.*—Dr. Brückner† has recommended the use of electricity in cases of scoliosis. In order to diminish the lumbar curvature, the lumbar portion of the left latissimus dorsi muscle should be faradised. The motor point of the nervus subscapularis longus, which animates this muscle, is situated at the edge of the muscle, by the arm-pit; the negative pole should be applied to this point,

* Wochenblatt der k. k. Gesellschaft der Aerzte in Wien. February 10, 1869.

† Berliner klinische Wochenschrift, 1869, No. 46.

while the positive is placed alternately to the left side of the lumbar vertebræ, and to the right serratus major, and between the vertebral column and the scapula. The elbow should, during this application, rest on the edge of the chair. At the same time the continuous current should be applied to both concavities for about five minutes. After three weeks of this treatment Dr. Brückner lets the patient wear a supporting apparatus with a steel-belt, and crutches under the arm-pits.

XXII.—INTRODUCTION OF DRUGS INTO THE SYSTEM BY THE AID OF ELECTRICITY.

Fabré-Palaprat* has thought it possible to introduce drugs into the human body by the aid of electricity. He fixed a compress, moistened with a solution of iodide of potassium, and covered by a platinum disc connected with the negative pole of a voltaic pile of thirty pairs of plates, on one of his arms, and another compress, moistened with a solution of starch, and covered by a platinum disc connected with the positive pole of the battery, on the other arm, after which the current was allowed to pass for some time. He says that after a few minutes the starch acquired a blue tinge, showing that the iodine had travelled from one arm to the other. From this and other observations he concluded that medicinal substances might by the galvanic current be introduced into the system, and then *ad libitum* either be allowed to remain in it, or removed from it after having traversed the body.

Our present physiological knowledge enables us to say that it is impossible, by any contrivance, to prevent the elimination of medicinal substances from the body; and

* Archives générales de Médecine, vol. ii. p. 432. Paris, 1833.

one of Fabré-Palaprat's propositions may therefore *à priori* be eliminated from the inquiry. The other proposition, viz., that electricity may serve to introduce drugs into the system, is likewise untenable, as those who have repeated Palaprat's experiments have never been able to perceive any passage of iodine from the negative pole of the battery through the human body to the positive pole. We must therefore conclude that Fabré-Palaprat's observations have not been made with sufficient care, and that he was consequently led to erroneous deductions. Perhaps he was hardly fit for making such observations, as, according to his own account, he suffered from 'ecstatic spasms' about the time when he worked on this subject.

In 1846, Dr. Klenke * announced that he had cured a number of more or less intractable diseases by the galvanic introduction of medicines into the system. For struma he introduced iodide of potassium, for syphilis mercury, &c. Dr. Hassenstein † has likewise published an abstruse memoir on this subject; but neither Klenke nor Hassenstein have been able to satisfy the profession of the accuracy of their observations.

Voltaic narcotism.—In 1859 Dr. Richardson * proposed to induce anæsthesia by a combination of electricity with narcotics. For this he used Pulvermacher's chains, and a solution of equal parts of tincture of aconite and chloroform. He experimented on dogs and rabbits, and afterwards on men; and produced anæsthesia to such an extent, that severe operations could be performed with little or no pain. The expectations which were at first entertained of this new mode of inducing anæsthesia have, however, not been realised. Dr. Waller has shown that the application of a mixture of equal parts of tincture of aconite and chloroform alone produces loss of vascularity and nearly complete

* Zeitschrift Wiener Aerzte, Mai 1846.

† Chemisch-electrische Heilmethode. Leipzig, 1853.

† Medical Times and Gazette, February 12, 1859.

anæsthesia in the human skin in ten or fifteen minutes; that electricity neither retards nor accelerates this process; that the anæsthesia is limited to the spot to which the narcotising mixture is applied, and that it is caused by the local absorption of the mixture; that this absorption may produce death in animals, and might be dangerous in infants and children; and that the action of the narcotic mixture with or without electricity, when applied to the healthy skin, is followed by a severe local inflammation of an obstinate character, which would be a bad complication in surgical operations.

