GUILLEMINOT'S HANDBOOK
of MEDICAL ELECTRICITY

HANDBOOK

OF

Electricity in Medicine

BY

DR. W. H. GUILLEMINOT

(Paris)

TRANSLATED BY

W. DEANE BUTCHER, M.R.C.S.

Surgeon to the

London Skin Hospital

With Eight Plates in Colours and Seventy-nine Illustrations

NEW YORK

REBMAN COMPANY

1123 BROADWAY

1906

LONDON

REBMAN LIMITED

129 SHAFTESBURY AVENUE

Printed in America

TRANSLATOR'S PREFACE

It has been well said that the man who has learned two languages possesses two souls. Still more truly may it be asserted, that he who has studied a science from the different points of view of two schools of thought, possesses a double understanding of his subject.

In the past, we have been greatly indebted to the school of French electrology, the school of *du Bois Reymond* and *Duchenne,* of *Apostoli* and *d'Arsonval.*

I trust I am doing a service to the English-speaking race, by introducing to its notice the more recent work of the French electro-therapeutic school, so ably summarized by *Dr. Guilleminot.*

W. DEANE BUTCHER.

Ealing, 1906.

PREFACE

Of all the subsidiary branches of medicine, Medical Electricity is the one which has made the greatest advances during the last few years.

Static electricity, and the Galvanic and Faradic currents have long been used for treatment. Recently, however, other forms of electrical energy, high frequency currents, sinusoidal currents, undulatory currents and others, have been introduced, and their therapeutic value abundantly proved. To these may be added the luminous and caloric radiations, the X-rays, and forms of radiations with every variety of wave length, from the slow vibrations of the Hertzian waves, up to high frequency currents, and the rapid oscillations of ultra-violet light.

Medical radiology, of which Röntgen radiology is but a branch, has considerably extended the domain of the medical electrician. The use of the newer radiations cannot be dissociated from electrical practice, practically because these radiations are usually generated by some form of electrical apparatus, and theoretically because all transverse oscillations of the ether are in reality electrical phenomena. *Maxwell's* electro-magnetic theory of light receives fresh confirmation every day.

The medical electrician, therefore, must be as well acquainted with radiant electricity as with current electricity.

His knowledge, however, must not end here. It is not enough to be an electrician and an expert operator. He must also be a master of physical biology. All vital processes are connected with electric phenomena,—osmosis, alterations in surface tension, ionisation, the various chemico-physical processes connected with assimilation and catabolism, the functions of nutrition and cell motion, are all accompanied by the production of electricity. They are occasioned by differences of potential which may be demonstrated experimentally.

If the progress of science finally enables us to master this force, which is the very essence of life, and to subjugate it, as steam has been subjugated to the service of mankind, we shall have ready to our hands the most potent curative agent ever imagined to modify the evolution and ameliorate the condition of living beings.

Unfortunately we have not yet arrived at this stage. None the less is it important for us to study all the facts which demonstrate the production of electricity by living tissue. Quite recently a new group of phenomena has been discovered, which if they are confirmed by further investigation, will establish a new link between life and electricity. The newly discovered radiations of MM. *Blondlot* and *Charpentier* add one more evidence of the fact that all perturbation of living tissue is accompanied by a difference of electrical potential, and creates around it a field of irradiation. Without anticipating discoveries still in a nebulous state, we may assert that medical electrology should embrace the study of animal electrogenesis which touches so nearly our very conception of life.

The practitioner who endeavours to employ the various forms of electric energy without a knowledge of the laws which govern them, is but an artisan working by rule of thumb, incapable of improvement, and always liable to failure.

Each year brings to us a long procession of new discoveries. Medical sciences cannot afford to await maturity before being formulated. As new materials accumulate in the laboratory, the whole of the raw material of past knowledge must be thrown into the furnace, and our scientific and medical theories must be recast.

I present this work therefore as a synthesis of our knowledge concerning the different forms of electrical energy. It has been written under the powerful impulse of *Prof. Bouchard,* and of a school which has done good services in all branches of medicine.

Prof. Bouchard has ever insisted on the idea that medicine must tend more and more to take its place among the exact sciences. His observations have always been made "chiffres en main." He is physicist, chemist and mathematician in turn. Hence he has ever welcomed with enthusiasm the advances of biological physics and medical electricity.

It was in his laboratory that he foretold the part that X-rays would play in medicine, at a time when the X-rays were a mere object of curiosity. In a few months he demonstrated the wide rôle that Radioscopy was destined to play in medicine. The diagnosis of pleurisy, tuberculosis, aneurism, and the influence of the Hertzian waves were studied at a very early period in the laboratory of the Hôpital de la Charité.

These researches were continued when *Prof. Bouchard* placed in my hands the direction of the Laboratory. Some of my arrangements of apparatus have come into general use, such as my focus-tube stand with indicator of incidence, and my high frequency spirals. Others, such as the ortho-diagraph and the radio-cinematograph, have given useful results in the study of the thoracic organs.

It was in this laboratory, as long ago as 1860, that *Prof. Bouchard* did his work on the injurious effects of coloured light of various wave lengths on the skin. Erythema pellagreux was identified as a solar erythema, and the "coup de soleil" was shewn to be the effect of violet radiations of short period.

Since then, whenever new facts or hypotheses have appeared, whether X-rays, high frequency currents, the radiations of *Blondlot,* or the radiation of radio-active substances, they have been received with enthusiasm, and subjected to a searching and critical examination. This work has been written with the dominant idea that medicine should draw as much assistance as possible from the accessory sciences, and more especially from physics. The theoretical study of electrical energy in the first part of my book should not discourage the student, nor should the study of physiological effects which I have treated in the second part. Both are the necessary prelude to the practice of electro-therapeutics.

With a knowledge of the science of electricity, the medical electrician will have a sense of intellectual satisfaction accompanying each step of his career, and will be duly armed, so as to be able to apply his art with precision and to mark out for himself new paths for conquest.

A mode of treatment which has given such unlooked for results in Cancer—the most incurable of all maladies, —may certainly expect further triumphs. There is much work to be done, and we may be certain that the future of Electro-therapeutics reserves for us still further surprises, and for humanity still greater services.

TABLE OF CONTENTS

(*The figures to the left indicate paragraphs, those on the right, pages.*)

INTRODUCTION

PART I.—PHYSICS

CHAPTER I.—The Galvanic or Continuous Current.

I. *General Considerations on the Action of the Galvanic Current.*

2. *Production of a Continuous Current for Medical Work.*

a. Factors Common to All Forms of Electric Generator.

b. Continuous Current Derived from a Battery of Galvanic Cells.

c. Continuous Current Derived from Accumulators.

d. Continuous Current from a Dynamo.

e. THE USE OF THE CONSTANT CURRENT FROM THE PUBLIC MAIN FOR MEDICAL PURPOSES.

3. *Medical Employment of the Continuous Current.*

CHAPTER II.—The Faradic Current.

1. *General Considerations.*

2. *Production of a Faradic Current in an Induction Coil.*

3. *Technique of Faradisation for the Medical Electrician.*

CHAPTER III.—Sinusoidal and Undulatory Currents.

CHAPTER IV.—High Frequency Currents.

1. *General Considerations.*

2. *Production of High Frequency Currents.*

3. *Employment of High Frequency Currents.*

CHAPTER V.—Static Electricity.

1. *General Considerations.*

2. Dielectrics—Condensors.

3. Electrostatic Quantities and Units.

4. Electrostatic Machines.

5. *Effects Produced by Static Machines.*
The Static Breeze. Effleuve. Sparking. Morton's Currents.

CHAPTER VI.—The Röntgen Rays.

1. *General Considerations.*

2. *The Crookes Tube or Focus Tube.*

3. *Character and Mode of Employment of the X-Rays.*

4. *Application of X-Rays in Medicine and Surgery.*

CHAPTER VII.—Galvano-cautery.

CHAPTER VIII.—Ozonisation.

CHAPTER IX.—Electricity as a Generator of Motion. Vibratory Massage. Passive Gymnastics, etc.

CHAPTER X.—Phototherapy and Thermotherapy.

CHAPTER XI.—Magnets and Electromagnets.

PART II.—PHYSIOLOGY.

CHAPTER I.—Physiological Action of the Continuous Current in its Constant State.

1. *Definitions.*

2. *Physico-Chemical Action of the Constant Current —Electrolysis—Cataphoresis.*

3. *Physiological Effects of the Continuous Current.*

4. *Appendix—Electric Phenomena Proper to Living Tissue—Animal Electrogenesis.*

CHAPTER II.—Physiological Effects of Variations of Current.

1. *General Considerations.*

2. *Effect Of the Variable State of Opening and Closure of a Continuous Current.*

3. *Physiological Action of the Faradic Current.*

4. *Physiological Action of the Galvano-Faradic Currents.*

5. *Physiological Action of the Sinusoidal Current.*

CHAPTER III.—High Frequency Currents.

CHAPTER IV.—Physiological Action of Static Electricity.

CHAPTER V.—Physiological Action of the Various Radiations.

CHAPTER VI.—Physiological Action of Ozone.

CHAPTER VII.—The Physiological Properties of Magnets. Mechanical Application of Electricity.

PART III.—MEDICAL TREATMENT.

CHAPTER I.—The Neuro-Muscular and Neuro-Sensitive Systems.

1. *General Considerations.*

2. *Electrodiagnosis and Technique.—Abnormal Reactions.—Motor Points.*

3. *Electrical Diagnosis and Treatment.*

a. Diseases of Muscles.

b. Affections of the Nerves.

c. DISEASES OF THE SPINAL CORD.

d. DISEASES OF THE MEDULLA OBLONGATA, THE PONS AND CEREBELLUM.

e. DISEASES OF THE ENCEPHALON.

f. NEUROSES.

g. LOCAL AFFECTIONS OF NERVOUS ORIGIN.

h. ANAESTHESIA.

CHAPTER II.—The Vascular and Lymphatic Systems.

CHAPTER III.—Bones and Joints.

CHAPTER IV.—Electrical Treatment in Gynæcology.

CHAPTER V.—Andrology.

CHAPTER VI.—Affections of the Kidney, the Bladder and the Urinary Organs.

CHAPTER VII.—Skin Diseases.

CHAPTER VIII.—Diseases Due to Defects of Nutrition.

CHAPTER IX.—Diseases of the Mouth, Throat, Nose, Larynx and Ear.

1. *The Nose and Nasal Fossae.*

2. *The Mouth.*

3. *The Larynx.*

4. *The Ear.*

CHAPTER X.—Diseases of the Respiratory Passages.

CHAPTER XI.—Affections of the Lower Digestive Tract.

CHAPTER XII.—Diseases of the Eyes.

CHAPTER XIII.—Malignant Tumours.

CHAPTER XIV.—Foreign Bodies.

INTRODUCTION

1. **Divisions.**—This work is divided into three parts.

Part I is devoted to the Physics of electricity and to questions of technique.

Part II deals with the physiological effects of the various forms of electricity, and with the other physical therapeutic agents in which electricity is the motive force.

Part III contains the medical portion of the work. The electro-diagnostic and electro-therapeutic treatment of each disease are treated together. Electro-diagnosis was formerly confined almost entirely to a single division of neuro-muscular pathology, but its scope has of late become greatly enlarged. The third part therefore forms a sort of compendium. Under each pathological condition are given firstly its diagnosis, and then the various methods of treatment.

PART I.

PHYSICS.

2. **Division of the subject.**—The medical electrician employs various forms of electrical energy.

Not only is electricity employed directly as a therapeutic agent, but it is also used as a generator of motion, heat, light, Röntgen rays and physico-chemical reactions. It is also used indirectly for such purposes as the generation of ozone. In the first part we propose to study briefly the physical facts which must be understood to enable us to utilise electrical energy in all its forms.

We shall take them in the following order:

I.—Galvanic Currents.

II.—Faradic Currents.

III.—Sinusoidal Currents.

IV.—High-frequency Currents.

V.—Electrostatics.

VI.—Röntgen Rays.

VII.—Electro-cautery.

VIII.—Ozonisation.

IX.—Electricity as a Generator of Motion in Vibratory Massage, etc.

X.—Phototherapy and Thermotherapy.

XI.—Magnetism and Electromagnets.

CHAPTER I.

THE GALVANIC OR CONTINUOUS CURRENT.

I.—General consideration on the action of galvanic currents.

3. **Definition.**—The term galvanic current, or continuous current, is applied to the phenomena which occur throughout the length of a conductor, the two ends of which are maintained at different potentials by an electromotive force.

The typical continuous current is that which is obtained from an ordinary galvanic cell. The current remains constant so long as the potential at the extremities of the conductor is kept constant, *i.e.,* when there is no variation in the condition of the cell during use.

4. **Character of the continuous current.**—Fig. 1 shows the curve of the continuous current, the lapse of time being represented by the abscissæ, and the strength of the current by the ordinates. The *variable period of closure* is

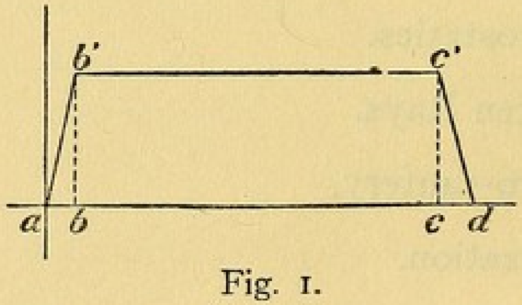


Fig. 1.

represented by a b. It is the interval during which the current is attaining its full value. If the circuit is closed instantaneously, a b' is nearly vertical. If, on the contrary, the current is increased gradually from zero to its full value by means of a rheostat, a b' will be oblique.

The *period of the permanent state* is represented by b c, the interval during which the current passes. If the current is constant, b' c' will be parallel to b c.

The *variable period of break* is represented by c d, the time that elapses during the opening of the circuit.

5. **Electrical quantities and units.**—When a current passes through a conductor there are a number of factors to be considered. These include the electromotive force, the difference of potential between the extremities of the circuit, the intensity of the current, the quantity of electricity, the resistance and conductance of the circuit, and the specific resistance and conductivity of the metal forming the conductor, the capacity of the conductor, the electric energy and the power of the current.

All these quantities require different units for their measurement, the Volt, Ampere, Coulomb, Ohm, etc., which are derived from the three fundamental units of the C.G.S. system.

6. **Fundamental quantities and units of the C.G.S. system.**—The three fundamental quantities in the C.G.S. system are:

Length	L
Mass	M
Time	T

The symbols L., M. and T. are usually used to represent these quantities.

The corresponding units employed are:

The Centimetre	C
The Gramme	G
The Second	S

7. **Derived Electro-Dynamic Quantities.**—All other

quantities, such as quantity of electromotive force, strength of current, etc., are derived from the fundamental quantities L., M. and T., and are expressed as functions of L., M. and T. The units used in the measurements of these quantities are similarly derived from the fundamental C.G.S. units.

Every derived unit has its own symbolic formula, composed of the letters L. M. T. with suitable indices. This formula is said to indicate the *dimensions* of the quantity, or the relation which the unit bears to the fundamental quantities. Thus the measurement of area has for its dimensions L^2, the product of two lengths. A velocity has the dimensions $\frac{L}{T}$ or $L\ T^{-1}$, since it is a length, the distance travelled, divided by the time employed in traversing the distance.

The strength of a magnetic pole is $\sqrt{L^3MT^{-2}}$ or $L^{3/2}M^{1/2}T^{-1}$, for it is the square root of a force, LMT^{-2} multiplied by a length L.

These symbols enable us to tell at a glance how a derived quantity will vary when we alter the value of one of the fundamental quantities from which it is derived.

8. **Derived Electro-dynamic Units.**—Electro-dynamic quantities are measured by units derived from the fundamental units.

The units used in practise are generally multiples or sub-multiples of the theoretical units. Thus the ampere, the practical unit of current, is $^1/_{10}$ of the C.G.S. unit.

The electrical units in general use are those adopted by the Congress of Chicago in 1893. They are called the International C.G.S. units.

9. **Intensity of Current I.**—The intensity of a current is the magnitude of the flow of electricity along a con-

ductor. Its dimensions are $L^{1/2}M^{1/2}T^{-1}$. The C.G.S. unit of intensity is the intensity of a current, which when traversing a conductor one centimetre in length, bent into an arc of a circle one centimetre in radius, will exert a force of one dyne on a unit magnetic pole placed at the centre of the circle.

The ampere, or practical international unit, is one-tenth of a C.G.S. unit. The unit chiefly used in medicine is the milliampere, equal to $\frac{1}{1000}$ ampere.

10. **Quantity of Electricity Q.**—When water flows through a pipe, the quantity of water issuing from the pipe in a given time is a function of the strength of the current. The strength of the current may therefore be measured by the quantity poured out in unit time, and the intensity of the current is therefore the quotient of the total quantity of water divided by the time.

Conversely, the total quantity of water obtained in a given time is the product of the strength of the current into the time. In order to obtain the symbolic formula for quantity therefore, we must multiply the expression for strength of current by the fundamental unit T.

In like manner the quantity of electricity is the product of the intensity of current by the time, and its formula is therefore $L^{1/2}M^{1/2}T^{-1}$ multiplied by T or $L^{1/2}M^{1/2}$.

The C.G.S. unit of quantity is the quantity carried by unit current in one second.

The practical unit is the Coulomb, which is equal to one-tenth of a C.G.S. unit.

11. **Electromotive Force E.**—The Electromotive force, E.M.F., is the physical or chemical cause which maintains a difference of potential at the two extremities of a circuit, and thus causes an electric current to flow through it.

A given quantity of water in falling will perform an amount of work proportional to the height through which it falls. When the quantity of water is kept constant, the work done may be taken as a measure of the height through which the water has fallen.

Similarly a given quantity of electricity will perform an amount of work proportional to its difference of potential, or the electro-motive force which causes it to move. This work is the product of the quantity into the electromotive force. Electromotive force is thus measured by work L^2MT^{-2} divided by a quantity of electricity $L^{1/2}M^{1/2}$. Its dimensions are therefore $L^{3/2}M^{1/2}T^{-2}$.

The unit of electromotive force is the force which, when applied to unit quantity of electricity, will produce one C.G.S. unit of work (one Erg).

The Volt, which is the practical unit of electromotive force, is 10^8 C.G.S. units.

12. **Difference of Potential V.**—The difference of potential caused by an electromotive force is a direct function of that force.

For the definition of absolute potential the reader should consult paragraph 143 of the chapter on Electrostatics.

The dimensions of the difference of potential will be the same as those of electromotive force, *viz:* $L^{3/2}M^{1/2}T^{-2}$. The unit is also the same for difference of potential and for electromotive force. The practical unit for both is the Volt.

13. **Resistance R.**—The resistance of a circuit is the obstruction which it offers to the passage of the electric current. The resistance of any conductor is a function of its cross section, its length, and a coef-

ficient called the resistivity, which varies according to the substance of which it is made.

The resistance is measured by the ratio of the E.M.F. to the current through the conductor. It is the quotient of an electromotive force by an intensity and is therefore represented by $L^{3/2}M^{1/2}T^{-2}$ divided by $L^{1/2}M^{1/2}T^{-1}$, or LT^{-1}.

The C.G.S unit of resistance is the resistance of a conductor through which unit electromotive force will cause unit current to flow.

The Ohm, the practical unit of resistance is 10^9 C.G.S. units of resistance. It is represented by the resistance at 0° Centigrade, of a cylinder of mercury 106.3 centimetres in height and weighing 14.4521 grammes.

14. **Capacity C.**—The capacity of a conductor is the ratio of its charge to its potential, $\frac{Q}{V}$. Its dimensions are T^2L^{-1}. (175 and 168.)

When a conductor is such that unit quantity of electricity increases its potential by one C.G.S. unit, that conductor is said to have unit capacity.

The practical unit of capacity is the Farad. It is the capacity of a conductor which when charged with one Coulomb has a potential of one volt. A Farad is equal to 10^9 C.G.S. units.

15. **Electric Energy or Work W.**—The unit by which all work is measured has the dimensions L^2MT^{-2}, being the product of a force LMT^{-2} into the distance, L, through which the point of application is moved. The C.G.S. unit of work is the Erg, which is the work done by one dyne in moving its point of application through a distance of one centimetre. The C.G.S. unit of electrical work is also the erg. The Joule, the practical unit of work, is equal to 10^7 ergs. It is the work done in one

second, by a current of one ampere, in passing through a conductor whose resistance is one ohm.

16. **Power P.**—The power of a machine is its rate of doing work. Power is therefore measured by the quotient of the work done L^2MT^{-2}, by the time taken T, and its formula is therefore L^2MT^{-3}.

The C.G.S. unit of power is the power of a machine which will do one erg of work per second.

The practical unit of electrical power, one Joule per second, is termed a Watt. The watt is equal to 10^7 ergs per second.

17. **Relations between the Different Quantities.**—(A) *Ohm's Law.*—The intensity I of a current is equal to the electromotive force E, divided by the resistance of the circuit R.

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

whence $$E = IR$$

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

(B) The quantity of electricity is measured by the product of the current into the time during which it is passing.

$$Q = IT$$

(C) The work W, produced by a quantity of electricity Q, is proportional to the electromotive force E which drives it.

$$W = QE = EIT = I^2RT$$

(D) The power is the work done in unit time. It is therefore measured by the total work EIT, divided by the time taken T.

$$P = EI$$

II. Production of Continuous Currents for Medical Work.

I. FACTORS COMMON TO ALL FORMS OF ELECTRIC GENERATORS.

18. **Character of current suitable for medical purposes.**—For medical work, continuous currents must be constant, *i.e.,* their characteristic curve should be a straight line parallel to the time axis of the curve. The maximum electromotive force should be from 40 to 50 volts, since the current should be capable of variation from 0 to about 250 milliamperes. Such a current may be obtained from a battery of primary cells, from accumulators, or from a dynamo; or if there is a continuous current supply from the public mains, this may be utilised directly.

For the application of the current we need resistances, conducting wires, and various measuring instruments. The whole apparatus for measurement and regulation is generally placed together on a distributing board or table.

19. **Constants of the Continuous Current Generator.**—Whatever form of generator is used for the production of the current, we may consider it as possessing a definite electromotive force E, and an internal resistance r.

In a primary galvanic cell the electromotive force is determined by the chemical reaction which takes place on the surface of the metal plate. Its value is therefore constant whatever the shape and size of the cell may be.

The current has, however, a certain resistance to overcome while traversing the liquid in the cell, in order to reach the positive electrode. This resistance, which varies with the composition of the liquid in the cell, and with the distance between the electrodes, is termed the *internal resistance* of the cell.

20. **Current generated by an electromotive force E, with internal resistance r.**—If the terminals of an electric generator be connected by a conductor of resistance R, the

current which will traverse the circuit is perfectly definite. We may determine mathematically its strength and power, and the difference of potential at the two terminals.

21. **Intensity of Current produced by a Generator with Constants E, and r, in a conductor of Resistance R.**—The strength of a current is equal to the electromotive force E, divided by the total resistance of the circuit, *i.e.*, by the sum of the internal and external resistances. This is expressed by the equation:

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

22. **Power of the Current.**—The power of a generator is given by the formula

$$P = EI$$

This power is composed of two portions, the *useful power* and the *internal power* which is dissipated as heat.