Dr. Richardson has since then given to the profession a far readier means of producing local anæsthesia in the ether-spray; and he has thus made ample compensation for any disappointment which may have been caused by the failure of voltaic narcotism.

XXIII.—EXTRACTION OF METALLIC SUBSTANCES FROM THE HUMAN BODY: THE ELECTRO-CHEMICAL BATH.

In 1855 M. Poey stated in a paper which was read before the French Academy, that it is possible to extract various metallic substances from the human body by the aid of electricity; whether they have been taken as remedies, or have become absorbed into the system of persons occupied in the different arts and trades in which their employment is required. He relates that an electro-plater, at Havana, who had frequently immersed his hands into solutions of nitrate and cyanide of gold and silver, became affected with a bad ulcer which resisted every treatment. On one occasion, while preparing a bath for electro-plating, he immersed his hands into the liquid, before the object to be plated had been in it, and noticed that the negative wire became covered with a metallic coating. From this it was concluded that these deposits came from the hands of the electro-plater, who was advised by M. Poey to repeat the operation in order to extract any particles of metal which might be remaining. The result was that his hand was completely cured.

The 'electro-chemical bath' consists of a large copper tub filled with water, and insulated from the ground; and the patient sits in the tub on a wooden seat, which is likewise insulated. If mercury, silver, or gold is to be extracted, the water in the tub is acidulated with nitric or hydrochloric acid; if lead is to be extracted, sulphuric acid is added. One end of the tub is connected by means of a screw with the negative pole of a battery of thirty pairs; while the positive pole is held by the patient in the right and the left hand alternately. The positive electrode is made of iron, and covered with moistened linen. The galvanic current now enters the body by one of the arms; it circulates, according to M. Poey's graphic description, everywhere, from head to foot, traverses all the internal organs, and even the bones, seizes every particle of metal which it meets on its journey, restores it to its primitive form, and deposits it on the entire surface of the sides of the tub, more especially opposite that part of the body where the metal is supposed to exist. M. Poey describes the case of a patient, who complained of pain in the arm in consequence of having taken mercury; the man was put into the bath, and the arm became delineated on the negative plate, by the deposit of the metallic molecules which came from the limb. He also states that he has drawn from the femur and the tibia of another patient a large quantity of mercury which, according to some physicians, had existed in these bones for fifteen years.

Further reports on the efficacy of the electro-chemical baths have since then been brought forward, but in a singularly objectionable manner. The latest publication on this subject contains, amongst other things, a fac-simile of the medals which have been awarded to a zealous advocate of the bath! It would have been much more satisfactory if, instead of that, scientific proofs of the possibility of extracting metals from the body had been given. For us it is impossible to understand how the galvanic current can convey into the liquid of the bath, and diffuse on the whole surface of the sides of the tub, metallic atoms which, according to the established laws of electro-chemistry, ought to be deposited only upon the surface of the electrodes. Again, in many cases patients are said to have been suffering from the effects of poisonous metals in the system, but no proofs of the actual presence of such metals in the body have ever been forthcoming. Let a patient be put into the bath where there is no doubt about the presence of a foreign metal in the system; as, for instance, one who has become blue by the prolonged use of nitrate of silver; when such a patient has been rendered white by the bath, I shall be convinced, but not until then. The American patient, Eli B., who made a tour of the European hospitals ten years ago, and who was a sort of celebrity as the 'blue man,' had taken a large number of electro-chemical baths at New York, in order to get rid of the blue colour, but without the least effect; and this is, in my opinion, a strong case against the electro-chemical bath. I willingly admit that in some cases of rheumatism and allied affections the electro-chemical bath may be of service, especially when combined, as is now often done, with a local application of the current to the suffering part; but there it does not act by extracting metals; nor can we doubt that in many cases the electro-chemical bath must be ineffective or hurtful, where a proper application of electricity to the suffering part alone might cure the patient.

XXIV.—THERAPEUTICAL USE OF ELECTRICITY IN MIDWIFERY.