(a) The external or useful power; *i.e.*, the available power P_u is given by

$$P_u = VI$$

where V is the difference of potential at the terminals, and I is the intensity of the current.

(b) The internal power $P\theta$ is given by *Joule's* law,

$$P\theta = rI^2.$$

Note—$P_u = VI$ might also be written $P_u = RI^2$, since $V = RI$.

The internal and external power are, therefore, of the same nature, and in the equation $P\theta = rI^2$, the quantity rI may be regarded as the fall of potential between the point of origin of the current and the battery terminals.

23. **Difference of potential at the Terminals.**—The useful or effective difference of potential is the difference of a potential between the two external terminals of the

electric generator. This is always less than the difference of potential originally set up by the electromotive force of the generator. The effective difference of potential V may be expressed as a function of E, r, the constants of the electric generator, together with I the current in the circuit, and R the external resistance.

From the formula

$$P = EI = VI + rI^2 \quad (22) \text{ we get}$$

$$\text{(a)} \qquad V = E - rI.$$

Now rI is, as we have seen, the drop of potential within the cell. Again

$$\text{(b)} \qquad V = E - r\,\frac{E}{R + r} = E\,\frac{R}{R + r}$$

These equations show that V, the difference of potential at the terminals, decreases as the strength of the current increases. V also decreases with any decrease of the external resistance, reaching zero when $R = 0$, *i.e.,* when the battery is short-circuited. As the current decreases and R increases, V approaches the value of E (the constant electromotive force of the generator), only reaching the value E in the limiting case when $I = 0$, *i.e.,* when R becomes infinite. This can only occur when the circuit is open.

24. **Relations required between R and r to give the maximum power.**—With a generator whose constants are E and r, we know that the useful power P_u is the product of the available difference of potential V and the current I.

$$P_u = VI.$$

I may be expressed in terms of E, r, and V.

$$I = \frac{E-V}{r} \text{ (from (a) in paragraph 23), therefore}$$

$$P_u = \frac{V(E-V)}{r}$$

(E-V is the factor which we have already met with as rI, the internal fall of potential.)

From this expression we see that the value of P_u increases with an increase in the value of V (E-V). Now this quantity is the product of two factors whose sum is a constant, since it is equal to E, the electromotive force of the generator. $(V + (E\text{-}V) = E.)$

Such a product will have a maximum value when the two factors are equal, *i.e.*, when $E\text{-}V = V$ or $V = \frac{E}{2}$

In this case $\frac{R}{R + r} = \frac{1}{2}$ and therefore R = 2. (23 b).

Thus, in order to get the maximum power from a generator with constants E and r, the resistance R of the external circuit should be equal to r the internal resistance.

When this is the case we get

$$V = \frac{E}{2}; \quad R = r;$$

$$I = \frac{E}{2r}; \quad P_u = \frac{V^2}{r} = \frac{E^2}{4r}$$

25. **Given an external circuit of non-variable resistance R, to vary the effective power by changing r the internal resistance.**—This is a very important problem in medical electricity. The resistance R of the human body cannot be varied at the will of the operator, and therefore cannot be reduced so as to equal r. The problem thus resolves itself into a choice of the best generator to obtain the maximum of useful power.

$$P_u = VI \text{ (par. 22, a,)}$$

$$V = RI \text{ (Ohm's law)}$$

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

$$P_u = RI^2 = E^2 \frac{R}{(R + r)^2}.$$

Since E is invariable, and R cannot be varied at will, we must reduce r to a minimum in order to make P_u as large as possible.

26. **Rules for obtaining the maximum effective power.**—With a generator whose constants are E and r, and a variable external resistance R, the useful power is greatest when R = r, *i.e.* when the external resistance has been so adjusted as to be equal to the internal resistance. When this maximum power, $P_u = \frac{E^2}{4r}$ (par. 24) has been attained, if we can diminish the value of r, whilst still keeping R constant, we may still further increase the available power. The generator will now no longer be working under conditions of maximum efficiency, but the power thus obtained is nevertheless greater than the maximum obtainable when r had its original value. By diminishing r, one of the constants of the generator, we have increased the maximum power which it was capable of rendering.

It is due to a confusion between these two propositions that some authorities have recommended batteries with high internal resistance for medical work.

27. **Efficiency.**—The efficiency of a generator is the ratio of the available power P_u to the total power P.

$$\frac{P_u}{P} = \frac{VI}{EI} = \frac{V}{E}$$

A generator working under conditions of maximum power has, therefore, an efficiency of $\frac{1}{2}$.

The maximum efficiency, *ie.,* $P_u = P$, is only obtainable when V = E, *i.e.,* when the circuit is open. The efficiency is greatest when the current is least. It is smallest when the current is largest, and approaches zero when the generator is short-circuited.

28. **Grouping of generators.**—Generators of electrical current may be coupled together in three different ways:—

(1) *In series:*—The positive pole of one cell is connected to the negative pole of the succeeding one, and so on.

(2) *In parallel:*—All the positive poles are connected together, and all the negative poles are also connected together.

(3) *Mixed grouping:*—Several cells are connected in parallel to form a group, and these groups are then connected together in series, or *vice versa.*

29. **Grouping in series of n generators whose constants are ϵ and ρ.**—In this case the group of generators has a total electromotive force of $n\epsilon$ and an internal resistance of $n\rho$.

The current in a circuit with external resistance R is given by

$$I = \frac{n\epsilon}{n\rho + R} \quad \text{(par. 21)}$$

The difference of potential at the terminals is given by

$$V = n\epsilon - n\rho I$$

30. **Grouping in parallel of n cells with constants ϵ and ρ.**—The electromotive force of such a group is equal to ϵ, and its internal resistance is $\frac{\rho}{n}$.

In a circuit with external resistance R, the current is,

$$I = \frac{\epsilon}{\frac{\rho}{n} + R} = \frac{n\epsilon}{\rho + nR}$$

and the difference of potential at the terminals is,

$$V = \epsilon - \frac{\rho}{n} I.$$

31. **Mixed grouping of n generators with constants ϵ and ρ.**—We may make t groups, each of q cells connected in parallel, and then connect up these groups in series. Or we may get the same result by making q groups, each consisting of t elements in series; and then connecting up these q groups in parallel.

The E.M.F. of this system is $t\epsilon$. The internal resistance r is given by

$$r = \frac{t}{q}\rho.$$

The strength of the current through a circuit with external resistance R, is given by the total E.M.F. divided by the total resistance

$$I = \frac{t\epsilon}{\frac{t\rho}{q} + R} = \frac{\epsilon tq}{t\rho + qR} = \frac{n\epsilon}{tq + qR}$$

The difference of potential at the terminals is given by V = E.M.F. — (internal resistance × current) therefore

$$V = t\epsilon - \frac{t}{q}\rho I.$$

32. **Power of a current produced by a battery of generators in a circuit of resistance R.**—Let n be the number of generators, and let them consist of t groups arranged in series, each group being formed of q generators in parallel.

Since $P_u = RI^2$, then from the values found in par. 31, we have

$$P_u = \frac{R\epsilon^2 n^2}{(t\rho + qR)^2}.$$

When all the elements are arranged in series this formula becomes

$$P_u = \frac{R\epsilon^2 n^2}{(n\rho + R)^2}.$$

When they are all in parallel it becomes

$$P_u = \frac{R\epsilon^2 n^2}{(\rho + nR)^2}.$$

33. **To connect up the generators so as to obtain the maximum power.**—In the general formula for the power

$$P_u = \frac{R\epsilon^2 n^2}{(t\rho + qR)^2}.$$

the numerator is constant.

The external resistance R is also constant, since we are considering the case of a current passing through a definite circuit, as for example the human body. P_u will be at a maximum when $t\rho + qR$ is a minimum, or, dividing throughout by the constant ρ, when $t + q\frac{R}{\rho}$ is a minimum.

The product of these two factors t and $q\frac{R}{\rho}$ is a constant $= n\frac{R}{\rho}$, since $t \times q = n$.

The sum of these factors is therefore a minimum when they are both equal, *i.e.* when $t = q\frac{R}{\rho} = \sqrt{n\frac{R}{\rho}}$.

From this formula we can at once calculate the required values of t and q.

We see also that $\frac{t}{q} = \frac{R}{\rho}$, from which we may deduce the rule, that when the external resistance is very great compared with the internal resistance, the elements should all be grouped in series. This is the case when a battery of simple cells is used for galvanisation. On the other hand, when the external resistance is small, the elements should be grouped in parallel.

Example: Given 36 cells, each having an electromotive force of 1.5 volts, and an internal resistance of 2 ohms, with an external resistance of 1000 ohms in the circuit. The maximum power P_u will be obtained when the cells are all joined up in series, and its value, as found from the above formula, will be 2.5 watts.

If the cells are arranged in a series of 18 groups, each group containing two cells in parallel, the wattage will be only .7.

If now the external resistance be reduced to 20 ohms, a maximum power of 10.09 watts will be obtained with 18 groups, each consisting of two cells.

With all the cells in series, the wattage would now only be 6.8, and with 9 groups of 4 cells each, it would be 6.07.

With an external resistance of .5 ohm, the cells should be arranged in 3 groups, each containing 12 cells in parallel. In this case the maximum value of P_u will be 10.12 watts.

34. **Various forms of Electrical Generators of Continuous current for medical work.**—The medical electrician may derive his current from a battery of galvanic cells (35), from accumulators (42), or from a dynamo (64); or he may make use of the public electric supply, whether this be a continuous current (76) or an alternating current (80).

2. CONTINUOUS CURRENT DERIVED FROM A BATTERY OF GALVANIC CELLS.

35. **Definition.**—A primary or galvanic cell is a generator of electricity which derives its energy from some chemical reaction, such as the combination of Zinc with Sulphuric acid. The negative pole is formed by a metal which is dissolved by the liquid. The positive pole is

made of some substance which is not acted upon by the liquid in which it is immersed.

36. **Constants of the cell.**—In common with all other forms of electric generator, the primary cell has two constants, its electromotive force and its internal resistance. The electromotive force is a characteristic of the special chemical action set up at the electrode, and does not depend on the area of the electrode. It varies with changes of temperature, since this also affects the intensity of the chemical reaction. The internal resistance depends on the nature of the liquid employed, the distance between the electrodes, and the area of their surfaces.

37. **Conditions required in the construction of batteries for medical use.**—Two varieties of battery are required for medical purposes, one stationary and the other portable. In the latter variety it is of importance to have the cells as small as possible.

The principal requirements for a medical battery are:

(a) The electromotive force of each cell should be as large as possible, so as to reduce the number of cells required.

(b) The internal resistance should be small (25).

(c) There should be no liberation of noxious gases.

(d) There should be no polarisation (38).

38. **Polarisation.**—Polarisation is a phenomenon set up while a cell is in action, tending to decrease its efficiency.

It is due to the deposit of hydrogen on the positive pole, forming a non-conducting sheath around it. It is also caused by the nascent hydrogen reducing the zinc sulphate formed in the cell, or by any other inverse chemical action which tends to set up an electromotive force in the opposite direction. It may sometimes be due to exhaustion of the exciting liquid.

Polarisation may be avoided by the use of depolarisers, which are in general substances capable of fixing the hydrogen. These may be either liquids, solutions or insoluble solids.

39. **Galvanic cells employed in medicine.**—The cells most frequently employed for stationary batteries are the following: *The Lalande and Chaperon cell.* This consists of zinc plates immersed in a 30 or 40 per cent. solution of caustic potash, with copper peroxide as a depolariser. Its E.M.F. is .8 to .9 volts.

The *Bergonié* CELL consists of a zinc plate in a 3 to 5 per cent solution of ammonium chloride. The depolariser is manganese dioxide. The E.M.F. is 1.45 volts, and the internal resistance with a 4 per cent solution is 1 ohm. The *Junius cell,* which is recommended by Bordier, consists of a zinc plate in a solution of caustic soda, with manganese dioxide as depolariser. Its E.M.F. is 1.6, and its internal resistance .25 ohm. Certain modifications of the *Daniell* cell are also used. The chief drawback of this cell is that the chemical action does not cease when the circuit is broken. (*Gaiffe, Remak, Callaud, Onimus.*)

The principal portable cells are those of the *Warren de la Rue,* and the *Marie-Davy* types, the former containing chloride of silver, and the latter sub-sulphate of mercury with zinc and carbon electrodes. Their internal resistance is greater than that of the cells already described. They are usually fitted up with a contrivance by which the zinc may be removed from the liquid when not in use.

40. **Arrangement of the cells.**—For medical use the cells are connected in series so as to obtain the greatest possible power (33). The current may be taken from the terminals of the battery, in which case a rheostat or a potential reducer must be inserted in the circuit to regulate the current (91); or the battery may be fitted

with a collector which enables the number of cells in circuit to be varied at will (41).

41. **Collectors.**—The collector is a device by which any number of cells can be introduced into the circuit by simply turning a handle. The following formula gives the increase of current caused by moving the indicator from one stop to the next.

$$I = \frac{n\epsilon}{n\rho + R} - \frac{(n - 1)\,\epsilon}{(n-1)\rho + R}$$

n is the number of cells in use.
ϵ the E.M.F. of each cell.
ρ the internal resistance of one cell.
R the external resistance.

Since R is some thousand times as large as ρ, the difference between the two denominators is less than $\frac{1}{1000}$ of their value, and this difference diminishes as n increases. We may therefore regard the two demoninators as equal, so that $\frac{\epsilon}{n\rho + R}$ represents the increase of current as the indicator is moved from one stop to the next.

If $\epsilon = 1.5$ volts, $\rho = 1$ ohm, and $R = 1000$ ohms, then on moving the indicator from 0 to 1, we shall get a current of 1.5 milliamperes. On changing from 39 to 40 cells, the increase in current will be about 1.4 milliamperes. The rapid increase of current caused by moving the indicator is very appreciable to sensitive patients even when the E.M.F. of each cell is only .8 volts. Collectors are therefore only suitable for portable batteries, where weight has to be economized.

3.—Continuous currents derived from accumulators.

42. **Definition.**—An accumulator is an indirect transformer of electric energy, the intermediary being a chemical action, the result of polarisation.

When an electric current passes through water it decomposes it, the hydrogen collecting at the negative pole and the oxygen at the positive pole. As this goes on, the strength of the current gradually decreases, since the hydrogen and oxygen cause an E.M.F. in the opposite direction, which partially neutralises the E.M.F. of the cell. This back pressure constitutes the phenomenon of polarisation.

When the primary current is cut off, the E.M.F. due to polarisation will cause a current in the reverse direction. This is called a secondary current.

Every electrolyte, as a liquid capable of being decomposed by a current is called, absorbs during decomposition a quantity of electric energy proportional to the quantity of electricity which passes through it, and to the back E.M.F. caused by the decomposition. If $E\rho$ be this back E.M.F. and Q the quantity of electricity passing, then W, the energy in Joules is given by

$$W = Q\,E\rho$$

This energy is given out by the accumulator as a secondary current.

Most accumulators consist of two plates of lead, or some salt of lead, immersed in dilute sulphuric acid. Other combinations, however, are occasionally used.

43. **Charge and discharge of an accumulator.**—The charging of an accumulator consists in furnishing it with electric energy. This is done by connecting the positive and negative poles of the accumulator with the positive and negative poles respectively of some convenient source of electricity. Rules for charging accumulators are given in par. 49.

An accumulator is discharged by closing its circuit, and allowing a current to pass.

44. **Phenomena of charge and discharge of an accumulator.**—We shall here only consider the case of accumulators with plates of lead or lead salts.

In 1860, *Planté* discovered that when two plates of lead are immersed in water accidulated with H_2SO_4 and connected to the two poles of an electric battery, the liquid is electrolysed. The lead plates are chemically altered, the positive plate being oxidised, and the negative one reduced. A peculiar property of this reaction is, that the oftener the process is repeated, the more readily does it occur. The negative pole assumes a greyish tint, whilst the positive pole shows the puce coloured lead oxide. In the original apparatus devised by *Planté,* the accumultor was formed by repeatedly charging and discharging two large sheets of lead. The area of the electrodes may be greatly reduced, and the E.M.F. of the discharge increased, by making accumulators of certain salts of lead.

If we examine an accumulator which has been formed by repeated charging and discharging, we shall see that the negative plate is of a spongy or porous appearance, an allotropic modification of lead possessing peculiar reducing properties. This spongy electrolytic lead is very readily oxidised. The positive lead plate is found to be coated with lead peroxide PbO_2.

When the accumulator is discharged a current passes externally from the positive to the negative plate, and internally from the negative to the positive plate. We therefore get oxidation at the negative, and reduction at the positive plate. The oxidation at the negative plate results in the formation of oxide of lead, which combines with the sulphuric acid to form sulphate of lead. If the liquid in the accumulator be analyzed after discharge, it will be found to be less acid than before, and the missing acid will be found on the negative plate in the form of sulphate of lead.

At the positive pole the peroxide is reduced to a lower oxide of lead.

When the accumulator is recharged, the current passes in the opposite direction. The reduction at the negative plate decomposes the sulphate and reprecipitates the metal, while the oxidation at the positive plate restores the oxide to a peroxide.

45. **Construction of accumulators.**—The principal difference in the various types of accumulators is in the constitution of their electrodes. Instead of forming the electrode naturally by the action of the accumulator, salts of lead which have been previously prepared are employed. The lead plates are used only as a support for these salts.

This method was first adopted by *Faure* in 1880. The lead plates are usually alloyed with two or three per cent of antimony, to render them more resistant to the action of the acid.

The positive pole is generally formed of minium, Pb_3O_4 and the negative of litharge, PbO. During the process of charging the minium is oxidised to lead peroxide.

$$Pb_3O_4 + 2\,O = 3\,Pb\,O_2.$$

At the same time the litharge is reduced to spongy lead.

$$Pb\,O + 2\,H = H_2O + Pb.$$

Electrodes are said to be autogenous, when formed naturally by the alternate charging and discharging of the accumulator, whereas they are said to be heterogenous when formed artificially from lead salts. The former is the *Planté* type, the latter the *Faure* type.

In the new *Edison accumulator* the negative electrode is of iron, and the positive electrode consists of an oxide of nickel with the approximate formula NiO_2. The electrolyte is a twenty per cent solution of KOH.

46. **Accumulator cells.**—The accumulators used for medical purposes do not need to be of very large capacity. They should be made as light as possible, so as to be portable. For this purpose celluloid cells are convenient. They are transparent and are at the same time lighter and less breakable than those made of glass. For greater security several such cells may be enclosed in a wooden case. Cells are also made of ebonite.

The plates of the accumulator should not touch the bottom of the cell, lest pieces of lead becoming detached from the plates and falling to the bottom should short-circuit the current. The plates are supported by some insulating material such as caoutchouc, glass, ebonite or porcelain.

The liquid in the cells is distilled water acidulated with sulphuric acid. The density of the liquid should be from 1.16 to 1.26, which corresponds to 20 to 30 of *Baumé's* hydrometric scale. (*Hospitalier, "Manuel de l'Electricité."*)

47. **Installation.**—The accumulators should be placed where they can be easily seen. They should be examined from time to time to see that there is no oxidation of the terminals, buckling of the plates, or internal short-circuiting from lead flakes which have fallen off the metal plates. Moreover, they should be carefully insulated by placing them in a box of sawdust supported by porcelain feet.

48. **Charging of accumulators.**—If a public electric main or a private source of electricity is available, the accumulators can be charged without removal. Otherwise they must be sent away to be charged. When they are to be charged on the premises, the terminals of the series of accumulators should be connected to a commutator which, when in the charging position, will connect the positive pole of

the accumulator with the positive pole of the electric source, and the negative pole of the accumulator to the negative pole of the electric source.

An amperemeter and a rheostat should be interposed between the commutator and the electric source. These are only of use whilst the battery is being charged, since the current used in medical work is only of the order of a milliampere. There should always be a cut-out fuse between the accumulators and the commutator, since accidents due to shortcircuiting may occur during charging or discharging. It should be an absolute rule always to use a bipolar cut-out, when working with a source of electric energy capable of giving a large discharge. The fuse should be as close as possible to the accumulator. Boxes are often made with spring contacts, in which case the accumulator is merely placed in the box, when the connections are made automatically.

49. **Methods of charging accumulators.**—There are several different methods of charging accumulators.

(a) From the public main with constant current.

(b) From public mains with alternating current, either monophase or polyphase.

(c) From voltaic cells, or small motors.

(d) By sending the accumulator to a charging station.

50. **General rules.**—The most important point is to determine the polarity of the terminals of the electric source. When using a constant current from the public mains this may be done by plunging the leads into water, and inverting a test tube filled with water over each wire; thus forming a simple voltameter. Bubbles of hydrogen will appear at the negative pole and will rise up in the tube, while the positive pole will become oxidised. Pole-finding test-papers are also sold; turmeric paper, for in-

stance, turns red at the negative pole, and ferrocyanide paper becomes white, owing to the liberation of potassium.

The number of accumlators placed in series should not be so great that E', the E.M.F. of the battery, will be greater than E, the E.M.F. of the source. The value of the current $\frac{E-E'}{R}$ must always be positive.

The most convenient charging current is one which gradually decreases in intensity as the accumulator becomes charged, *i.e.*, as E' the counter-electromotive force increases.

As a general rule this charging current should vary with the surface of the plates. In the same type of accumulator therefore, the intensity of the current should be proportional to the weight of the cell. For any one type the best current intensity can be given in terms of the weight of the electrodes.

This optimum charging current should be marked on the accumulators.

51. **To determine when the accumulators are properly charged.**—The signs that an accumulator is charged are the following:

(a) The voltage of each cell reaches a value of from 2.4 to 2.6 volts; whereas before charging it was only 1.8 volts, and during charging 2.1 to 2.2 volts.

(b) The liquid begins to bubble. The gases liberated by the electrolysis of the water are no longer used up by the chemical reactions occurring at the electrodes.

(c) The density of the electrolyte remains constant, since no more acid is liberated by the electrodes.

Those who are familiar with accumulators can often judge of the acidity of the liquid by tasting it.

For the medical electrician the first two methods are the most convenient. A voltmeter should be used for testing the accumulators when full, and for indicating when they need recharging. The voltage should never be allowed to fall below 1.8.

52. **Recharging accumulators from the constant current mains.**—If the public electric supply is employed for driving a Ruhmkorff coil, for X-ray work or the like, the same supply may be used for charging the accumulators.

With a pressure of 110 volts, the rheostat required to send a current of 8 amperes through the coil, will also serve for charging the accumulators. Theoretically, to use a current of 110 volts most economically, 30 to 40 accumulators should be charged at once. Practically, we generally charge from 10 to 20 accumulators only, the surplus energy being dissipated in the rheostat as heat.

If, however, there are only one or two accumulators to be charged, or if they require frequent recharging, they may be introduced into a shunt circuit with one or more incandescent lamps in the main circuit to act as resistances.

53. **Charging an accumulator from the alternating current main.**—The problem of charging accumulators from an alternating main is much more complex. Several methods may be employed.

(1) The current may be converted into a direct current by means of a rotating transformer. This may be either a motor-dynamo, *i.e.,* a motor driven by the alternating current, coupled to a generating dynamo; or a current convertor, which transforms the current directly.

(2) The alternating current may be converted into an uni-directional oscillating current by means of a Villard current rectifier. (55.)

(3) The current may be transformed by interposing an electrolytic valve. The Wehnelt interrupter is one form of such a valve.

54. **Rotary transformers.**—In the motor-dynamo the electric generator is connected to the motor either by a belt or by a flexible shaft. The motor is the ordinary alternating current motor. The size of the dynamo is determined by reference to the uses to which it is to be put. If it is only required to charge accumulators, it need only be large enough to give the necessary voltage and amperage for this purpose. When direct transformers are used the same considerations will determine the constants of the apparatus chosen.

We do not recommend this method of charging for medical work for several reasons:

(1) The motor causes too much noise and vibration. It is heavy and cumbrous and needs special supervision.

(2) It is too expensive an apparatus to be used merely for charging accumulators for electrolysis and galvanisation.

(3) The current from the main is useful for so many purposes that it is better to adapt it for charging the accumulators, rather than to install a separate apparatus.

55. **Villard's current rectifier.**—This apparatus, which is particularly applicable to monophase alternating currents, is very suitable for medical use, since it can be also used as an interruptor for X-ray and high frequency work.

It consists of a vibrating spring L L', magnetised by a coil B which encircles without touching it. This coil is connected through a self-induction coil to a branch current from the alternating main. The end of the vibrating spring passes between the poles N. and S. of a permanent magnet. As the phase of the current alters, it is attracted to either pole alternately. By this means the oscillations of the vibrating spring are rendered synchronous with the period of the current.

The amplitude of the oscillations is controlled by a small piston which dips into water. The extremity of the vibrator is attached to a mercury break interposed in the main circuit of the alternating current.

By suitably regulating the plunger, the vibrator and the self-induction of the exciting circuit, the apparatus may be so adjusted as to break the circuit at any desired point in the current curve, thus allowing only one phase to pass.

To drive a Ruhmkorff coil the contact should be broken at the maximum point of the curve; when used for charging accumulators it should be broken at the zero point.

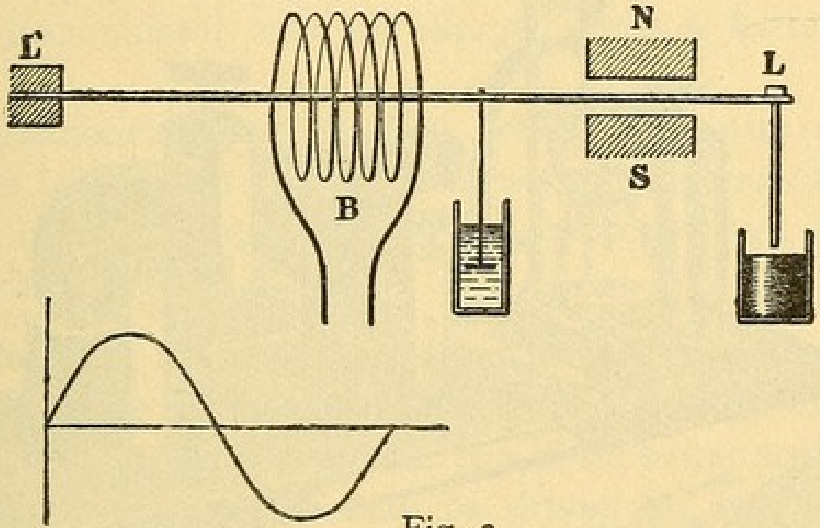


Fig. 2.

The phase of the vibrator is always slightly behind that of the current. This retardation can be increased by various means.

1. Increasing the self-induction of the exciting current.

2. Raising the level of the mercury and thus causing the plunger to travel further before contact is broken.

3. Increasing the length of the plunger by means of the screw adjustment.

The retardation of phase may be diminished by—

1. Decreasing the self-induction.

2. Lowering the mercury level.

3. Shortening the length of the plunger.

We must remember that by increasing the depth to which the plunger dips into the mercury we increase the mean amperage of the current. When the break occurs at the zero point the interruptor works silently.

When it gets out of adjustment we are warned of the fact by an alteration in the note. For a complete description of this apparatus we must refer the reader to the *Archives d'Electricité Médicale de Bordeaux* of April 15, 1902.

By using this rectifier we can charge 15 to 20 accumula-

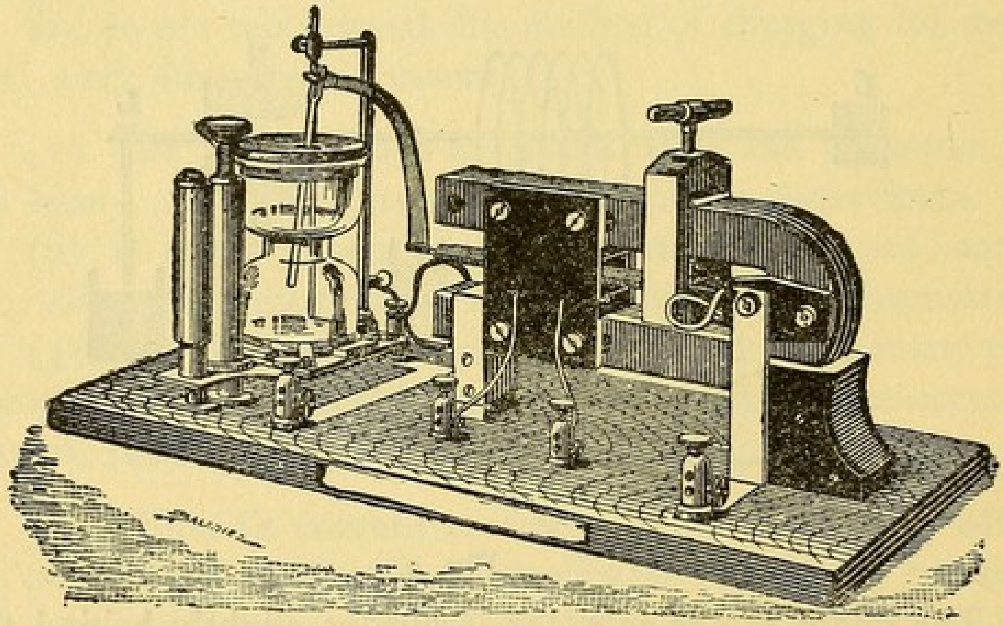


Fig. 3. Villard interruptor and current rectifier.

tors in series. If more than 20 accumulators are required at once the best plan is to divide them into two equal series and connect the two series together in parallel.

56. **Charging accumulators from the alternating current by employing electrolytic valves.**—If the two terminals of an alternating current are connected, the one to a plate of charcoal or lead and the other to a plate of porous aluminium, and these two plates are immersed in an alkaline solution, the current can only pass in one direction. Such an arrangement is called an electrolytic valve. By

means of this apparatus a continuous current may be obtained from the alternating mains. Four valves are used, arranged in the form of a Wheatstone bridge. *Wehnelt's* interruptor is based on the same principle.

This method will undoubtedly come into favour, but as yet it has not been quite perfected for general use.

57. **Charging accumulators by means of galvanic cells.**—This method is not to be recommended. If, however, no other source is available, and a considerable current at low voltage is required, as, for instance, for electro-cautery, the accumulator may be charged from a battery of cells.

For galvanisation and the like, when a pressure of 30 to 50 volts is required and only a few milliamperes of current, it is more advantageous to work directly from a battery of primary cells.

58. **Charging accumulators by means of a dynamo.**—When we require various forms of electric energy and no public electric supply is available, it will be better to invest in a small dynamo. This may be driven by gas, petrol, steam, compressed air, water, wind or any other agent available.

The dynamo will also serve to furnish electric light, and should be capable of supplying all the electric energy required, at once economically and conveniently.

When charging accumulators, if the E.M.F. furnished by the dynamo is much larger than that of the accumulators, the charging should be combined with the lighting system.

For electrolysis and galvanisation we require from 15 to 25 storage cells of small capacity. This means a maximum E.M.F. of from 40 to 60 volts. Since the best size for a dynamo for general use is one which gives about 70 volts, there will be but little waste when it is used in this way.

We shall return to this question when we come to discuss the use of the dynamo for the production of a continuous current. It will, however, generally be found more convenient to use it to charge accumulators rather than to work directly from the dynamo.

When charging accumulators from a private dynamo we should be careful that the rheostat, amperemeter and a cut-out fuse are included in the circuit.

59. **Charging stations.**—When the accumulators have to be sent out to be charged, it is better to have two sets of batteries. At the charging stations they are unwilling to charge only 15 or 20 cells at a time, since it is much more economical to charge a large number at once. We are, therefore, often kept waiting for several days before the batteries are ready. Also the constant shaking and displacement soon spoil an accumulator.

Accumulators of large capacity should be used for X-ray and high frequency work when a high potential is required. For other purposes, such as galvanisation and electrolysis, a battery of primary cells may be used with advantage.

60. **Accumulator constants.**—The constants of an accumulator are the same as those of a primary cell, *i.e.,* the electromotive force and internal resistance. With accumulators we have another important consideration; *viz.,* their capacity. The relation which the power and capacity bear to the weight of the plates is of great practical importance. In the *Edison* accumulator with iron negative and nickel positive plates, the power per unit weight is very high.

The electromotive force of an accumulator during discharge varies from 1.9 to 2 volts. It may rise, when fully charged, to 2.5 or even 2.8 volts, but this is for only a very short time, and it soon decreases. When the discharge is nearly completed the voltage falls to 1.8, or even lower. The *Edison* accumulator gives only 1.1 volts.

As the internal resistance is very low, a large amuont of current is obtainable. The current should not, however, be allowed to exceed about .8 ampere per kilogramme of electrode, otherwise the cells rapidly deteriorate. This current corresponds to about 1.4 watts per kilogramme of electrode.

The capacity of an accumulator is the quantity of electricity which it will furnish before being completely discharged. This quantity is expressed in ampere-hours.

The capacity is proportional to the surface, and therefore for a given type it will be proportional to the weight of the plates. Each type of accumulator has a definite capacity per kilogramme of plate.

For the production of continuous currents we do not need accumulators of very large capacity, since the current required is small. Comparatively light cells may, therefore, be used for this purpose.

The average capacity of an accumulator is 6 to 10 ampere-hours per kilogramme of plate.

61. **Capacity efficiency.**—The capacity efficiency is given by $\frac{Q_d}{Q_c}$, *i.e.,* the ratio of the quantity of electricity Q_d, given out when the accumulator is discharged, to the quantity Q_c required to charge it. This ratio is about 90 per cent, but since the capacity varies with the rate of discharge the efficiency of the accumulator will also vary with this factor. The lower the rate of discharge the greater will be the efficiency. Hence accumulators are very economical when used to furnish galvanic currents.

62. **Energy efficiency.**—The energy efficiency is the ratio of the energy of the current of discharge W_d, to the energy of the charging current W_c.

This value is given by the expression

$$\frac{W_d}{W_c} = \frac{\int_o^{T_d} V_d\ I_d\ dt}{\int_o^{T_c} V_c\ I_c\ dt}$$

where T_d, V_d, I_d are the time of discharge, the difference of potential and the intensity of current during discharge, and T_c, V_c, I_c, the time taken, the difference of potential, and the intensity of the current during charging.

This efficiency varies with the rate of charge. In practice its maximum value is about 80 per cent.

63. **Mode of arrangement of accumulators.**—For obtaining galvanic currents, accumulators should be connected in series, for the reasons described in the article on primary cells. A current collector should never be used with accumulators; the addition of two volts to the circuit, each time the handle is moved forward, would cause an unpleasant shock to the patient.

4.—Continuous current from a dynamo.

64. **Disadvantages.**—The medical practitioner who has no public electric supply at his disposal, but who only requires a continuous current, will content himself with a battery of primary cells. If, however, he requires electricity for other purposes, either medical or domestic, he must have recourse to a dynamo.

It is not advantageous to use the current from the dynamo directly for galvanisation for several reasons.

I. Any sudden change in the current in other branches of the supply, as when an electric light is turned off, will cause a sudden alteration of the galvanic current, which will give a shock to the patient.

2. The dynamo may require to be run merely to furnish the continuous current, an expenditure of power out of all proportion to the electromotive force required.

3. The motor of a dynamo requires constant attention whilst at work.

4. The current from a dynamo is not a typical continuous current, the curve which represents it is of an undulating character.

For these reasons it is preferable, when a dynamo is employed for lighting purposes, to charge a battery of accumulators whilst the light is in use, and to use these accumulators for the production of the galvanic current. We will, however, give a description of the principle and management of a dynamo and the method of employing it to furnish a continuous current when necessary.

65. **Principle of the dynamo.**—When a closed conductor moves in a magnetic field, so that the number of lines of force passing through the circuit varies, a current of electricity is induced in the conductor.

The direction of the current is given by *Lenz'* law; *viz.* "The direction of the induced current is such that the lines of force which it produces, oppose the variation in the flux of force which induces the current."

66. **Character of an induced current.**—The electromotive force caused by a given change of the flux of force, depends on the rapidity of the change; *i.e.* the induced E.M.F is proportional to the change of flux per unit of time.

$$E = \frac{d\Phi}{dt}$$

On the other hand the total quantity of electricity forced round the circuit, depends on the change in the flux of force and on the resistance of the circuit.

$$Q = \frac{\Phi}{R}$$

The intensity of the induced current at any moment is measured by the quotient of the quantity of electricity produced, into the time taken to produce it.

$$I = \frac{dQ}{dt} = \frac{d\Phi}{Rdt}$$

67. **Magneto-electric machines and dynamos.**—A magneto electric machine differs from a dynamo in that the former is excited by a permanent magnet, whereas the latter is excited by an electro-magnet. Dynamos are now almost universally employed for practical work.

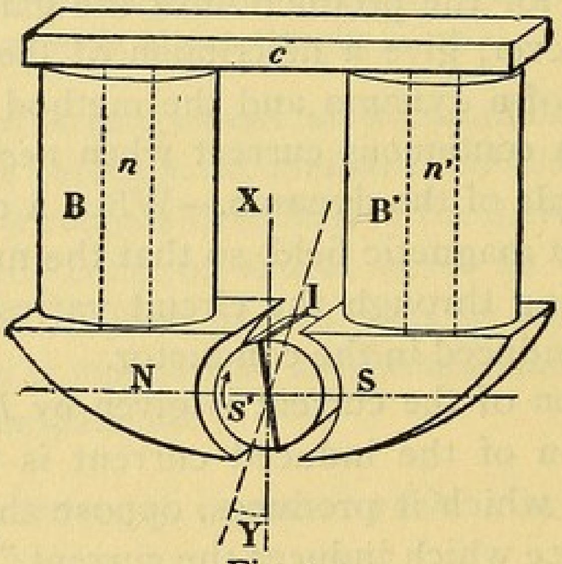


Fig. 4.

The soft iron core of the electro-magnet is bent so that its two poles are opposite each other. In Fig. 4, BB' are the magnetising coils encircling the iron cores nn' of the magnet; NS are the two *polar pieces*.

The polar pieces are hollowed out so as to form a cylindrical opening between them, in which is placed the secondary coil for the induced current. This coil is wound on a soft iron core termed the armature.

The armature will as far as possible complete the magnetic circuit, becoming itself magnetised with its north pole opposite to the south pole of the magnet and *vice versa.* It will preserve this polarity in spite of the fact that it is rotated about an axis perpendicular to the plane of the electro-magnet and passing through the line joining the centres of the two poles of the electro-magnet.

Whether the armature is at rest or revolving, its poles will always occupy the same position relative to the poles of the electro-magnet. In *Siemen's* armature the induction coil is wound round the core of the armature in layers covering it completely. In other forms, the ring or drum armatures, the spirals are arranged in different ways around the periphery of the ring.

68. **Induced current.**—Consider a loop of wire wound longitudinally round the cylindrical core of a *Siemen's* armature like that shown in Fig. 4. The maximum change of flux will occur when the coil is crossing the polar plane NS.

The minimum change of flux will occur when the coil is passing the perpendicular position XY. It is true that in this position the coil cuts the greatest number of lines of force, but a small alteration of its position will not greatly alter the number of lines cut. In this region the rotation of the armature during a small interval dt will produce the minimum change in the value $d\Phi$. In the plane XY, this change will be zero.

This line XY in which the induced electromotive force is zero is called the neutral line, or line of commutation. The latter term is given because, in accordance with *Lenz'* law, the direction of the induced current will change at that spot, being in one direction while the generatrix I passes from Y to X, and in the other direction while the generatrix is passing from X to Y.

69. **Form of the induced current.**—If we consider the

loop, I, Fig. 4, rotating with constant velocity, we see that the E.M.F. of the induced current will increase from the neutral line X to the polar line NS, and then decrease again from NS to XY. In the quadrant YN, the E.M.F. will increase with the sine of the angle between the loop and the neutral line. In the quadrant NX, it will decrease with the sine of the angle between the loop and the neutral line. A curve may be drawn as in Fig. 5 to show

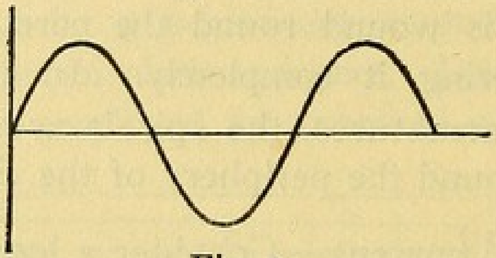


Fig. 5.

the change of current with time. The abscissæ representing the time will be of the form $\int_{T1}^{T} dt$, and the ordinates representing the E.M.F. of the form $\int_{T1}^{T} \frac{d\Phi}{dt}$. The current thus obtained is called a sinusoidal current. Such a form is useless where a continuous current is required; we shall therefore consider the method of converting this variable current into a continuous one.

70. **Rectification of dynamo currents.**—A continuous current may be obtained in the following manner. Let the coil be cut at a point on the axis of the armature, and the ends connected to two semicircular metallic rings on the axis of rotation. The current may be collected by means of two brushes, each brush being placed so as to touch one ring of the commutator only so long as the current is flowing in one direction. By this means the current collected by each brush will be always in the same direction, but of an oscillatory character. If there are several coils on the armature, the sum of the currents

induced in all the coils will become more and more constant as the number of coils increases, since the phase of the current in each coil is different. This is the principle of the constant current dynamo. It does not give a strictly constant current, but a slightly oscillatory one, which approximates to the constant current as the number of coils is increased.

71. **Types of dynamos for producing a continuous current.**—The method of exciting a dynamo and the mode of winding it varies in different types.

(1) *Classification according to mode of excitation.*

The current which excites the electro-magnet may be derived from the induced current or it may be independent of it. The former method, which is termed self-exciting, is the only one used in medicine. Of this there are three varieties.

(a) Series excitation, where the whole of the induced current passes through the electro-magnet.

(b) Shunt excitation, where a part only of the induced current passes through the electro-magnet.

(c) Compound excitation, which consists of two distinct windings to the electro-magnet, one in series and the other a shunt.

(2) *Classification of dynamos according to the method of winding the armature.*

(a) *Siemen's* winding, already described in par. 67.

This method is not suitable for obtaining large differences of potential; the different wires bearing the induced currents are too close together where they cross one another at the closed end of the armature.

(b) *Gramme* winding, in which the coils are wound round a ring which revolves between the poles, each coil being connected to one sector of a collector placed on the axis. Fig. 6.

(c) The drum winding in which the secondary wire is wound on a series of cylinders fixed around the core of the armature.

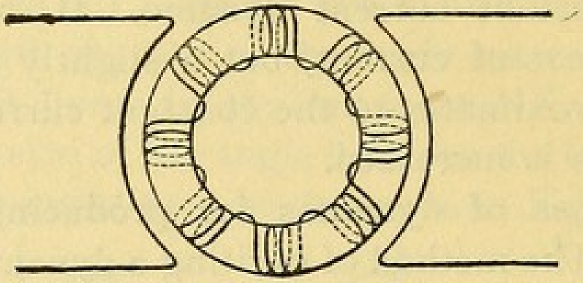


Fig. 6.

72. **Adjustment of the brushes.**—The induced current is taken from the collector by means of copper collecting brushes. If there were no self-induction, the brushes might be placed on the neutral line of the collector where the induced E.M.F. is zero. (68)

Owing to the retardation due to self-induction the brushes must be placed behind the zero line, in order to prevent sparking at each break of contact.

This displacement from the neutral line is called the *lead,* and the angle which the line of the brushes makes with the neutral line is the *angle of advance.*

73. **Dynamos for medical use.**—In studying the current from a direct current dynamo, we have to consider its intensity I, the difference of potential at the terminals V, and the electric power VI.

The rate of rotation of the armature, or its angular velocity, is measured in revolutions per minute.[1]

[1] The C.G.S. unit of angular velocity is the radian per second. This is the velocity of a cylinder which revolves about its axis through one radian in one second. The radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.

One revolution per second is equal to an angular velocity of 2π radians per second, and one revolution per minute is $\frac{2\pi}{60}$ or .1047 radians per second. The practical unit of angular velocity, one revolution per minute, is therefore equal to .1047 C.G.S. units of angular velocity.

The E.M.F. driving the current through the secondary circuit is the sum of the external difference of potential V and the fall of potential in the induction coil itself. This internal fall of potential rI occurs in all electric generators and varies with the power of the dynamo. The internal energy $rI \times I$, or thermic energy, is dissipated as heat, causing an increase in the temperature of the generator. The ratio $\frac{rI}{E}$, *i.e.*, the ratio of the internal fall of potential to the total electromotive force, and therefore also the ratio of the internal power to the total power, is generally about .06 for a dynamo of 2000 watts, .055 for one of 4000 watts, and so on, decreasing as the power of the dynamo increases.

From this it follows that, having calculated the theoretical electromotive force of a dynamo with N turns in the secondary coil, having an angular velocity ω and magnetic flux Φ, we must deduct a variable fraction of the value thus obtained in order to determine the available voltage.

The medical electrician does not, as a rule, need to trouble himself with these theoretical calculations. He need only remember that the induced E.M.F. is proportional to N the number of turns in the winding of the armature, to ω the angular velocity, and to Φ the flux of magnetic force through the circuit.[1]

74. **Choice of a dynamo.**—The first point to consider when choosing a dynamo is the maximum power which it will be required to furnish. To determine this we first find the maximum voltage required.

Thus if it is to be used to drive a 15- to 20-inch Ruhm-

---

[1] For details of dynamo constants, the reader should consult Hospitalier's "le Manual de l'electrician."

The formula for the E.M.F. is

$$E = \frac{N . \omega . \Phi}{60} 10^{-8}$$ volts for induction coils with windings in parallel.

$$E = \frac{p . N . \omega . \Phi}{60} 10^{-8}$$ volts for coils wound in series.

where p is the number of sections on the commutators.

korff coil it should be capable of giving a difference of potential of 60 volts. If a Wehnelt interruptor is to be used 100 volts are required. For charging 20 accumulators in series 60 volts will be needed, whereas 70 volts is the most convenient E.M.F. for electric lighting.

Having decided on the voltage, we have next to determine the power in watts required to supply the whole of the apparatus which is to be used simultaneously. As a basis for this calculation we may note that a five candle power incandescent lamp requires 15 watts; a 10 candle power lamp requires 32 watts, and a 32 candle power lamp 100 watts.