Bertholon in France, Herder, Stein, and Kilian in Germany, and Drs. Radford and Barnes in this country, have recommended and used electricity in cases of tedious labour and hæmorrhage from the uterus, especially in some forms of placenta prævia; and for originating uterine contractions in cases where it is necessary to induce premature labour. As to the mode of application, Kilian has recommended applying a galvanic forceps, the blades of which consist of two different metals. Dr. Radford proposed the application of one pole to the abdominal parietes over the fundus uteri, and of the other to the os uteri by means of a vaginal conductor. Mr. Cleveland, on the contrary, has directed the two poles to the abdomen externally, and the same proceeding has been adopted by Dr. Barnes, while Dr. F. W. Mackenzie insists that it is necessary to apply the positive pole to the nape of the neck and the negative to the cervix uteri, if we wish to act energetically upon the contractile fibre-cells of the uterus.

Professors Simpson and Scanzoni consider electricity in midwifery all but useless, and believe that when uterine action has apparently been excited by galvanism, this has been either a mere coincidence, or it has resulted from the impression made on the mind of the patient, or by mechanical irritation of the uterus or the abdominal parietes by the electrodes. Dr. F. W. Mackenzie's experiments, however, certainly show that in cases of placenteal presentation, in which profuse hæmorrhages continue to recur, notwithstanding the employment of the plug and other means, before the os is sufficiently dilated to admit of manual assistance; and in cases of hæmorrhage in the early months of pregnancy, which resist other treatment, and which from the constricted state of the os and cervix uteri do not admit either of mechanical or manual interference, faradisation is invaluable.

This is corroborated by the experience of Dr. Kühn,* who used the induced current in the case of a woman in whom, eighteen hours after delivery, the placenta had not been expelled on account of atony of the uterus. One

* Comptes rendus, October 1860.

conductor was placed to the cervix, another to the abdominal parietes above the uterus. The circuit had scarcely been closed when the uterus contracted and expelled the placenta.

The most recent experiments on this subject have been made by M. de St. Germain,* who states that in no case have uterine contractions been induced where they had not already spontaneously commenced. This explains, according to him, the discredit into which the electric current has fallen as a means of inducing premature labour. He has also found that, wherever labour pains have commenced, occurring at intervals of fifteen or twenty minutes, on the application of the conductors to the lateral parts of the abdomen, in about ten minutes, a remarkable increase of the uterine contractions occurs, and that contractions so induced are much more prolonged and more painful than others. The dilatation of the os uteri has constantly taken place with rapidity, and a fact to be particularly insisted upon, especially as it is not noticed by Barnes and Radford, is that the expulsion of the placenta immediately follows that of the infant, being either spontaneously projected beyond the vulva or capable of removal without the slightest traction. In two cases only the infant exhibited a slight bluish colour, but in these the cyanosis could be explained by constriction. M. de St. Germain believes that faradisation should be submitted to further investigations, and expects that it will prove chiefly useful for a rapid expulsion of the placenta.

Puerperal eclampsia.—Mr. Parsons, of Islip,† has recorded the case of a woman who, during her seventh confinement, was taken ill with severe and frequent eclamptic fits, with complete cessation of uterine contractions. He applied galvanism (faradisation) externally, with immediate effect, the bags of membrane becoming tense and protruding

* Medical Times and Gazette, November 13, 1869.

† British Medical Journal, vol. i. 1868.

through the os. Within three-quarters of an hour from the commencement of the galvanism the child was born; the galvanism was again applied after the placenta had been expelled, in order to ensure perfect contraction. Although there was albuminuria, the patient made a good recovery, and never had a return of the fits afterwards.

In conclusion, I will say a few words on the accidents which may be caused by an injudicious application of electricity. This powerful agent is not one of those remedies which, if they do no good, can do no harm; but on the contrary, it may, in the hands of an inexperienced operator, do a great deal of mischief. Blindness has been caused by an improper application of the continuous current to the face; fainting, cramps, hysterical fits, and palsies have been induced by administering powerful shocks; and fresh apoplectic attacks have thus come on in patients who had suffered before from hæmorrhage into the brain. Accidents of this kind can only be avoided if the operator is guided by physiological knowledge and sufficient therapeutical experience. With this remedy more than with any other the mode of application has an all-important bearing upon the results; for it is not electricity that cures diseases, but the physician, who may cure diseases by means of electricity.

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