From 600 to 1200 watts are required for an arc lamp of 400 to 1000 candle power capable of well lighting a room 20 by 30 feet, or of giving sufficient illumination for a hall 36 feet square.

A 15- to 20-inch coil requires from 5 to 12 amperes at a pressure of 40 to 60 volts, or about 700 watts. It must be remembered that if the dynamo is producing a pressure of 90 volts, while the coil can only carry 45 volts, the remaining 45 volts is wasted as heat in the rheostat. We must, therefore, allow for 1100 watts instead of the 540 watts (12 amp. × 45 volts) actually required. If the pressure of the dynamo is only 50 volts we need only allow about 600 watts for the coil.

For heating purposes we allow 600 to 700 watts for every 1000 cubic feet of space.

For small apparatus, such as plate warmers, foot warmers, kettles, etc., 20 to 200 watts are sufficient.

The power required for motors will be dealt with in paragraph 75.

Having added up all these quantities and made allowance for the fact that although we may intend to use the larger apparatus (lighting, motors, heat and light baths, etc.) alternately, it is occasionally found necessary to run them simultaneously, we have the two factors, voltage and power, necessary to determine the size and description of dynamo required. The further specification may safely be left to the manufacturer.

75. **Motors for driving dynamos.**—The motive force may be electricity, steam, gas, compressed air, petrol, water or wind. The important point is to determine the power required to drive a given dynamo and to choose motor accordingly.

The *efficiency* of a dynamo is the ratio of the power of the current given out by the dynamo to the power supplied by the motor. The *co-efficient of transformation* is the ratio of the total power given out by the dynamo P_t to the power of the motor P_m

$$\text{Coeff. transf.} = \frac{P_t}{P_m}$$

The useful electric power of the dynamo P_u is only a fraction of the total power, and this fraction varies with the absolute value of the power. The *electric efficiency* of the dynamo is given by $\frac{P_u}{P_t}$.

In order to chose a motor we must know the ratio of the useful power of the dynamo to the power of the motor which drives it. This ratio $\frac{P_u}{P_m}$ is the *industrial efficiency.*

The industrial efficiency for medical dynamos is relatively small, since the efficiency is always less with small machines. The industrial efficiency will also vary with the type of machine employed.

In a well-designed dynamo the industrial efficiency $\frac{P_u}{P_m}$ varies from 60% for 1000 watts, to 67% for 2000 watts, and 70% for 4000 watts. This difference is chiefly due to the variation in the electric efficiency, which is about 75% in a 1000 watt dynamo, and rises to 82% in a 2000 watt dynamo.

In order to drive a 1000 watt dynamo (about 1.33 horse power) the motor must have a power of at least $1000 \times \frac{100}{60}$ watts, nearly 1660 watts, or 1.66 poncelets.

With smaller machines the power of the motor must be double or even triple the number of watts furnished by the dynamo.

Instead of the poncelet, which is 100 kilogramme-metres per second, manufacturers usually use the horse power of 75 kilogramme-metres per second as the unit of measurement of power. One horse power is .75 poncelet, or 750 watts, and one poncelet is 1.33 horse power.

Since the efficiency of small motors is very variable we should be guided by the maker in the selection of a motor of suitable power.

5. THE USE OF THE CONSTANT CURRENT FROM THE PUBLIC MAINS FOR MEDICAL PURPOSES.

76. **Form of the continuous current supplied from the mains.**—Like all currents generated by dynamos, the current from the public mains is not strictly constant. In a diagram of the current the intensity will not be represented by a straight line parallel to the time axis.

It approximates, however, very closely to the constant current form, in consequence of the large number of windings on the armature used. Such a current may, therefore, be used for galvanisation.

77. **The constant current from the mains.**—The continuous current from the public main may be used for galvanisation either directly or indirectly.

78. **The direct use of the public supply for galvanisation.**—There are several objections to the direct use of the

current from the mains for galvanisation. Some of these have already been mentioned in paragraph 64. To these must be added the danger of short circuiting from the electrode to earth through the patient's body. It is, therefore, absolutely necessary to insulate both patient and operator from the earth by a wooden stool with glass feet, or some such means.

79. **Indirect use of the constant current mains.**—The continuous current from the mains may be used indirectly for galvanisation in several different ways.

(1) It may be used to charge the accumulators for the supply of the galvanic current for medical purposes. (52.)

(2) It may be transformed into a continuous current of lower voltage. For this purpose a small dynamo is used, driven by an electro-motor supplied from the mains. This method has been described in paragraph 64.

Since the dynamo is required only for the production of a galvanic current, it should be of small power. The maximum voltage required is about 40 volts, and the maximum current 250 milliamperes.

(3) The galvanic current may also be obtained from the continuous current mains by using a direct transformer in lieu of a motor and dynamo.

A transformer consists of an armature with two windings, one of which receives the current from the mains, while the other supplies an induced current of low tension. The lightness and cheapness of this apparatus, and the absence of sparking make it a very convenient mode of obtaining a galvanic current.

80. **Use of the alternating current main for producing continuous currents.**—In order to use the alternating supply for the production of a continuous current, the alternating current must be rectified either by accumulators or

by mechanical transformers. This method has been already described in the paragraph on charging accumulators from the alternating mains. Electrolytic valves do not give a sufficiently continuous current to allow of their being used for galvanisation.

III. Medical employment of the continuous current, Resistances, conductors, measuring instruments, etc.

81. **General considerations.**—The practical application of the constant current requires the use of conductors, resistances, rheostats, measuring instruments, the various forms of apparatus for therapeutic application, the metronome, interruptors, reversers, etc.

The human body to which the current is applied may be considered as a portion of the external circuit, possessing its own definite resistance. The general laws of currents apply also to the passage of electricity through the body. These are:—

1. The relations between the voltage V, the current I, and the resistance R.

2. The fall of potential along a circuit with varying resistance in different portions.

3. The intensity of a current circulating through two or more parallel branches.

82. **Relation between the three quantities V, I, & R.**—If V be the difference of potential between any two points of a circuit, R the resistance of the portion of the circuit between those two points, and I the current in the circuit, then by *Ohm's* law

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

$$V = RI$$

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

From these three equations the value of any one of these quantities may be obtained if the other two are known.

83. **Fall of potential along a conductor of uniform or variable resistance.**—Consider a battery of primary cells driving a current through a circuit which consists of a human body interposed between two metal conductors. What will be the fall of potential along this circuit, and how will it vary in the metal conductors and in the body? In other words, how will the difference of potential at the poles of the battery compare with the difference of potential between the electrodes at their point of junction with the body?

Since I, the intensity of the current, is the same throughout the circuit, it is clear from the formula $V = R\ I$, that the difference of potential between any two points will be proportional to the resistance of the circuit between those points.

Let us suppose that the total resistance of the whole circuit is 2000 ohms, and that the difference of potential at the terminals of the battery is 40 volts. If we take two points in the circuit such that the resistance between them is 1500 ohms, the difference of potential between these two points will be

$$\frac{1500}{2000} \text{ of } 40 \text{ volts} = 30 \text{ volts.}$$

In general, the difference of potential V' between two points separated by a resistance R', is a fraction of the total voltage V, expressed by the equation $V' = \frac{R'}{R} V$, where R is the total resistance of the circuit.

This formula shows us that to avoid waste of potential we should use conductors, whose resistance R' is negligable in comparison with the resistance of the body.

The same considerations teach us to use thick wires for supplying the current to electric cauteries, lamps, etc.

84. **Intensity of currents in parallel circuits—Use of resistances.**—When a circuit is completed by means of two conductors connected in series, the total resistance is equal to the sum of the resistances of the two conductors.

When the circuit is completed by two conductors which are connected together at both ends, the conductors are said to be connected in parallel. In this case a portion of the current passes through each conductor.

The intensity of the current in either branch is given by $I = \frac{V}{R}$ where V is the difference of potential between the ends of the conductor and R the resistance of the conductor under consideration.

The total current in the circuit will be the sum of the currents in each branch—that is to say, the circuit will act like a single circuit with a resistance less than the resistance of either branch.

In this way an *equivalent resistance* may be found which will replace the series of parallel conductors.

85. **Calculation of equivalent resistances.**—The current passing through the various branches of two or more conductors connected in parallel is found by Ohm's law

$$i_1 = \frac{V}{r_1}\,;\; i_2 = \frac{V}{r_2} \quad \text{etc.}$$

hence the total current

$$I = \frac{V}{r_1} + \frac{V}{r_2} + \frac{V}{r_3} + \;\ldots\ldots = V\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}\right)$$

The equivalent resistance is the single resistance which may be substituted for the set of conductors without altering the current. If R be this resistance

$$I = \frac{V}{R} = V\left(\frac{1}{R}\right)$$

and therefore $$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \cdots$$

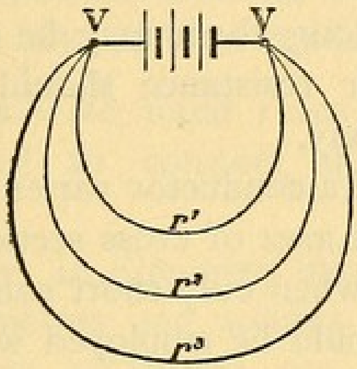


Fig. 7.

The reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the resistances of the different branches.

86. **Lines of flux in a broad conductor.**—When a current passes from a filiform conductor, such as a metal wire, into a conductor of considerable thickness, such as the human body, it spreads out. The lines of flow spread out around the direct line, joining the two points of juncture with the wires, becoming further apart and therefore less dense as they get further from these points. (Fig. 8.)

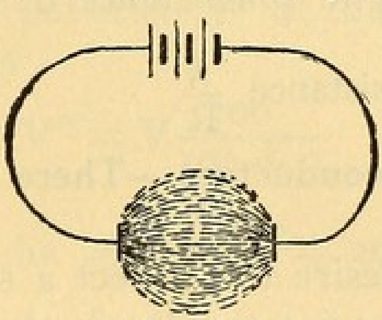


Fig. 8.

The current will produce its greatest effect on the body at the points of application of the wires, where there is the greatest intensity per unit of cross section. This energetic action at the points where the current enters and leaves the body is called the *polar action* of the current.

87. **Conductors for medical galvanisation.**—The conductors employed for galvanisation should be such that the fall of potential along them may be as small as possible, and therefore their resistance should be small compared with that of the body.

The resistance of a conductor varies directly as its length, and inversely as its area of cross section. Thin wires may, therefore, be used when only short conductors are required, but thick wires should be employed when the conductor is long.

All metals are not equally good conductors. The *specific resistance,* or *resistivity* of a metal, is the resistance of unit length of a bar of that metal of unit cross section.

The resistivity of a given metal varies with the temperature.

If ρ_0 be the resistivity at 0°, and ρ the resistivity at a temperature θ, we get approximately $\rho\theta = \rho\theta\ (1 + a\theta)$ where a is the coefficient of temperature and varies with the metal considered.

The *conductivity* of a metal is the reciprocal of its resistivity $\frac{1}{\rho}$. The *conductance* of a conductor is the reciprocal of its resistance $\frac{1}{R}$

88. **Choice of conductors.**—There are two cases to be considered.

(1) We may desire to connect a distant generator of electricity to some intermediary apparatus placed close to the patient, such as a current reducer, a rheostat or a current collector.

(2) A flexible conductor may be required to connect

the terminals of utilisation to the electrodes which are applied to the patient.

In the first case we have merely to supply an adequate path for the current; in the second, flexibility, lightness and convenience are also to be considered.

89. **Electrophores.**—No fixed rules can be given for the conductors used to connect different pieces of apparatus.

Copper wire 1 mm. in diameter has a resistance of 2 ohms per hundred metres and weighs 700 grammes per 100 metres, or about 1½lb per 100 yards. This will serve as a useful basis from which to reckon. Suppose we wish to pass a galvanic current through a minimum resistance of 100 ohms, with a maximum current intensity of 200 milliamperes, and that the generator is 50 metres from the patient.

Since $V = IR$, the difference of potential V at the terminals of the generator will be $(100+2)$ ohms $\times .2$ amperes $= 20.4$ volts, if we are working with primary cells and a collector, and without any adjustable resistance so that there is no resistance besides that of the wires and the patient to be accounted for.

The difference of potential V" at the points of utilisation will be given by

$$V'' = V\frac{100}{100+2}$$

and will therefore be $20.4 \times \frac{100}{102} = 20$ volts. The fall of potential in the leads will be .4 volts per hundred metres.

The diameter of the wire employed will vary with the length required and with the resistance of the other portions of the circuit. As a rule it is better to use thick wires, those used for movable electric lights are a very convenient size.

The insulation of the conductors is of great importance. In moist situations such as cellars, etc., cotton or silk should not be used as an insulating material. Vulcanised rubber is the best substance for such use. When the conductor is placed underground, a lead tube should be employed in addition to the insulating material.

The most elementary precautions of insulation are often neglected on the plea that the difference of potential is small and the currents weak. The loss from such causes may nevertheless be considerable. There is also a danger that badly insulated wires may come into contact with the wires of the electric light service, or other high potential wires. Insulated wires should always be used, and if of any great length, they should be protected by a wooden moulding. Where several different conductors are placed close together, as in passing through a hole in a wall, the leads should be insulated with rubber tubing as carefully as if they were wires of high potential. Many accidents would be avoided if these simple precautions were employed.

90. **Flexible conductors.**—Flexible conductors are made of metallic braid, or of several fine copper wires covered by some insulating material, the ends being soldered to a suitable contact piece. Flexible conductors are very liable to break, and when there is an interruption of the current, the flexible conductors should always be examined first.

91. **Resistance.—Rheostat.—Potential-reducers.**—Except in the case of a galvanic battery with a current collector, the strength of the current is usually regulated by means of a variable resistance introduced into the circuit.

Two methods of introducing a resistance into the circuit are shown in Figs. 9 and 10.

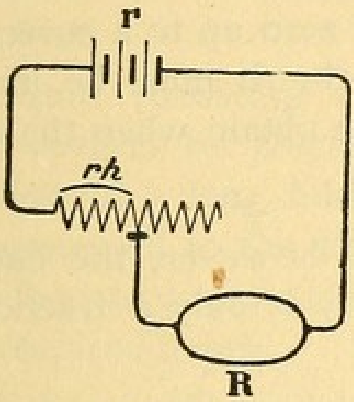


Fig. 9.

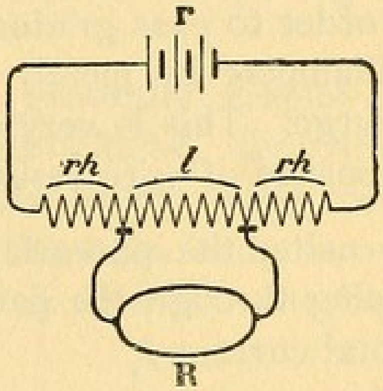


Fig. 10.

The resistance may be simply connected in series with the circuit of utilisation, as in Fig. 9. This is the ordinary *rheostat* arrangement.

In the *potential reducer* arrangement, shown in Fig. 10, the resistance only is introduced into the main battery circuit, and the circuit of utilisation is joined up in parallel with the resistance.

These distinctive terms, potential reducer and rheostat, though commonly used in medical electricity, are not altogether satisfactory, since the result in both cases is to diminish the difference of potential at the terminals of utilisation and the term rheostat is often used for any form of adjustable resistance.

In the application of a galvanic current to the human body, the use of the potential-reducer is much to be preferred.

When the rheostat arrangement is used,* the intensity

*Let R, be the resistance of the body.
E, the E.M.F. of the generator.
r, the internal resistance of the generator.
rh, the resistance of the rheostat in series.
ρ, the resistance of the portion of the potential-reducer in parallel with the circuit of utilisation in Fig. 10.

of the current passing through the body will be given by

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

In order to pass gradually from zero up to a current of 1 milliampere by merely varying rh, rh must be indefinitely large. This is very difficult to obtain when the rheostat consists of wire resistances.

By using the potential-reducer, however, the current I passing through the patient's body is only a fraction of the total current I_t

$$I = I_t \frac{\rho}{R + \rho}$$

The total current is itself the quotient of E by the sum of the internal battery resistance r_1, the external resistance rh_1, and the equivalent resistance of the two conductors in parallel $\frac{1}{\frac{1}{s} + \frac{1}{R}}$

$$I_t = \frac{E}{r + rh + \frac{1}{\frac{1}{\rho} + \frac{1}{R}}}$$

The advantage of this method is that we can gradually increase the current through the body from zero to 1 milliampere by altering ρ sufficiently to increase the fraction $\frac{\rho}{R + \rho}$ of the current which passes through the body, instead of having to alter the total current.

The portion of the current passing through the resistances in the parallel circuit is of course wasted; this is, however, of no practical disadvantge.

92. **Rheostats.**—Rheostats or variable resistances may be either metallic or liquid. In *Lewandowski's* rheostat the resistance is formed of a tapering bar of graphite.

Liquid rheostats are more generally employed. In that devised by *Duchenne* of Boulogne, the resistance consists of a long tube filled with water. One rheophore is connected to the bottom of the tube, and the other is attached to a movable rod which dips into the liquid to any desired depth.

In *Bergonié's* model a very high resistance is obtained by employing as electrodes carbon rods terminated by glass capillaries through which the conducting liquid has to pass. This instrument is very useful for medical galvanisation, where it is important to avoid a shock on starting the current. The U-shaped rheostat, designed by *Bergonié* and *Bordier,* is on the same principle. In order to alter the resistance the U-tube is raised or lowered, the electrodes trodes remaining fixed.

93. **Potential-Reducers.**—These may be either liquid or metallic. *Gaiffe's* circular metallic potential-reducer is a convenient form.

The instrument should be so constructed that when the current in the circuit of utilisation is zero the useless current passing through the resistance shall be also cut off.

94. **Instruments for measuring galvanic currents.**—The instruments required for measuring the galvanic current are the voltmeter and the milliamperemeter. In exceptional cases we may also require apparatus for measuring the resistance.

The resistance of the human body is measured by a special process described in paragraph 257.

95. **Measurement of current—Galvanometer—Electro-dynamometer—Milliamperemeter.**—When an electric current passes along a conductor parallel to a magnet, the magnet tends to place itself at right angles to the current, in such a manner that the north pole of the magnet will be on the left side of the current. (*Ampere's* law.)

If the magnet be so suspended that there is a constant mechanical force tending to restore it to its original position, the amount of the deviation will be a measure of the current passing in the wire. The galvanometer is an instrument in which this repulsion between a current and a magnet is made use of in order to measure the current. In the original form of galvanometer the circuit was fixed and the magnet movable. The oscillations of the magnet needle caused this method to be abandoned in favour of a fixed magnet.

Aperiodic galvanometers are now used, in which the wire carrying the current is wound round a frame which rotates about a fixed magnet. An index attached to this frame shows at once the number of amperes or milliamperes without any preliminary oscillation.

An electrodynamometer is an instrument in which the fixed magnet is replaced by an electric circuit wound as a solenoid. The movable circuit is arranged in the same way as in the galvanometer and is connected in series with the solenoid so that the current to be measured passes through both. The solenoid will change its poles as often as the current changes its direction. The deviation will thus always be in the same direction whichever way the current flows. An electro-dynamometer is, therefore, capable of measuring an alternating current.

The milliamperemeter is a very delicate aperiodic galvanometer or electro-dynamometer constructed to measure thousandths of an ampere. It is usually graduated to measure from 1 to 75 milliamperes.

Some instruments are provided with a shunt by means of which a current up to 250 milliamperes may be measured. The shunt is a resistance placed in parallel with the movable coil, so that 4-5 of the current will pass through it, and only 1-5 through the coil.

When the shunt is in use the total current will, therefore, be five times as great as that registered by the index. In some instruments two different shunts are provided.

96. **Measurement of difference of Potential—Voltmeter.**—Differences of potential in a galvanic circuit are measured by means of a voltmeter. A voltmeter is a galvanometer or electro-dynamometer of very high resistance, introduced in parallel with the main circuit, and connected to the two points whose difference of potential it is desired to determine.

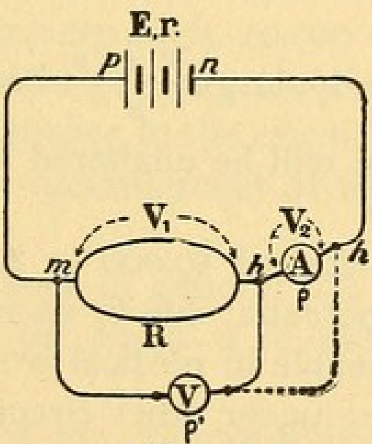


Fig. 11.

In Fig. 11 E.r. is the galvanic battery and mh the body of the patient. The circuit p m h h' n consists of three parts, the conductors pm, h'n, whose resistance is negligable; the body of the patient, mh, and the milliamperemeter A. The fall of potential along the circuit will be irregularly distributed in accordance with the varying resistance of its several parts. The difference of potential to be measured is that between m and h. The voltmeter is, therefore, introduced into the circuit between these two points, as shown by the continuous lines in the figure.

The act of introducing the voltmeter will in itself diminish the difference of potential between m and h, for the current now has two routes of resistances R and ρ', where originally it had but one, R.

The difference of potential was originally $\dfrac{E}{\dfrac{r+\rho}{R}+1}$

This now becomes $$\frac{E}{\dfrac{r+\rho}{R}+\dfrac{r+\rho}{\rho'}+1}$$

The quantity by which the potential difference is diminished will decrease as ρ', the resistance of the voltmeter circuit, increases.

When ρ' is infinitely large $\dfrac{r+\rho}{\rho'}$ becomes 0 and the difference of potential will be unaltered by the introduction of the voltmeter.

Even with a voltmeter of 10,000 to 20,000 ohms' resistance, the change of potential due to its introduction is considerable. We are unable in medical work to use the voltmeter as is often done under other circumstances, by introducing it into the circuit, reading the voltage, and then cutting it out again. The resistance of the human body is of the same order as that of the voltmeter, and when the voltmeter is cut out there is an instant rise of potential between the terminals of utilisation.

An amperemeter placed at A will indicate the total current, only a portion of which passes through the patient's body, the remainder passing through the voltmeter only.

The portion passing through the body will be a fraction of the whole represented by $\frac{\rho'}{\rho' + R}$.

In order that this fraction should approximate to unity, ρ' would have to be infinitely large compared with R. This is impossible when R is the human body, even if we have a voltmeter of 20,000 ohms' resistance, such as that used by *Bergonié*.

To remedy this defect we may connect the voltmeter to the points m and h'. In this case the milliamperemeter will give the true current, but the voltmeter will no longer give the true voltage between the terminals of utilisation, but will indicate the total difference of potential between m and h'; *i.e.*, the fall of potential in the patient's body plus that in the amperemeter. $I\ (R + \rho)$.

In medical galvanisation there is no method of measuring both the voltage and the amperage accurately. Even when the resistance of the milliamperemeter is very low and that of the voltmeter very high, 10,000 to 20,000 ohms, the two measurements when taken together will be inexact. When we have a voltmeter in the circuit we must be content with an approximate measurement of the current by means of the amperemeter.

The milliamperemeter in general use has a resistance of .5 to 3 ohms when the shunt is in use, and 3 to 5 ohms without the shunt.

In consequence of the impossibility of determining I and V simultaneously, we are unable to calculate the resistance of a body by the direct application of the formula $R = \frac{V}{I}$ of *Ohm's* law. All we can do is to calculate the total resistance of the portion nh' of the circuit, and subtract from this the known resistance of the milliamperemeter and the electrodes. The remainder will be the resistance of the body.

97. **Measurement of Resistance.**—We have seen that when the resistance of a conductor is small, we may estimate its magnitude approximately by *Ohm's* law, $R = \frac{E}{I}$ measuring I by an amperemeter in the main circuit and E by means of a voltmeter of high resistance, at least 1000 times as great as the resistance to be measured. The error is only of the order of $\frac{1}{10}$ per cent and may be neglected for practical purposes.

This method, however, is inapplicable for measuring the resistance of the human body, which is several thousand ohms. We must have recourse to a special mode of procedure which the reader will find described in the second part of this book, par. 259.

He will also find there methods of measuring the resistance of the body for faradic currents. The measurement of the body resistance is complicated by phenomena of ionisation and polarisation, which are more suitably dealt with in the physiological section.

98. **Accessory instruments.**—*The current reverser,* of which there are many different forms, is a switch by means of which the direction of the current through a circuit may be reversed. *Interruptors* are used in galvanisation to intermit the current in the circuit of utilisation from time to time. They may be fixed on the switchboard or on the handle of the electrode. For electrodiagnosis the latter arrangement is more convenient.

A *Metronome* is used to move a plunger dipping into mercury, to produce automatic interruptions of the galvanic current. It is also employed as the motive power in *Bergonié's* rhythmic reverser.

The handles, plates or pads, by means of which the current is applied to the body, are called *electrodes.*

An *indifferent electrode* is a plate of considerable size, covering a large area of the body, and thus reducing the polar action to a minimum. The *active electrode* is of smaller size and is applied to the region where we wish to produce polar action or stimulation.

Electrodes are made of a conducting substance such as tin, carbon or copper. This is covered with a pad of some soft, spongy material with an outer layer of lint, gauze, cloth or chamois leather.

CHAPTER II.

THE FARADIC CURRENT.

I. General Considerations.

99. **Definition.**—A faradic current is the current induced in a conductor when placed in a magnetic field, the strength of which is rapidly alternating between its maximum value and zero.

The faradic current was discovered by *Faraday*, in 1831. It is usually obtained by means of the induction coil invented by *Ruhmkorff* in 1851.

100. **The Ruhmkorff coil.**—This instrument is shown in Fig. 12. The primary or inducing coil is a coil of thick

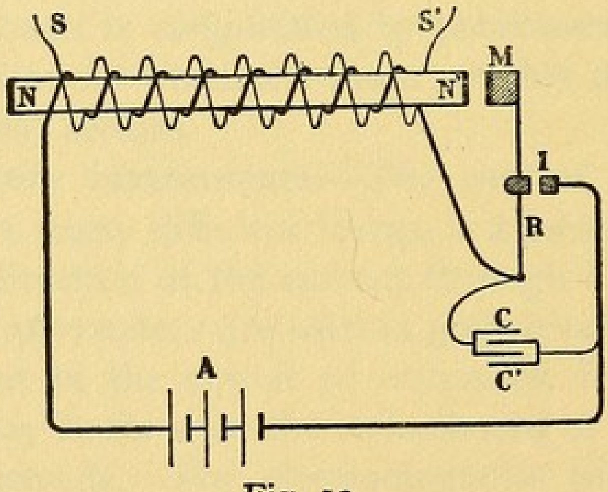


Fig. 12.

insulated copper wire wound spirally round a core of soft iron, or a bundle of soft iron wires. NN'.

Around this primary coil is wound the secondary coil of thin insulated wire.

A current from a source of electricity, A, is passed through the primary circuit and is suddenly stopped and restarted at regular intervals.

These periodic interruptions are made automatically. One of the simplest means of doing this is shown diagrammatically in Fig. 12.

When the two parts of the interruptor I are in contact the current passes through the primary circuit, magnetising NN' which attracts the iron hammer M and thus breaks the contact; M is then brought rapidly back to its original position by the spring R, contact with I is re-established and the process is repeated.

II. Production of a faradic current in an induction coil.

101. **Theory of the magnetic circuit and the magnetic field.**—The magnetic flux in a magnetic circuit is analogous to the electric flux in a conductor of electricity through which a current is passing.

The *magnetic circuit* is the term applied to any metallic system which includes a magnet or an electromagnet. An ordinary horseshoe magnet and its armature forms a simple magnetic circuit.

Even when there is no armature we still speak of a magnetic circuit, the armature being replaced by the layer of air between the poles, through which the lines of force pass to complete the circuit.

A magnetic circuit is said to be *closed* when it is entirely composed of metal. It is said to be *open* when there is an air space in the circuit, or a gap in the magnetic ring.

A bar magnet, or the core of a Ruhmkorff coil, forms part of an open magnetic circuit, the lines of force spreading out at the ends and bending back to join and close the circuit in the surrounding air.

The whole of the space, whether metallic or non-metallic,

5

which is traversed by lines of magnetic force, is called the *Magnetic Field.*

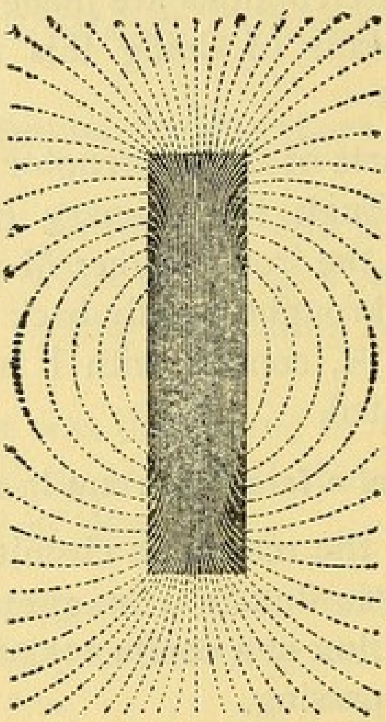


Fig. 13.—Lines of magnetic force in a magnetised bar and in the surrounding air.

102. **Laws of the Magnetic Circuit.**—In any magnetic circuit, whether closed or open, the lines of magnetic force form closed curves. The *magnetic flux* along these lines of force is analogous to the electric current.

There is also a *magnetic resistance* of the circuit termed its *reluctance,* which is analogous to the resistance of a conductor of electricity.

The magnetic flux is caused by a *magnetomotive force,* just as the flow of the electric current is caused by an electromotive force.

These three quantities: magnetomotive force F, magnetic flux Φ, and reluctance R are related to one another by the equation $\Phi = \frac{F}{R}$ which is analogous to the equation $I = \frac{E}{R}$ of *Ohm's* law.

The unit of magnetic flux is the *Maxwell,* that of magneto-motive force is the *Gilbert,* while the unit of reluctance is called an *Oerstedt.*

$$1 \text{ maxwell} = \frac{1 \text{ gilbert}}{1 \text{ œrstedt}}$$

The reluctance of a magnetic circuit is proportional directly to the length of the circuit, and inversely to its cross section and its magnetic permeability.

The *magnetic permeability* is a property of the particular substance of which the circuit is made. The *reluctivity* of a substance is the reciprocal of its magnetic permeability.

103. **Generation of magneto-motive force—Electromagnets.**—The usual method of generating magneto-motive force is to pass an electric current through a wire solenoid surrounding an iron core.

The magnetic force generated in the iron core is proportional to I the strength of the electric current, and to n the number of turns of wire in the solenoid.

If I is measured in amperes, the magneto-motive force in gilberts is given by $F = .4\pi nI$.

The product nI is termed the number of *ampere-turns* in the system.

The magnetomotive force generated by one ampere-turn is $.4\pi$. The magnetic flux F measured in gilberts is, therefore $.4\pi$ times the number of ampere-turns. One gilbert is thus $.4\pi$ ampere-turns, and one ampere-turn is $\cdot 4\pi$ gilberts.

In practice we do not measure the magneto-motive force by means of its proper unit, the gilbert, but by the ampere-turn, a unit which belongs to the generator of the force.

When we speak of a magneto-motive force of 20 ampere-turns we mean the force which is generated by a current of 20 amperes passing once round the core, or by 1 ampere passing through a coil of 20 turns, or by any other arrangement such that $nI = 20$.

This force of 20 ampere-turns is equal to $20 \times \cdot 4\pi$ gilberts.

The intensity H of a magnetic field developed by one ampere-turn varies inversely with the length of the circuit in which the magneto-motive force is generated. The unit of intensity of magnetic field is the field developed by one ampere-turn one centimeter in radius. Unit magnetic field is sometimes termed a magnetic field of one ampere-turn per centimetre.

The C.G.S. unit of magnetic field is $\frac{1}{\cdot 4\pi}$ ampere-turns, or ·8 ampere-turns per cm. It is called a *gauss,* and may be defined as the intensity of a field which, when acting on unit magnetic pole, exerts on it a force of 1 dyne.

104. **Residual magnetism—Hysterisis.**—When a magnetic substance has been subjected to a magnetic field its magnetisation persists for some time after the exciting field is removed. This *residual magnetism* is ephemeral in character and generally disappears at once when the magnet is shaken. If the magnetism persists for some time the magnet is said to be *permanent.*

Hysteresis is another important phenomenon of magnetic induction. When a magnetic body is magnetised by the influence of a magnetic field, and the intensity of the field is reduced to zero, the demagnetisation of the body will not be complete.

This lagging behind of the demagnetisation is called *hysteresis.* It is due to the *coercive force,* a property of a magnetic body which tends to preserve its magnetisation when once acquired.

105. **Electric induction in a magnetic field.**—When a metallic circuit is placed in a magnetic field it is traversed by an electric current whenever the flux of magnetic force through the circuit varies (65). The time during which the current passes is equal to the duration of the variation in the flux of magnetic force.

The electromotive force of the induced current depends on $\frac{d\Phi}{dt}$ the *rate of change* of the magnetic flux (65).

The *direction* of the induced current is determined by *Lenz'* law: *i. e.*, "the direction is such that it tends to prevent the change of flux which causes it."

In the Ruhmkorff coil of Fig. 12, when the interruptor I suddenly makes contact, the primary current is established with great rapidity, and the magnetic flux in the core quickly attains its maximum value. When the circuit is broken the flux rapidly decreases from this maximum value to zero.

These changes of magnetic flux induce two momentary currents in the secondary circuit, the "make" current during the first period, and the "break" current during the second.

The duration, electromotive force, strength and power of these currents are all functions of the *rate of change* of the magnetic flux. They depend on the ratio of the total change in the flux, to the time in which that change takes place.

106. **Factors determining the time during which the induced current passes.**—The time during which the flux of magnetic force varies, on making or breaking the current in the primary, depends on several complex factors.

When the primary circuit is closed, there is a magnetic flux in the core of the induction coil, the lines of force being of the form described in par. 101. This magnetic flux induces a current of self-induction in the primary circuit as well as an induced current in the secondary circuit.

From *Lenz'* law it follows that these two induced currents will tend to cause a flux of force in the core in a direction opposite to that of the original flux.

We require to study the character of this contrary flux, in order to estimate the retardation it will cause in the primary increase of magnetic flux.

When the primary circuit is broken, the suppression of the magnetic flux induces a current in both circuits in the same direction as the current in the primary. This induced *extra current* in the primary will spark across the gap of the interruptor, causing the *spark of rupture* or the *extra current spark.*

While this spark is passing it acts as a conductor across the gap of the interrupted circuit, thus prolonging the duration of break. As the resistance of the spark is unknown, it is impossible to know how the magnetic flux varies during its passage.

107. **Character of induced currents.**—In order to understand the formulæ which apply to induced currents, we must consider several factors.

(1) *Factors relating to the electrical induction produced in a conductor by a variable magnetic field.*

The quantity of electricity forced round the circuit is proportional, directly to the change in the magnetic flux and inversely to the resistance of the circuit; $Q = \frac{\Phi - \Phi^1}{R}$

Φ and Φ' being the value of the flux before and after the change, both measured in the same direction.

The electromotive force driving the electricity through the conductor is a function of the rate of change of the flux of force. $E = \frac{d\Phi}{dt}$.

The intensity of the current is given by $\frac{E}{R}$, and therefore

$$I = \frac{d\Phi}{R\,dt}$$

These three formulæ express algebraically what has already been stated in par. 102.

(2) *Factors relating to the current induced in one circuit by a current passing through a neighbouring circuit, i.e., to the phenomenon of mutual induction.*

The induction developed in a straight wire by a current passing through another wire parallel to it, is completely analogous to induction caused by a magnetic field. This will be readily understood when we realise the identity between a bar magnet and a solenoid, and then regard the straight wires as a portion of one turn of the coil.

Let I be the intensity of the primary current circulating through one of the wires, and Φ the flux of magnetic force intercepted by the second wire. For a given pair of wires the ratio $\frac{d\Phi}{dI}$ will be constant. In other words a change dI in the primary current will always produce the same change $d\Phi$ in the intercepted flux.

This ratio, $\frac{d\Phi}{dI}$, is the *coefficient of mutual induction* of the system of wires, and is represented by the symbol

$$L_m = \frac{d\Phi}{dI}$$

The quantity of electricity induced in the second circuit is given by $\frac{\Phi - \Phi'}{R}$, so that as the flux changes from zero to a maximum or *vice versa*, the quantity of electricity induced is given by $Q = \frac{L_m I}{R}$

A knowledge of the coefficient of mutual self-induction is of great importance in the construction of induction coils. In many cases this coefficient can be calculated from the dimensions and position of the wires.

For two parallel wires of length l, with a distance d between them, the coefficient of mutual induction is given by

$$L_m = 2l \left[\log_e \frac{2l}{d} - 1\right]$$

For two equal parallel circles of radius r, separated by a distance d

$$L_m = 4\pi r \left[\log_e \frac{4\pi}{d} r - 2.45\right]$$

For two concentric coils, the external coil being of N turns and length l, and the internal coil of N' turns and with a sectional area S'.

$$L_m = \frac{4\pi N N' S'}{l}$$

(3) *Factors due to self-induction, i.e., to the induced current produced in a circuit by changes in the current circulating in that circuit.*

The *coefficient* of *self-induction* L_s is the ratio of the variation of flux intercepted by a circuit to the variation of intensity of the inducing current in that circuit. $L_s = \frac{d\Phi}{dI}$

For a linear conductor of length l and radius r

$$L_s = 2l \left[\log_e \frac{2l}{r} - .75\right].$$

For a solenoid of length l, and cross section S, with one layer of N turns,

$$L_s = \frac{4\pi N^2 S}{l}$$

The practical unit of mutual induction and of self-induction is the *Henry,* which is equal to 10^9 C.G.S. units. It is the induction in a circuit of which the induced E.M.F. is 1 volt, when the inducing current varies at the rate of 1 ampere per second.

108. **The time constant of an induction coil.**—There is one constant of a Ruhmkorff coil which medical electricians will find of great importance. This is the *time constant,* the ratio of the coefficient of self-induction of the primary to its resistance $\frac{L_s}{R}$. When the primary circuit is closed the self-induction in the primary and the induced current in the secondary both tend to oppose the increase of the magnetic flux, and thus delay the starting of the inducing current. Considering only the retardation due to self-induction, we can determine approximately the duration of the change of flux during "make." For this purpose we may use *Helmholtz'* formula for I_t, the strength of the current at a time after the closing of the circuit.[1]

$$I_t = \frac{E}{R}\left(1 - e^{-\frac{R}{L_s}t}\right)$$

In this formula R, the quotient of the E.M.F. by the resistance, gives the maximum strength of the current when it has attained a steady state.

L_s is the coefficient of self-induction of the primary in *Henrys,* t is the time which has elapsed since the closure of the circuit, and e is 2.7183, the base of the Naperian logarithms.

From this formula we see that the greater the coefficient of self-induction L_s the smaller will be the term $\left[1 - e^{\frac{-Rt}{L_s}}\right]$ and therefore the greater will be the time required by the current to reach its maximum value $\frac{E}{R}$. On the other hand, with the same self-induction, the greater the resistance R, the shorter is the time required for the current to attain its maximum value.

[1] Note. For further details see Hospitalier, Manuel de l'Électricien.

The point of importance is that for every circuit there is a certain definite time required for the current to increase from zero to a given fraction of its final value, and this time will always be the same whatever the final value of the current employed may be.

For any one coil then we may determine the time required for the current to reach $\frac{1}{x}$ of its maximum value; $\frac{1}{x}$ being any fraction we choose. The fraction used in practice is ·6343, for this is the value of

$$\left[1 - e - \frac{R}{L_s}\right]t \text{ when } \frac{R}{L_s} t = 1.$$

For a given induction coil then, the question resolves itself into this. What is the time required for the current to increase from zero to the value for which

$$\frac{E}{R}\left[1 - e^{-\frac{R}{L_s}t}\right] = \frac{E}{R} \times .6343.$$

This time will be $\frac{L_s}{R}$, since it is the value for which $\frac{R}{L_s}t = 1$. This value $\frac{L_s}{R}$ is called the *time constant* of the coil.

109. **Forms of the induced current.**—The induced current has two phases. In the first phase, the current at "make," it is in the opposite direction to the inducing current; in the second, the current at "break," it is in the same direction. (*Lenz'* law.) In all electric transformers, and also in induction coils, the electromotive force in the two coils is approximately proportional to the number of turns in each coil. If the secondary coil has 500 turns and the primary coil 50 turns, the induced E.M.F. will be approximately 10 times that of the inducing current.

Fig. 14 shews values of the electromotive forces. The thick line represents the E.M.F. of the primary current, while the dotted line ϵ shows that of the induced current. The thin line σ is the E.M.F. in the primary due to self-induction.

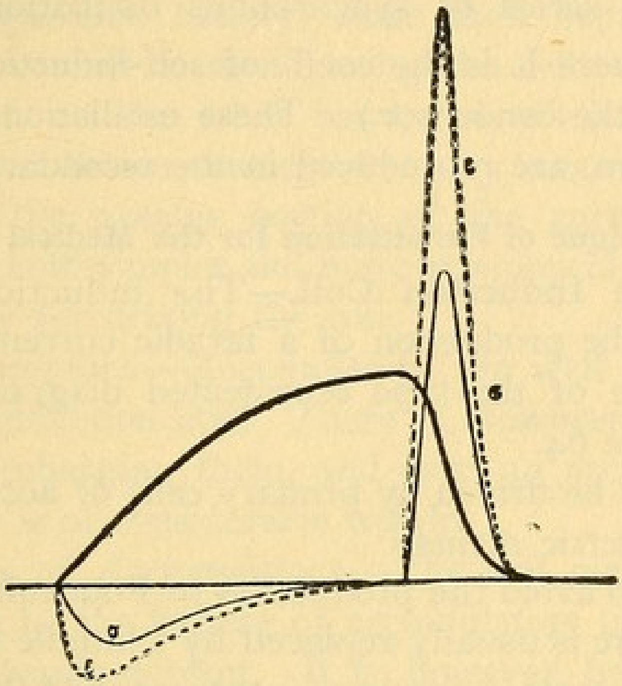


Fig. 14.

Fig. 15 is a diagram of the ordinary faradic current on a larger scale. It differs from the foregoing in the length of

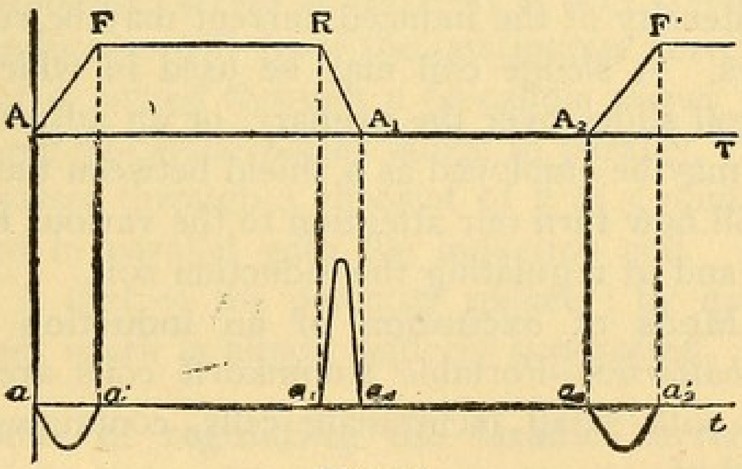


Fig. 15.

time during which the primary current remains constant. The duration of this period increases with the slowness of vibration of the interruptor.

Large coils are usually furnished with condensors to suppress the extra current spark. (106.) When the condensors are used there occurs in the primary circuit, at the moment of break, a series of synchronous oscillations of period $2\pi\sqrt{LC}$ (where L is the coeff. of self-induction and C the capacity of the condensor). These oscillations, which rapidly die down, are reproduced in the secondary circuit.

III. Technique of Faradisation for the Medical Electrician.

110. **The Induction Coil.**—The induction coils employed for the production of a faradic current for medical purposes are of the type represented diagrammatically in Fig. 12, page 64.

They may be driven by primary cells or accumulators, or from the electric mains.

In order to avoid the production of Foucault currents the solid iron core is usually replaced by a bundle of iron wires.

There are various forms of interruptor of the "trembler" type in which the rate of oscillation can be regulated at will. We need not enter into further details of their construction.

The intensity of the induced current may be regulated in two ways. A sledge coil may be used in which the secondary coil slides over the primary, or an adjustable metal cylinder may be employed as a shield between the two coils.

We will now turn our attention to the various methods of exciting and of regulating the induction coil.

111. **Mode of excitation of an induction coil.**—(1) *Special batteries*—Portable Ruhmkorff coils are generally supplied with small bichromate cells, containing a liquid composed of

Potassium bichromate	100 grammes
Sulphuric acid	200 grammes
Water	800 grammes

(2) *Galvanic Batteries.*—It is not advisable to use the same batteries for the induction coil and to furnish the gal-

vanic current for medical purposes. It will be found very unsatisfactory to drive the coil by the current from a few cells of the galvanic battery, since their capacity is but small, and it is well to avoid using the cells of a battery unequally. If, on the other hand, the whole number of cells is used and the current cut down by means of the current-reducer, the greater portion of the current will be wasted. It is both simpler and more economical to employ a special battery for driving the coil.

(3) *Accumulators.*—Accumulators are well adapted for use with an induction coil. There is, however, the inconvenience of recharging them, and even an accumulator of small capacity is of considerable weight.

(4) *Battery of Accumulators.*—The coil may be conveniently driven by the battery of accumulators used for supplying the galvanic current. It is, however, better to have two batteries, one for the coil and the other to supply the galvanic current. These may be charged at the same time by using a suitable system of commutators.

(5) *Continuous current supply.*—It is very convenient to drive the induction coil from the continuous current main. The current is passed through a 60-candle power lamp, or through three 24-candle power lamps in parallel. The current then passes through a rheostat of 2 to 5 ohms' resistance, placed in parallel with the induction coil. This arrangement is that of the potential reducer; by its use the extra current spark is almost entirely suppressed.

112. **Mode of regulating the faradic current.**—The intensity of the induced current is regulated by altering the strength of the magnetic field inside the secondary coil. This may be done in two ways.

(1) By employing the *du Bois-Reymond* sledge coil. The secondary coil can slide in a direction parallel to its

axis, so as to surround the primary coil either partially or entirely, thus varying the intensity of the magnetic field within the coil.

(2) By inserting a movable metallic cylinder between the two coils. In this cylinder Foucault currents will be produced, *i.e.*, induced currents which are entirely confined to the metal cylinder itself. The energy absorbed by these eddy currents is dissipated as heat. By interposing such a screen between the coils we diminish the magnetic induction in the secondary. The induced current will be a minimum when the inner coil is entirely covered by the screen.

113. **Bergonié's apparatus for rhythmic faradisation.**—Faradic currents are employed to produce a sort of muscular gymnastics resembling the normal physiological contraction. When the faradic current is suddenly turned on it is found that the muscular contraction is more forcible than voluntary contraction. The muscle thus soon becomes fatigued if the application is prolonged without intermission. *Bergonié* has, therefore, devised an apparatus which produces a faradic current which will not cause this excessive fatigue. The current gradually increases in strength up to a given value, remains constant for some time at that value, and then gradually decreases again to zero. This process is repeated periodically.

The rhythmic variations are obtained by passing the secondary current from an induction coil through a rotating rheostat, which gradually decreases the resistance in the circuit from infinity to a given minimum, keeps it at the minimum value for a certain time, and then increases it again to infinity. Another method may be employed for the same purpose; we may use a sledge coil which is made to oscillate backwards and forwards rhythmically.

114. Watteville currents. Galvano-faradisation. — It is sometimes desirable to combine the galvanic with the faradic current. This may be done by introducing

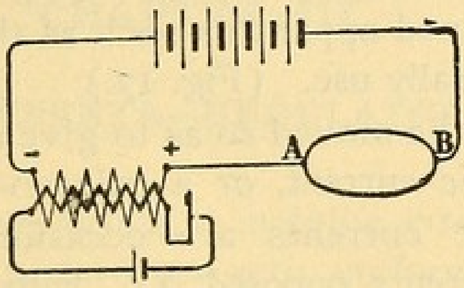


Fig. 16

an induction coil into the galvanic circuit, the secondary circuit of the coil being connected in series with the galvanic circuit. It should be joined up so that the

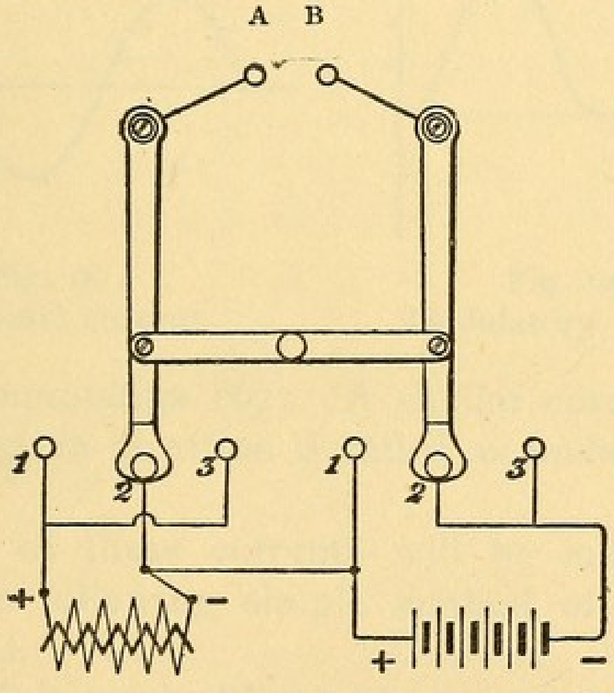


Fig. 17.—A.B. Terminals of utilisation.
Position 1. Faradic current only.
" 2. Galvanic current only.
" 3. Galvano-faradic current.

principal current, the current of break, is in the same direction as the galvanic current; the positive pole of the battery being connected to the negative pole of the secondary and *vice versa.* The electrodes, A B, Fig. 16, may be inserted at any point in the circuit.

To avoid the danger of connecting the wires up wrongly, a combined apparatus such as that designed by *Watteville* is generally use. (Fig. 17.)

The switch can be moved so as to give a simple faradic current, a galvanic current, or a galvano-faradic current.

Galvano-faradic currents are occasionally employed with the two currents opposed, *i.e.*, with the current of "break" in the opposite direction to the galvanic current.

CHAPTER III.

SINUSOIDAL CURRENTS.—UNDULATORY CURRENTS.

115. **Definition.**—When a metallic circuit, such as a Siemen's coil (67), revolves with uniform velocity in a magnetic field, the current collected by the brushes is *sinusoidal, i.e.,* the intensity of the current is proportional to the sine of the angle between the plane of the coil and

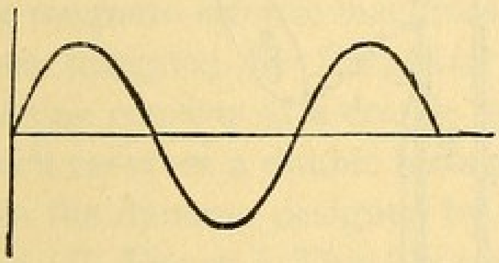


Fig. 18.
Sinusoidal current.

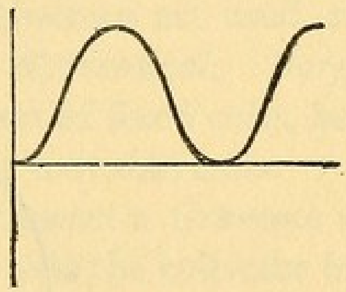


Fig. 19.
Undulatory current.

the line of commutation (67). A similar current which does not change in direction is called an *undulating* current.

The nature of these currents will be more readily grasped if the following simple method of producing them is studied.

In Fig. 20, E is a tube filled with water, with two electrodes, P and N, one at the top and the other at the bottom of the tube, which are connected to a battery.

a and *b* are another pair of electrodes, one of which, *a,* is fixed, while the other, *b,* is moved up and down by an insulated rod T, attached to an eccentric B, moved by the wheel R.

In the first place let *a* be placed midway between P and N, and level with the middle point of *b*'s path. Since the fall of potential between P and N is uniform, it is evident that the difference of potential between *a* and *b* will be approximately proportional to the sine of ω, the angle which the crank moving B makes with the horizontal.

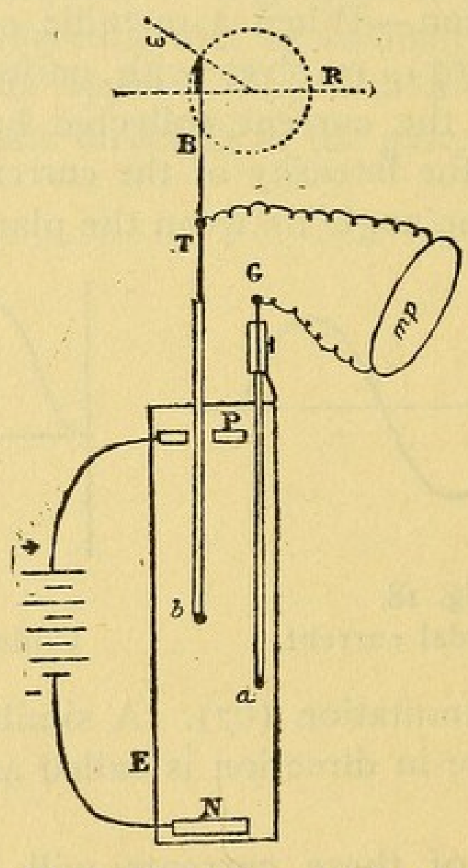


Fig. 20.—mp = utilization.

The difference of potential between *a* and *b* will also be of the same sign as the sine of the angle ω, since when *b* and *a* are in the same horizontal plane, their polarity will be reversed. At that point sine $\omega = 0$, and in the next quadrant the sign of sine ω will be reversed.

If now we depress *a*, so as to be level with the lowest point reached by *b*, the form of the current will be the same, the ordinates being approximately proportional to sine ($\omega + K$), where K is a constant depending on the position of *a*.

In the first position of *a* we get an alternating sinusoidal current; in the second position we get an undirectional undulatory current.

These currents were first introduced into medicine by *Prof. d'Arsonval.*

116. **Generators of sinusoidal and undulatory currents.**—Sinusoidal and undulatory currents may be obtained by means of apparatus with a variable resistance, working on the principle described above (115). They may also be produced by the use of *Leduc's* oscillating rheostat, but as a rule magneto-electric machines or dynamos are used, such as those designed by *Bergonié* and *d'Arsonval. Bergonié's* machine consists of a double hexagon of fixed coils, between which revolves a double hexagon of movable coils.

In the dynamo designed by *d'Arsonval* a *Gramme* ring is used (G, Fig. 21). This has on one side the collector brushes

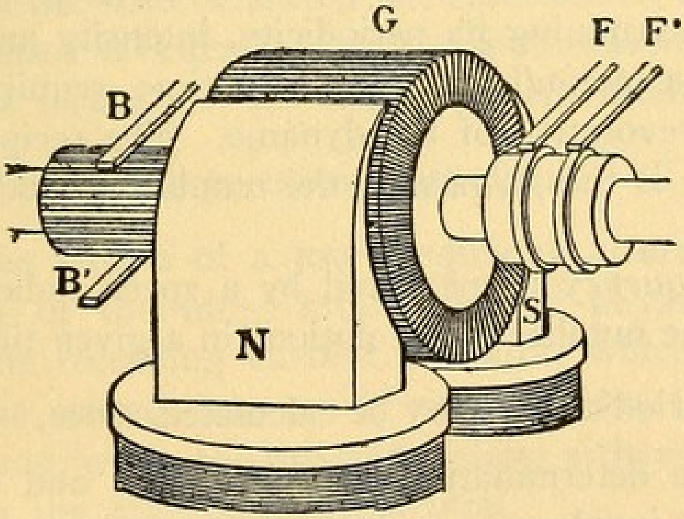


Fig. 21.

BB', and on the other two metallic rings, one of which is connected to each half of the *Gramme* ring. These brushes are in contact with the springs FF'.

When the armature revolves between the poles of the exciting electro-magnet NS, a sinusoidal current is collected by the springs FF', and a continuous current by the brushes BB'. By using one brush and one spring an undulatory current may be obtained between B and F'.

117. **Regulation of sinusoidal and oscillatory currents.**—In the use of sinusoidal and oscillatory currents two adjustments have to be made; for the frequency and for the voltage.

(1) The frequency is regulated by the velocity of rotation of the dynamo or oscillating rheostat.

(2) The maximum voltage may be regulated by varying the current in the electro-magnet and thus changing the intensity of the magnetic field. When an oscillating rheostat or potential reducer is used the intensity of the primary current may be reduced by increasing the resistance in the circuit.

118. **Measurement of sinusoidal and undulatory currents.**—The measurements of a sinusoidal current consists in determining its periodicity, intensity and E.M.F.

(1) The *periodicity* T is the time required for one complete revolution of the dynamo. The reciprocal of the periodicity is the *frequency,* the number of revolutions per unit time.

The *frequency* is measured by a speed indicator, which marks n the number of revolutions in a given time t. From this the periodicity T may be calculated, since, $\frac{n}{t} = \frac{1}{T}$.

(2) The determination of the E.M.F. and intensity of the current involves several different measurements. There will be a maximum E.M.F. and a maximum intensity, a minimum E.M.F. and intensity, and an average E.M.F. and intensity.

For a sinusoidal current the mathematical average value should be zero. In practice, however, we take the average for each semiperiod separately.

From a medical point of view the quantities most necessary are the *efficient intensity* of current and the *efficient E.M.F.* The value of these two quantities is found by multiplying the respective maximum values by $\frac{\sqrt{2}}{2}$ or .707.

$$\text{Efficient E.M.F.} = \frac{\sqrt{2}}{2} \text{ maximum E.M.F.}$$

$$\text{Efficient current} = \frac{\sqrt{2}}{2} \text{ maximum current.}$$

An idiostatic electrometer may be used to measure the E.M.F. A knowledge of this quantity, however, is of little practical importance. On the other hand it is of the greatest importance for us to know the intensity of the efficient current. A sinusoidal current may be measured by means of an electrodynamometer or universal milliamperemeter. In this instrument the index is attached to a movable coil rotating inside a fixed coil. The direction of the deviation is thus always the same whatever the direction of the current, since the phase of current changes simultaneously in both coils. This instrument gives the efficient intensity of the current. The maximum intensity is about $\frac{10}{7}$ of this.

119. **The Graph of a low frequency alternating current.**—One of the most interesting of physical instruments is the recording current indicator, which traces the form of the current curve. In such a curve the abscissæ give the time, while the ordinates show either the current intensity or the difference of potential.

These actual records of current variations are of the greatest interest. For further details of the construction of the apparatus we must refer the reader to a paper by *Blondel,* in the *"Revue Générale des Sciences Pures et Appliquées"* of July 15, 1901.

We will describe the original model devised by *d'Arsonval* for his physiological experiments on the "curve of excitation," or curve of the variable electrical state on which physiological excitation depends.

120. **D'Arsonval's apparatus for determining the excitation curve or diagram of the variable state of low frequency alternating currents.**—*D'Arsonval's* apparatus consists of a powerful electro-magnet producing an annular magnetic field. Within this field is placed a light movable coil, the turns of which are merely cemented together with shellac. The current to be studied passes through this coil, which will dip more or less into the magnetic field according to the intensity and direction of the current. The coil is supported on the membrane of a manometric capsule, and the oscillations of the coil are thus transmitted to an air drum which, in its turn, carries the style which records them on the revolving cylinder. By this means we can obtain a graphic record of the duration and intensity of any electric wave of low periodicity.

With very rapid oscillations the inertia of the recording apparatus impairs the accuracy of the curve. *D'Arsonval,* therefore, replaced it by an optical diagram. A ray of light falls on a small concave mirror, attached to the membrane midway between the centre and the circumference. The oscillating spot of light is received on a screen, and if the whole system is rotated about an axis so as to cause a displacement of the spot perpendicular to the oscillation, the current curve will be depicted on the screen.

121. **The Oscillograph.**—Two improvements have been introduced into the modern oscillograph. The inertia of the system has been reduced, and the self-induction introduced into the circuit by the instrument itself has been diminished.

In *Weiss'* bifilar instrument the current passes through two parallel wires which oscillate between the poles of the magnet. The motion of the wires is rendered apparent by the movement of a mirror attached to them.

In *Blondel's* soft iron oscillograph the current passes through two small coils, one on each side of the interpolar space. A bar of soft iron, carrying a mirror, oscillates between the two coils.

A ray of light reflected by this mirror falls on a second mirror, oscillating at right angles to the first. In this way we can depict variations of a current alternating as often as 250 times per second.

We must always make a correction for the self-induction of the instrument, except in the bifilar type where the coefficient of self-induction is practically nil. When the curve of potential difference is required the exciting coils are used as voltmeters, and their coefficient of self-induction being then much larger cannot be neglected. For further details we must refer the reader to the paper by *Blondel* quoted above.

CHAPTER IV.

HIGH FREQUENCY CURRENTS.

I. General Considerations.

122. **High Frequency.** The special physiological properties of the high frequency currents introduced by *Prof. d'Arsonval* place them in the front rank of therapeutic agents. They are alternating currents whose direction is reversed over a million times per second.

With the phonic wheel designed by *Sieur* we can get as many as ten thousand alternations per second. The physiological effects of such a current differ from those of an ordinary alternating current of low frequency, but we must increase the oscillations to a million or even a thousand million per second before we get what is generally understood by "high frequency." The period of such a current is of the order of a millionth to a thousand millionth of a second. The wave length is therefore a millionth or a thousand millionth of 300,000 kilometres; since 300,000 kilometres per second is the velocity of high frequency waves, of light waves, of X-rays, and of all transverse vibrations of the ether. This wave length of from 300 metres to 30 cm. or even less, brings the high frequency undulations into relation with the luminous waves. They prolong the scale of wave lengths at the infra-red end of the spectrum just as X-rays seem to prolong it at the ultra-violet end.

II. Production of High Frequency Currents.

123. **Production of the High Frequency Currents.**—*Hertz* first observed that high frequency currents are

generated by the disruptive discharge of a condensor in a circuit whose resistance is less than $\sqrt{\frac{4L}{C}}$; L being the coefficient of self-induction of the circuit and C the capacity of the condensor.

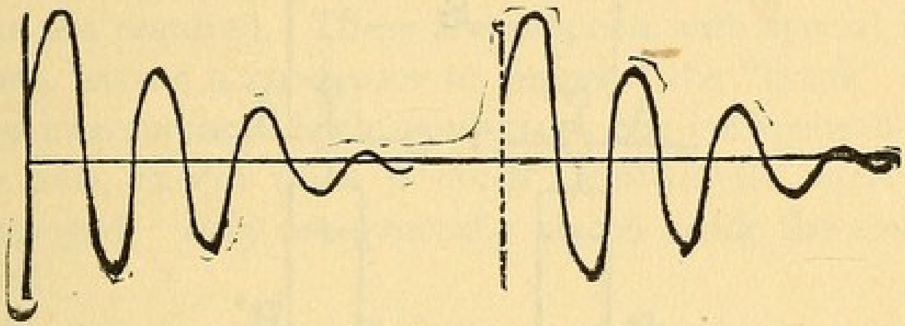


Fig. 22.

Fig. 22 represents the form of these oscillations, which die down with great rapidity. Their period is given by $T = 2\pi\sqrt{LC}$. Any reduction in C, the capacity of the condensor, or L, the self-induction of the circuit, diminishes the time of oscillation, and therefore the wave length of the radiations. In *Hertz'* detonator the capacity is very small. When L and C are both large, very long waves can be obtained.

124. **Choice of a Condensor for High Frequency Currents.**—*Tesla* employed a single *Leyden* jar for obtaining high frequency discharges; the usual arrangement, that employed by *d'Arsonval,* is shown in Fig. 23.

The inner coatings of two Leyden jars, BB', are connected to the rheophores of an induction coil P. A spark gap AA' is inserted between these jars. The outer coatings of the Leyden jars are connected together by a coil of copper wire CC' having a large coefficient of self-induction.

The resistance offered by the self-induction of such a coil to the passage of a variable current is enormous; so large indeed that a lamp mounted in parallel with it at DD' will

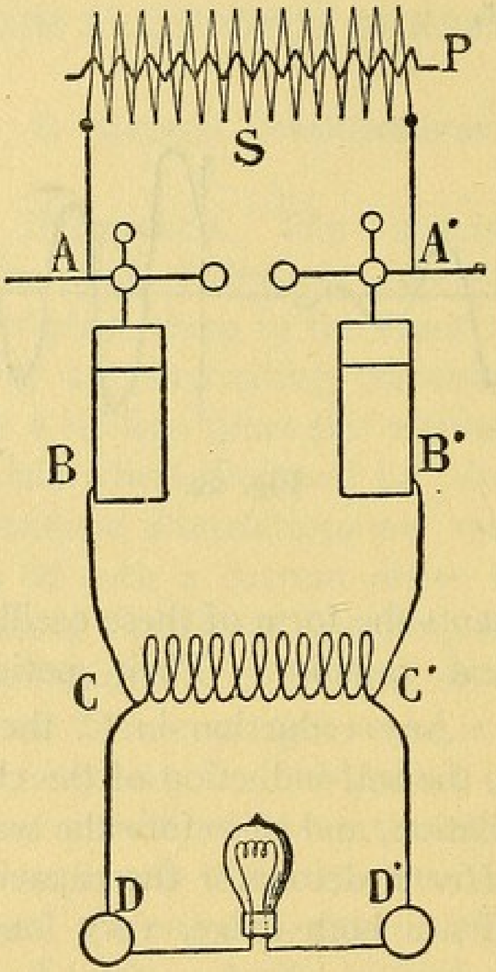


Fig. 23.—d'Arsonval's high frequency apparatus.

become incandescent, although its true resistance is infinitely greater than that of the coil.

Various types of condensors may be employed. Leyden jars, plate condensors, and oil condensors. It is possible to extemporise a condensor or to replace one which is damaged, by gumming tinfoil on a glass jar or a plate of glass, and immersing this in sand soaked with paraffin, or even in dry sand.

The spark gap should be enclosed in a box or thick case, to diminish the noise as much as possible.

125. **Electrical Source for High Frequency Apparatus.**—Any source of high tension electricity may be used, but an induction coil or an alternating current transformer is more convenient than a static machine.

For high frequency work coils giving 10-inch to 18-inch sparks are required. These are supplied with special interruptors, having a condensor to suppress the "break" spark in the interruptor. Such condensors are indispensable for large coils, except when *Wehnelt's* electrolytic interruptor is employed. They are generally placed inside the stand of the coil.

126. **Interruptors.**—Two types of interruptors may be employed for large coils; mechanical and electrolytic.

127. **Mechanical interruptors.**—Mechanical interruptors may be subdivided into several groups.

(1) Those in which the break is made between two metal surfaces, as in the old form of trembler or in the improved form of platinum break attached to large coils.

If the break occurs sharply when the hammer is moving with the greatest velocity and not at the end of its path, as in *Charpentier's* atonic interruptor, it will work satisfactorily in air. In *Radiguet's* interruptor the two copper surfaces of contact are immersed in petroleum.

(2) In the second class of interruptors a metal rod is immersed in a vessel of mercury, with a layer of alcohol or petroleum covering its surface.

A vertical up-and-down motion is imparted to the metallic rod by means of a rotary motor, or by the electrically sustained vibration of a tuning fork. Almost every electrical instrument maker has his own form of interruptor. For working from an alternating current *Villard's* interruptor is very convenient. (55.)

(3) The third class consists of mercury interruptors. Further descriptions of the numerous forms of these instruments may be found in the catalogue of any instrument maker. Any one of them is suitable for the production of high frequency currents.

128. **Electrolytic interruptors.** *Wehnelt's* electrolytic break consists of a vessel filled with a ten per cent solution of H_2SO_4. A platinum wire, surrounded by a glass tube, except just at the tip, dips into this solution and is connected to the positive lead of an electrical source, giving a pressure of 110 volts.

An electrode of some metal such as lead, which is not attacked by the acid, is immersed in another part of the vessel. When the current passes the water is decomposed, and this is accompanied by an evolution of heat which sets up the phenomenon known as *calefaction.* The bubbles of oxygen collected round the heated platinum point form a non-conducting sheath which interrupts the circuit. The moment the current is arrested the bubbles cease to form, contact is made between the liquid and the wire, and the current passes once more.

The current may be regulated by altering the length of platinum wire in contact with the water, or a rheostat may be introduced into the circuit. *Wehnelt's* interruptor may also be used with accumulators, but in that case a very large current is required and the electrolyte should be warmed.

The composition of the electrolyte and the arrangement of the electrodes has been modified by different makers. A condensor is not required for the induction coil when a Wehnelt interruptor is used.

The self-induction of the primary should be less with an electrolytic interruptor than with the slower mechanical interruptors. The less the coefficient of self-induction of the primary, the less will be the difference between the make and break currents in the secondary. It is the self-induction which retards the current of make and enforces the current of break in the primary. The ordinary induction coil has an average coefficient of self-induction which will allow of its being used with either form of interruptor.

Coils are also made with variable self-induction, the primary consisting of two separate coils, as in the *Radiguet* induction coil of 1902. These are much to be preferred for medical use.

129. **Current transformers for high frequency currents.**—An alternating current supply may be used directly for the production of high frequency currents. The original arrangement has been much improved lately by the apparatus designed by *Messrs. Gaiffe.* A transformer with closed magnetic circuit is employed to raise the potential from 110 volts to 15,000 volts. This high tension alternating current can then be used directly to charge the high frequency condensors.

We only require to convey just sufficient charge to the condensor to cause a spark to pass across the detonator gap, and therefore if one wave of the alternating current brings sufficient electricity at a potential high enough to reach this limit, we shall get a spark for every wave or semi-period. With the alternating current supplied to Paris this would mean 84 discharges per second. In practice we generally get more than one spark per wave, since the capacity of the Leyden jars is small compared to the charge of each phase of the alternating current.

This arrangement has two disadvantages. A permanent arc is often established between the knobs of the spark gap unless some means are adopted to suppress it. The most efficacious of the devices designed for this purpose is to blow out the arc by a current of air. The second disadvantage is that the waves of high frequency are reflected backwards into the secondary circuit, and injure the transformer. This makes it impossible to employ a higher pressure than 15,000 volts, which is insufficient to yield results that are really satisfactory.

At *Prof. d'Arsonval's* suggestion *Messrs. Gaiffe,* of Paris, have lately devised an instrument far in advance of anything obtainable before. The principal improvement is the employment of a special apparatus which prevents this backward flow of the high frequency waves.

In Fig. 24, SS' is the secondary of a transformer capable of raising the potential of the current supplied by the alternating current mains from 110 volts to 60,000 volts. LL' are Leyden jars whose inner coatings are connected with

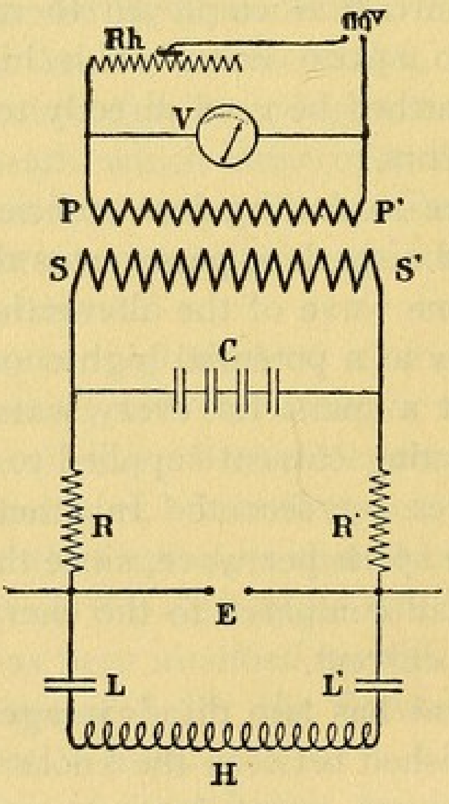


Fig. 24.

SS'. A spark gap E is interposed in this circuit. The outer coatings of the Leyden jars are connected to a self-induction coil H. The condensor C and the liquid resistance RR' are designed to prevent the return of high frequency waves to the coil. These would subject the contiguous spirals of the secondary to differences of potential greater than the insulating material can stand, and the insulation would be injured. The liquid resistances RR', each of about 150,000 ohms, are introduced in the leads between the coil and the Leyden jars. A multiple plate condensor C is placed in parallel with these resistances.

The chief purpose of the liquid resistances is to avoid the formation of an arc, while the condensor prevents the return of the high frequency waves.

This apparatus is equally suitable for high frequency and for X-ray work, and is a real advance in the construction of apparatus for medical purposes.

III.—Employment of high frequency currents.

130. **Methods of employing High Frequency Currents.** High frequency currents may either be employed directly by allowing the current to pass through the body as described in paragraph 131, or by *d'Arsonval's* auto-conduction method, in which the enormous inductive force of the high frequency current is used to induce auto-conduction currents in the human body.

High frequency currents may also be utilised for effleuvation. This is done by inducing similar currents in a neighbouring circuit; these currents will have an augmented potential due to the effects of resonance in the circuits. (138.)

131. **Direct application.**—If we attach a rheophore to each end of the self-induction coil in *d'Arsonval's* apparatus, and connect these to a body of high resistance, the high frequency current will pass through the body in preference to going through the coil, in consequence of the large

resistance to oscillating currents offered by the self-induction of the latter.

Thus if the patient's body is placed in parallel with the self-induction coil the high frequency currents will pass through it, while the coil will act as a sort of lightning conductor, offering an alternative route to the currents of low frequency, which will pass by preference through the less resisting metallic conductor.

Direct applications of high frequency currents may be *stabile* or *labile*. They are called stabile when the electrodes, either bare or covered with wet cloth, are applied firmly to one spot. When, on the contrary, the electrodes are constantly moved from place to place over the region to be treated the application is said to be labile.

Another method of direct application of high frequency currents is the so-called *electrification by condensation,* in which one end only of the coil is connected to the patient. For this purpose a couch is used having an insulated mattress, under which is a large sheet of lead. This is connected to one end of a d'Arsonval helix.

The patient, placed on the couch, holds in his hand an electrode connected to the other end of the helix. A condensor is thus formed, in which the mattress is the dielectric and the lead sheet and the patient form the two armatures. This condensor is charged and discharged with every alternation of the current.

The precise interpretation of the phenomena of high frequency condensation is not as yet satisfactorily explained.

132. **Auto-conduction, d'Arsonval's method.** — Any conductor placed within an enveloping high frequency circuit becomes the seat of currents of auto-conduction similar to Foucault currents.

These currents of auto-conduction may be demonstrated by forming an electric circuit with a lamp and a coil of wire, and placing this within a large d'Arsonval solenoid. The lamp will become incandescent when the high frequency current is turned on.

Currents of auto-conduction in the living body may be demonstrated by bending the arms in a circle concentric with the high frequency circuit and holding a lamp of low voltage between the two hands. The experiment will be more successful if the hands have been previously dipped in a slightly alkaline solution of sal ammoniac. The lamp will glow when high frequency currents are passed.

In practise treatment by means of auto-conduction is given in two ways:—

(1) By placing the patient inside d'Arsonval's large solenoid made of thick copper wire or copper ribbon. The oscillating currents caused by the discharge of the condensor traverse the whole length of this coil.

(2) By placing the patient between two flat spirals which are wound in the same direction and traversed by high frequency currents passing in the same direction. (138.)

133. **Oudin's Resonator.**—We may increase the potential of high frequency currents by means of a *resonator.* These are of two kinds, single pole resonators and resonators with two poles.

There are two varieties of single pole resonators—the helix and the flat spiral.

There are three varieties of bipolar resonators—the *d'Arsonval* helix, the *Oudin* resonator as modified by *O'Farrill, Lebailly* and *Rochefort,* and the flat spiral resonator.

134. **Oudin's unipolar resonator.**—*Oudin's* first resonator was formed of a helix of copper wire, a point near one end of which was connected to one extremity of a d'Arsonval coil. (124.) The effleuves were given off from the opposite extremity of the resonator.

When the lower end of the helix was connected to the other end of the self-induction coil the effects were improved, and these were still better when the self-induction coil was

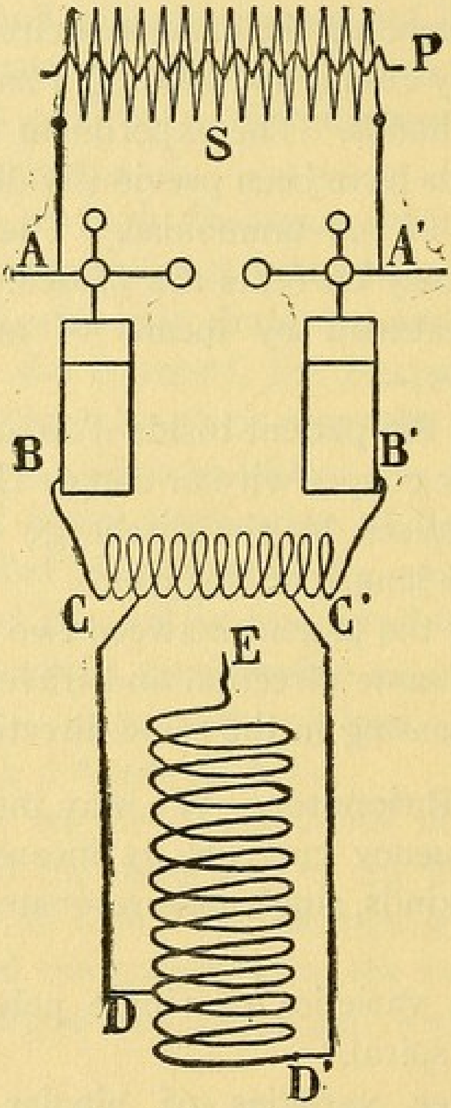


Fig. 25.—Oudin's unipolar resonator.

entirely suppressed. This is the form ultimately adopted by *Oudin*. (Fig. 25.)

The improved form of *Oudin's* resonator is therefore a helix of copper wire 2½ mm. in diameter, consisting of 50 turns with a distance of 8 mm. between each turn.

In this helix the current due to the discharge of the

Leyden jars circulates through three or four of the lowest coils. Phenomena both of induction and of resonance result; induction effects due to the influence of the lower coils on the upper portion of the helix, and resonance effects in the upper portion.

This phenomenon of reinforcement is called resonance from its analogy with acoustic resonance, since the quantity of the effleuve may be increased by tuning the helix to correspond with the exciting coil. This is done by adjusting its coefficient of self-induction.

135. **Guilleminot's flat spirals for high frequency.**—In-

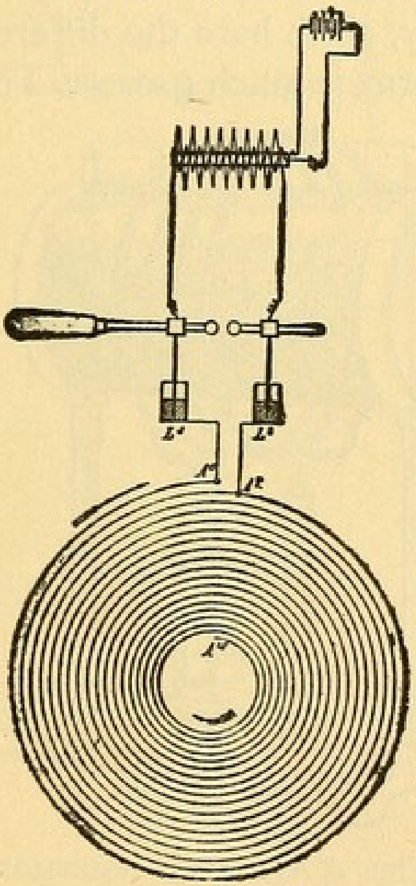


Fig. 26.—Guilleminot's high frequency spiral.

stead of a helix we may use a flat spiral.[1] The author's form of spiral resonator is so constructed that the excitation is

[1] H. Guilleminot, Archives d'electricité Médicale, 1901, No. 287.

caused by a single turn, the outer one, which acts as the inducing spiral.

In practise the adjustment is not made by altering the coefficient of self-induction of the inducing spiral. This is kept constant and a subsidiary coil of thick wire, with an apparatus for regulating its self-induction, is introduced into the exciting circuit.[1]

The spiral is formed of 18 turns of wire, 2 mm. thick, held in place by radii of catgut. The smallest circle has a diameter of 33 cm., and the largest a diameter of 83 cm. The interspaces between successive turns increase in width towards the periphery, since here the difference of potential between successive turns is much greater. The various forms

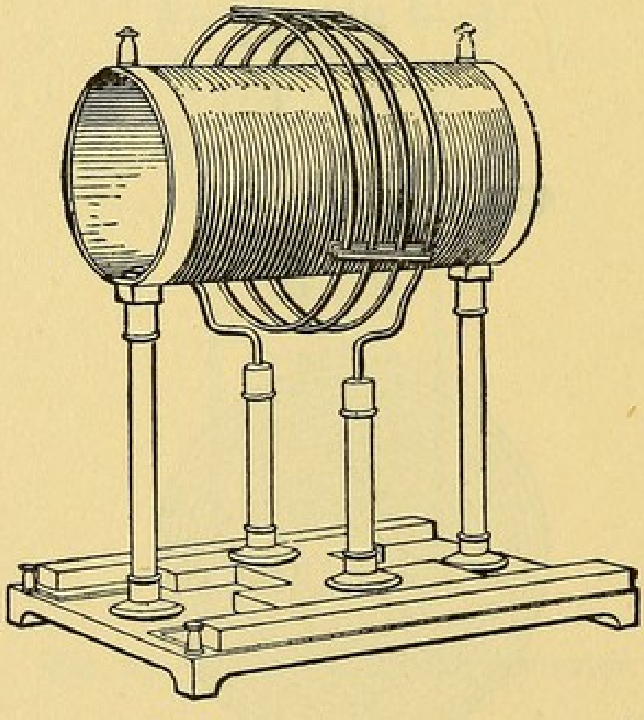


Fig. 27.—The d'Arsonval resonator coil.

of exciter used in applying high frequency currents in medicine are attached to the centre of the spiral.

136. **Bipolar resonators—The d' Arsonval coil.**—The d'Arsonval coil consists of a helix of fine wire wound on a

[1] H. Guilleminot, Academie des sciences, 1902.

cylinder which carries the induced current. Around this at a distance of several centimetres are three or four turns of thick wire, which can be moved along the cylinder so as to be placed at either end or in the middle of the fine-wire helix.

Suppose the thick coils to be placed around the middle of the cylinder, as in Fig. 27. Effleuves of equal strength will

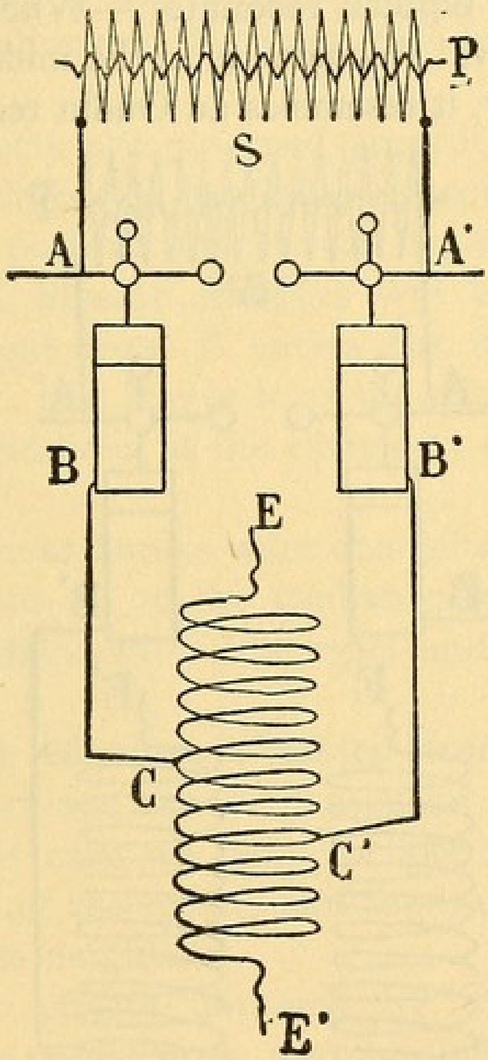


Fig. 28.—Bipolar resonator, O'Farril and Lebailly type.

be given off from both ends of the helix, and these will mutually attract each other.

This is termed the bipolar effleuve. At any given moment the two effleuves will be of opposite signs, the signs changing simultaneously when the direction of the current changes, which it does some thousand million times per second.

If the inducing coil is pushed towards one end the effleuve at that end will decrease to nil, and the coil will act as an unipolar resonator.

137. **Oudin's bipolar resonator.**—When the inducing coil of a d'Arsonval resonator is in the middle of the cylinder, as in Fig. 27, it resembles an Oudin resonator with the

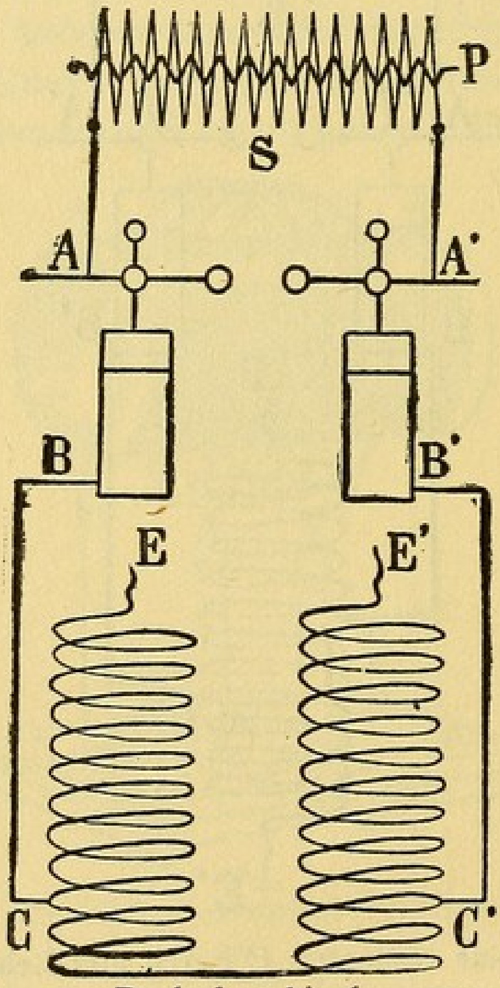


Fig. 29.—Rochefort bipolar resonator.

inducing current applied to its central portion which is insulated from the rest.

If the central portion of the main coil itself is used for the inducing current, we get the *O'Farril* and *Lebailly* type of resonator, which is merely an Oudin resonator excited by means of its own median coils. Fig. 28.

If we duplicate the resonator in the above type we get the *Rochefort* resonator; Fig. 29 is not an exact representation of *Rochefort's* arrangement, since he uses two pair of condensors, one for each solenoid, but it shows clearly the relationship between this and the previous types.

Different effects are obtained according to the direction of the discharge in the inducing coils.

If B be the positive and B' the negative armature of the condensors, bipolar effleuves will be obtained only when the current from B enters the first helix at the median point C, and leaves it at the extremity, whilst it enters the second helix at the extremity and leaves at the median point C'.

If the positive armature were connected to the extremities of both coils, or to the median points of both coils, the resulting effleuves would repel and not attract one another.

138. **Bipolar effleuves obtained from flat spirals.**— Spiral resonators are better adapted for studying bipolar effects. In this case we have to take into account the mode of coupling the spirals and the mutual influence of one spiral on its neighbour.

(1) Bipolar effects obtained by coupling. In the high frequency condensors, we may consider the direction of the discharge to be from the external positive armature of one condensor to the external negative armature of the other condensor.

We get a bipolar effleuve of opposite signs when this current is made to pass centripetally through one spiral and centrifugally through the other. If the effleuve producing poles of the two spirals are now connected, the effleuvation will cease.

Effleuves of the same sign will be obtained from both poles if the current circulates centripetally in both spirals, or centrifugally in both. If now the two effleuve producing poles are connected, the effleuves are not neutralised but reinforce one another.

(2) Bipolar effects may also be obtained by the influence of one spiral on another in its neighbourhood if

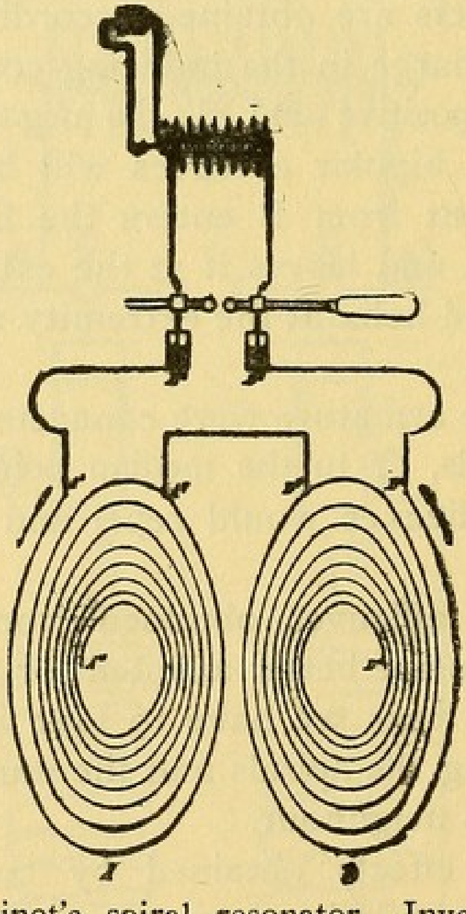


Fig. 30.—Guilleminot's spiral resonator. Inverse coupling for obtaining bipolarity.

we connect only one spiral in the condensor circuit, and place another insulated spiral opposite to it. When the current passes through the first spiral, the central pole of the insulated spiral will give out effleuves of the same sign if its windings are in the same direction, and effleuves of opposite sign if its windings are in the opposite direction.

There are several ways of using flat spirals for medical purposes.

(1) *Use of two spirals to give a bipolar effleuve* (Fig. 30).—Place the two spirals parallel, so that one spiral is right handed and the other left handed.

Connect A'B', the outer extremities of the spirals, to LL', the external coatings of the two Leyden jars, and connect the two median points together by a flexible wire. These median points A" B" mark the boundary of the inducing and induced currents and are at the completion of the first turn of the spiral.

(2) *Arrangement of two spirals to produce effleuves from a body interposed between them.*—Place the two spirals parallel to each other with their windings in the same direction.

Connect the terminal of one condensor with the outer extremity of the first spiral; connect the median point of the first spiral with the outer extremity of the second spiral; connect the median point of the second spiral with the terminal of the second condensor.

With this arrangement the effleuves will repel each other, but an object placed between them will pour effleuves towards both spirals.

(3) *Employment of two flat spirals for auto-conduction.* The two spirals wound in the same direction are arranged as before, but instead of only one turn, 8 to 12 turns of the spiral are made use of for the inducing current.

Under these circumstances there are no effleuves, but intense auto-conduction effects are produced in any body of sufficient capacity interposed between the terminals.

139. **High frequency electrodes or exciters.**—The

form of exciter used depends on the kind of high frequency treatment required.

1. *Direct application.*—For this purpose uncovered metal electrodes are used. These may be of various shapes, plates, buttons, cylindrical handles, or the special conical electrodes devised by *Doumer.*

2. *Direct application with the interposition of a sheet of glass.*—For this the so-called condensing electrodes of *Oudin* are used.

3. *Sparking.*—When it is desired to produce sparks blunt points or balls are used.

4. *Effleuvation.*—The most suitable exciters for producing effleuves are the metallic pencil, the brush, the multiple-point, the cup, or other electrode with an extended discharging surface.

140. **Measurement of High Frequnecy Currents.**—High frequency currents may be measured by means of the thermic galvanometer. Since the current is an alternating one we can only measure the efficient intensity, *i.e.,* the intensity of a continuous current which would give the same thermal effects.

The thermic galvanometer is an instrument for measuring the elongation of a wire, due to the heating effect of the current which passes through it.

We may also use the induction amperemeter devised by *Gaiffe* and *Meylan.* This measures the repulsive force between the original current and the current which it induces in a coil attached to the indicator.[1]

The thermic galvanometer is placed in series in the circuit. It is the only type in practical use. It is only employed when we are using the direct application of high frequency currents; for auto-conduction no instrument for measuring the current is of any practical value.

[1] Dénoyes. Les courants de haute frequence, Montpelier.

CHAPTER V.

STATIC ELECTRICITY.

I. General Considerations.

141. **Definition.**—The fact that under the influence of friction certain substances, such as amber, will attract light bodies, was known to the ancient Greeks.

Resin, glass and many other substances possess this property, which may even be observed in metals, provided that they are suitably supported by a handle of glass or other insulating material. If, however, they are touched with a wire connected to earth, metals at once lose this property of attraction.

Bodies like amber, resin, glass, or insulated metal are said to be *electrified* by the friction, and the electricity which remains on the body is termed *static electricity*. The phenomenon which takes place along the metal wire connected to earth is an exhibition of *dynamic electricity*. If by some means the electrified body could have its electric charge replaced as fast as it was removed by the wire connected to earth, we should have a constant electric current along that wire. A body charged with electricity may be compared to a reservoir full of water having no outlet, while the electric current corresponds to the flow of water through the conduit pipes.

A body charged with electricity has certain mechanical properties, the manifestation of which leaves its electric mass unaltered. An electric current, on the other hand, has properties due to the transmission of a charge or perturbation. The phenomena occurring in the neighbourhood of a body possessing a fixed static charge of electricity will be different from those produced by the transmission of the electric state from one point to another.

Bodies which, like amber, glass and resin, remain charged with electricity even when connected to earth, are called *insulators, dielectrics,* or *non-conductors.* Bodies which, like metals, can only be charged when placed on an insulating support are called *conductors.*

The most conspicuous property of electrified bodies is their ability to attract other light bodies until they come into contact with them, and then to repel them. A body thus repelled by electrified glass will be attracted by electrified resin. This phenomenon, which was early observed, led to the supposition that there were two sorts of electricity, the vitreous or positive electricity, and the resinous or negative electricity.

Two bodies charged with electricity of the same sort repel each other. If charged with opposite kinds of electricity they attract each other.

It was from the study of static electricity, the earliest form discovered, that the electric fluid hypothesis was deduced. The neutral fluid with which all bodies are charged was held to be decomposed by friction into equal quantities of positive and negative electrical fluids.

142. **Fundamental properties of electrified bodies.**—The properties of electrified bodies may be considered under two headings.

(1) *Mechanical action.*—Consisting of the mutual attraction and repulsion of electrified bodies.

(2) *The inductive action* of electrified bodies on other bodies in their vicinity. This is termed electrostatic induction.

143. **Mechanical action.**—From the medical point of

view the mechanical action of electrified bodies is of but little interest. Since, however, it forms the basis of most systems of measurement, it is necessary to be acquainted with its fundamental principles.

Two bodies charged with electricity of the same sign, whether positive or negative, repel each other with a force F, which is proportional to the quantities of electricity q and q' on the two bodies, and inversely proportional to the square of the distance d, between the two bodies. (*Coulomb's law.*)

$$F = f\frac{qq'}{d^2}$$

f is a coefficient dependent on the medium in which the bodies are placed. In air or vacuo f is equal to unity.

Consider two equal quantities of electricity of the same sign, ($q = q'$) placed on two small bodies whose centres are 1 cm. apart. We say that these bodies are charged with unit quantity of electricity, if F, the repulsive force between them, is 1 dyne, the bodies being in air or vacuo so that $f = 1$.

In the electrostatic system of measurement, therefore, the unit of quantity of electricity is derived from the mechanical action of electric forces. It is the quantity of electricity which, when placed at unit distance from an equal quantity of the same sign, repels it with unit force.

144. **Electrostatic induction.**—An electrified body creates around it an electric field, *i.e.* a space throughout which the effects of the electric forces due to the presence of the electrified body may be observed.

Every body placed in an electric field becomes electrified by induction. In the two fluid theory this is explained by supposing that in an electric field, the neutral fluid is decomposed into equal quantities of two electric fluids of opposite signs. The fluid of the same sign will place itself as far as possible from the inducing body, whereas the fluid of opposite sign, being attracted by it, will place itself on the side nearest to the inducing body. When the electric field is removed, the two fluids recombine and the body resumes its neutral state.

If the induced body be connected to earth, the electricity of the same sign as the inducing body flows to earth, and the induced body remains charged with electricity of the opposite sign.

If the contact with earth be broken, and the electric field afterwards removed, the induced charge will be retained, and will spread over the whole surface of the induced body.

The attraction of light bodies by an electrified rod may be readily explained by these facts. If any light insulated body be placed in an electric field, the charge of opposite sign induced on it will be nearer the charged body than the charge of the same sign. Hence, the attractive force will be greater than the repulsive force, since the quantities of electricity of either sign are equal and the force varies inversely as the square of the distance. If the light body be uninsulated, it will possess an induced charge of opposite sign only and the attractive force between the two bodies will be proportionately greater.

When the light body comes into contact with the charged body, its induced charge neutralizes a portion of the original charge. On contact, it will take a portion of the original charge, and since the two bodies have now charges of the same sign they will repel one another.

145. **Laws of electrostatic induction.**—I. When a charged body is completely surrounded by a conductor, the total charge induced on the inner surface of that conductor is equal and opposite to the charge on the inducing body, whatever the distance between the charged

body and the conductor. An equal charge of the same sign as the inducing charge will be spread over the external surface of the enveloping conductor. If now the conductor be connected to earth, this latter charge disappears and only the internal opposite charge remains.

II. When an electrified body is surrounded by a conductor connected to earth, there is no external electric field due to the system. This results from the equal and opposite values of the inducing and induced charges.

If the conductor only partially surrounds the charged body, it will nevertheless act as an electric screen. A wire gauze is a very efficient electric screen. An aluminium plate connected to earth is often placed in front of a focus tube, in order to shield the area under examination from the electric field due to the focus tube. The plate must not be insulated, since in that case the similar charge induced on the further side of the plate would create a fresh electric field.

146. **Distribution of the electric charge on a conductor.—Surface density.**—The electric charge is confined to the external surface of a conductor. Thus a hollow sphere, when electrified, shows no trace of electrification on its internal surface.

The surface density σ at any point, is the quantity of electricity on unit area of surface at that point; $\sigma = \frac{q}{S}$

The electric density is the same at all points on the surface of an electrified sphere, insulated in space and protected from all external electrical influences. It is variable over the surface of non-spherical conductors. On an ellipsoid, for example, the surface density at the extremity of two axes is proportional to the length of these axes.

If we take two given points on a conductor the ratio between their surface densities is a constant, so that if now we double the charge on the conductor we shall double the density at both points.

147. **The equilibrial layer.**—If at every point on a charged conductor we draw a normal whose length is proportional to the electric density at that point, we shall envelop the conductor by a surface termed the equilibrial layer. It is a representation of the manner in which the electric fluid, if materialised, would be spread over the surface of the conductor.

In investigating the influence of an electrified conductor on external charges, the solution depends on determining the magnitude and direction of the attractive and repulsive forces between the external charge and every element of surface of the charged conductor, the forces being proportional directly to the electric mass and inversely to the square of the distance.

In the case of a sphere, the action of the electric charge on its surface is the same as if the whole charge were collected at the centre of the sphere.

The resultant action of the charge on any point within the sphere is zero. The electric forces at any point can, therefore, be easily calculated for a spherical conductor.

148. **Electrostatic pressure.**—An electrified conductor behaves as if every particle of the electric fluid exerted a repulsive force on every other particle. The resultant of these repulsive forces at any point is called the *electrostatic pressure* at that point, and is normal to the surface of the conductor.

If the material atoms of the conductor were not bound together by cohesion they would yield to this electrostatic pressure and the body would expand. This phenomenon may be observed when a soap bubble is electrified; it increases in size as the charge on it is increased. Electrostatic pressure thus acts in the opposite direction to atmospheric pressure.

The electrostatic pressure over the surface of a conductor varies with the surface density of the charge. *Lord Kelvin* has shown that it is proportional to the square of that density.

149. **Discharge of electricity from a point.**—A point may be considered as the extremity of the major axis of a much elongated ellipsoid. The ratio of the long to the short axis in this case being very large, the electric density at the point, and consequently the electrostatic pressure at the point, will be indefinitely increased. In fact this pressure becomes so great that there is an exodus of electricity from the point.

The *aigrette* and *electric breeze* from a static machine are due to the badly conducting molecules of air being violently driven away from a pointed conductor by the electric discharge.

The phenomena due to sparks, aigrettes, the electric arc, etc., are further described in par. 173.

150. **The Electrostatic field.—Lines of force.—Flux of Force.**—Imagine a unit mass of positive electricity M, placed in the vicinity of a conductor charged with static electricity. Each element of the electric layer around the conductor will have its separate action on the mass of electricity M. The resultant of all these separate forces is called the *electric force at the point M.*

Any space within which electric force is exercised is called an *electrostatic field.*

A *line of force* is a line drawn in an electric field to show the direction of the electric force at any point in that field, or, since the line of force may be a curve, it is more correct to say that the tangent to the line of force at any point shows the direction of the electric force at that point.

If a conductor be placed in an electrostatic field, each element of its surface dS will intercept a certain number of lines of force.

If dS is normal to the lines of force, the product FdS is termed the *flux of force,* F being the electric force at that point. If dS is inclined to the lines of force, the flux of force is FdScos χ, when χ is the angle which the lines of force make with the normal to the surface dS.

151. **Electric potential.**—The word potential as an adjective is often used in a general sense. To say that a body possesses potential energy is to say that in its dynamic equilibrium it possesses a certain store of hidden energy which is not in evidence at the moment, but which is capable by some artifice of being transformed into work.

In virtue of the principle of the conservation of energy, a body can only possess potential energy if this energy has been accumulated by work previously done on the body, which work can be afterwards given up by the body. Potential energy is then the equivalent of work done—former work which produced an accumulation of energy in the body, and future work which will be manifested by the liberation of the potential energy and its conversion into effective energy.

As a substantive the word potential has a more definite meaning, which is not confined to electricity.

The idea of universal gravitation formulated by *Newton* implies the idea of a gravitational potential, just as the laws of electric charges demand an electric potential. Electric potential may even come in time to be regarded as a special form of gravitational potential.

Electric potential is usually defined by comparison:—Difference of potential being analogous to difference of level in hydrostatics.

It is, however, better to seek the true definition of absolute potential at once, even if the idea is more difficult to grasp. The conception of potential is easier to realize in electrostatics than in electrodynamics.

Consider an uncharged conductor isolated in space. Let a unit charge of electricity be brought up to it from a distance, and let this operation be repeated again and again.

At each repetition, the charge on the conductor will be increased by unity, and at the same time the surface density of the electricity on the conductor will increase, and with it the electrostatic pressure.

Each time a unit charge is brought up to the conductor the force of repulsion between it and the electric charge on the conductor will increase, and the work done in bringing any one unit to the conductor will therefore be greater than that required for the preceding unit.

On the other hand, if a unit electric mass leaves the conductor, it will be repelled with greater force when the conductor is more highly charged, and therefore will be capable of doing more work.

The greater the charge on a body, the greater is the work required to add unit charge to that body.

The greater the charge on a body, the greater the energy rendered available when that body loses unit charge.

Electric potential is merely the expression of this work; the work locked up when the conductor was charged, and liberated during the discharge of the conductor. The potential of a given conductor therefore increases with its charge.

The result will be the same if the conductor diminishes in size while the charge remains constant; the repulsive force of the electric elements for each other and for the unit charge will be increased. It is this which leads to the conception of capacity when dealing with condensors.

152. **Experimental definition of potential.**—The theoretical definition of potential given above gives a precise idea

of its true nature. The potential of a body is the work done in adding unit charge to that body.

An experiment may help us to realise better this idea of potential.

We may take a metal sphere 1 cm. in radius mounted on an insulated handle. If it is brought into contact with different points of an electrified conductor of irregular shape we shall find that the charge which it takes up is always the same.

Consider now two spheres of different sizes, both charged with equal quantities of electricity. The testing ball will pick up a different charge, according as it is brought into contact with the large or with the small electrified sphere.

The first experiment shews that the charge picked up by the testing ball is not a function of the surface density, since this varies at different points on the surface of a condensor.

The second experiment shews that the charge picked up by the testing ball is not a function of the quantity of electricity, since this quantity was equal on the two spheres, and yet the amounts collected were unequal.

The amount of electricity collected from a conductor is a function of the *electric state* of the conductor.

Potential is thus often defined as the electric state of a conductor, but this is only substituting one word for another.

If we take an electrified conductor of irregular shape and connect some point of it to a gold leaf electroscope by means of a wire, the deviation of the leaves will be the same whatever point is touched by the wire.

If the charge of electricity on the condensor is doubled the deviation of the leaves will shew a corresponding increase, which is again the same whatever point on the conductor is touched by the wire. If the conductor is connected to earth, and then submitted to the action of an electrified body, the gold leaves will not move.

If we take two bodies, each of which causes the same deviation of the electroscope, and join them by a wire, there is no passage of electricity along the wire. The electric state of each of the bodies remains unaltered.

If, however, the electric state of one body is higher than that of the other, *i.e.*, if it had a greater potential, then when the two are joined there will be a passage of electricity from the body at high potential to the body at low potential.

There will be a transference of electricity, and the force causing the motion, the electromotive force, is proportional to the difference of potential between the two bodies.

153. **Potential at the surface of a conductor.—Equipotential surfaces.**—An equipotential surface, like the surface level of a liquid, is a surface in which all points have the same potential. If any two points on such a surface be connected by a conductor, there will be no flow of electricity along the conductor.

The surface of a conductor must necessarily be an equipotential surface. If it were not so electricity would flow along the conductor from one point to another until the potential was equalised.

154. **Potential as a function of electric mass.**—When a system of electric charges acts on an external point the

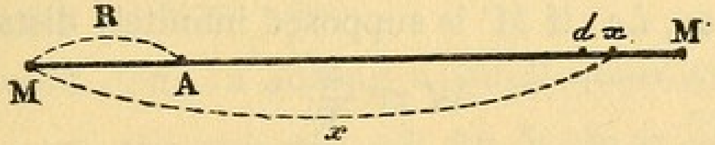


Fig. 31.

action of these electric masses may be compounded, and replaced by a single resultant force with a single point of application. Therefore in studying the effect of a system of electric masses m, m', m" . . . on an external body, such as a unit electric charge placed outside a conductor, we may replace them by a single mass M, acting at a point which is called the *centre of action,* or *centre of application* of the resultant force.

Let M (Fig. 31) be the centre of action of a system of charges spread over a surface of any shape, and M' a unit electric charge placed at a considerable distance, x.

What will be the work required to move M' from its present position to some other point, A? This amount of work will be an expression for the difference of potential betwen the points M' and A.

Let M' move through a small distance δx. If δx be small enough the repulsive force F between M and M' may be regarded as constant throughout δx. The work done during this elementary displacement will therefore be $F\delta x$.

From *Coulomb's* law $F = \frac{MM'}{x^2}$ or since M' is unity, $F = \frac{M}{x^2}$. If we integrate the work done between M' and A we get, when the distance $MA = R$,

$$W = M\left(\frac{1}{R} - \frac{1}{x}\right).$$

This is the same expression as that to which in gravitational phenomena *Green* gave the name of "difference of potential" due to the displacement of a mass M from A to M'.

If $x = \infty$, *i.e.,* if M' is supposed infinitely distant, we get

$$W = \frac{M}{R}$$

This is the expression for the "potential at infinity" or *absolute potential* as a function of the electric mass.

The potential at the point A, or the work necessary to bring unit electric mass from infinity to a distance R from the centre of action of a charge M, is therefore equal to $\frac{M}{R}$

the quotient of the electric charge M by the distance R.

The above definition still holds good when A is a point on the surface of a sphere, on which are situated the charges m, m', m".

The potential of the surface of the sphere will be the quotient of the total charge q by the distance, which in this case will equal the radius of the sphere. The potential at the surface of a sphere is, therefore, given by $V = \frac{q}{r}$, where $m + m' + m'' + .. = q$.

More generally, if A is situated on the surface of any conductor having a charge q, the potential of that conductor, or the work required to add to it one unit of electricity will be given by $\frac{q}{R}$, R being a quantity which is termed the *capacity* of the conductor. This quantity R is of dimensions (L).

155. **Potential energy of a conductor.**—As we have just seen, the potential of a conductor is the work required to increase its charge by unity. If we add all the quantities of work which have been done in placing each elemental charge on the conductor we shall get the total work done in charging it, and this will be the total potential energy stored in the conductor.

Imagine a sphere or radius r, and charge q. Its potential is given by $V = \frac{q}{r}$.

The work done in adding a small quantity dq, to the charge q on the sphere, will be $V.dq = \frac{qdq}{r}$, and the charge will be $q + dq$.

If we add another dq to the charge, the work required will be $\frac{(q + dq)\,dq}{r}$ and so on.

Repeating this process until the charge q has been increased to q', we find by integration that the total work done is $W = \frac{(q + q')^2 - q^2}{2r}$

If we start with an uncharged body, ($q = o$) the work done in giving the sphere a charge q' is $W = \frac{q'^2}{2r}$.

The work required to give a conductor of capacity r, a charge q, is therefore the square of the charge, divided by twice the capacity, or $\frac{q^2}{2r}$. This is the total potential energy accumulated in the charged body, the whole of which is set free when it is discharged.

This proposition may also be stated in the following form. When a conductor is charged to a potential $V = \frac{q}{r}$, the potential energy is

$$\frac{q^2}{2r} = \frac{q}{r} \times \frac{q}{2} = \frac{1}{2} Vq .$$

$$W = \frac{q^2}{2r} = \frac{1}{2} Vq .$$

The potential energy is one half the charge multiplied by the potential.

156. **Potential energy of a conductor kept at constant potential.**—Imagine a sphere with electrical charge q. Its potential is $\frac{q}{r}$, and its potential energy $\frac{q^2}{2r}$.

Now imagine some means by which its potential may be kept constant during discharge, and we shall thus get the source of a constant electric current.

Since the potential remains constant, the potential energy corresponding to a loss of charge q is

$$q \times \frac{q}{r} \text{ , or } W = \frac{q^2}{r} .$$

When the potential is kept constant the expenditure of potential energy due to the exodus of a charge q, is twice the expenditure when the potential is allowed to sink from $\frac{q}{r}$ to zero.

157. **Capacity.**—When the idea of potential as a function of the electric charge has been thoroughly grasped, we readily understand the idea of capacity. The capacity of a conductor is merely the number which represents the ratio between the charge q and the potential V.

To get a clearer idea of this notion of capacity, take an insulated sphere and place on it an electric charge q. Connect it to an electroscope and note the deviation.

Bring an uncharged conductor close up to the insulated sphere, but do not allow it to touch it. The leaves of the electroscope will fall, although there has been no decrease of the charge on the sphere.

Place a plate of glass between the insulated sphere and the uncharged conductor; the gold leaves will fall still more. Now surround the insulated sphere by two thick insulated metallic hemispheres, so as to form a larger sphere. The gold leaves will again collapse, although the larger sphere thus formed has the same charge as the original sphere.

The ratio of the new potential to the original potential is inversely proportional to the radii of the two spheres.

In all these experiments we have simply altered the capacity of the sphere, keeping the charge constant. The potential, as measured by the electroscope, has dropped whenever the capacity has been increased.

Let us look at it from another point of view. We may take our insulated sphere, charge it with a quantity of electricity q, and measure the potential and surface density of the charge.

If the charge be doubled, we shall find that both potential and surface density will be also doubled. For any given conductor, therefore, there is a fixed ratio between the charge q and the potential V.

This ratio $\frac{q}{V} = C$ the capacity of the conductor.

A conductor is said to have unit capacity when the addition of unit charge will increase its potential by unity.

II. Dielectrics—Condensors.

158. **Influence of two charged conductors on one another—Condensors.**—When an uncharged conductor is brought near a charged conductor, the capacity of the latter is increased, so that for the same charge it will now possess a lower potential. This arrangement of two conductors separated by air or some other insulating material is called a *condensor.*

The ratio of the capacity of a conductor, to its capacity when forming part of a condensor is termed the *condensing force* of the condensor. It is equal to the ratio of the charges required to produce a given potential before and after the conductors are arranged as a condensor.

159. **Types of Condensors.**—The most perfect type of condensor is the spherical condensor; two concentric spherical conducting surfaces separated by a layer of air or other insulating material. The external sphere has an orifice through which an insulated wire may be passed to make contact with the inner sphere.

In practice we generally use plate condensors or cylindrical condensors.

160. **Capacity and condensing force of a condensor.**—Consider a spherical condensor whose inner sphere has a radius R, and outer sphere a radius R', the dielectric between them being air. We find that the capacity of such a spherical condensor in air is given by $C' = \frac{RR'}{R'-R}$.

If the spheres are large, R and R' will differ but little and R R' may be replaced by R^2. If R' — R, the thickness of the dielectric, be called d, we now get $C' = \frac{R^2}{d}$.

This may be written $C' = \frac{4 \pi R^2}{4 \pi d}$; but $4 \pi R^2$ is S the surface area of the sphere, therefore $C' = \frac{S}{4 \pi d}$.

This formula gives the capacity of a condensor in terms of its area and the thickness of the dielectric, when that dielectric is air.

Thus a condensor of 10,000 square centimetres area, and 1 cm. thickness of dielectric between its plates, will have a capacity of $\frac{10,000}{4\pi}$, *i.e.* about 800 electrostatic units or .0009 microfarads (168).

161. **Specific inductive capacity.**—The dielectric separating two conductors must not be regarded as an inert body which merely prevents a spark from passing between them. On the contrary, the dielectric is the chief seat of the electric phenomenon of condensation. We may considerably increase the capacity of an air condensor by interposing a sheet of glass between the plates.

The *specific inductive capacity* K of a dielectric is the coefficient by which the capacity of an air condensor must be multiplied in order to give the capacity when the air is replaced by that dielectric.

The force exerted by an electric mass through a dielectric is inversely proportional to this coefficient K.

Coulomb's law only holds good when the dielectric is air. When the air is replaced by some other dielectric the factor $\frac{1}{K}$ must be introduced into this forumla.

$$F = \frac{1}{K} \frac{qq^1}{d^2}$$

III. Electrostatic quantities and units.

162. **Electrostatic system of units.**—We might measure the various electrostatic quantities, the charge, the potential, and the capacity of a condensor, in electrodynamic units, which are based on the action of an electric current on a magnet pole (par. 5).

Electrodynamic units are, however, seldom used in electrostatics. A more convenient method of connecting electrical quantities with the fundamental units is based on the force exerted between two static charges (143). The two systems are incompatible, since the one is based on dynamical movements resulting in the transmission of a disturbance, the electric current; whilst the other is based on mechanical properties peculiar to electricity when at rest.

There is, however, a definite relation between the units of these two systems, both of which are derived from C.G.S. units.

In the formula expressing the ratio between any pair of units in the two systems, there always appears a coefficient v.

This coefficient v has the dimensions of a velocity, and its numerical value is equal to the velocity of light, 300,000 kilometres per second.

This remarkable coincidence formed the starting point of *Maxwell's* work, which resulted in the establishment of the electromagnetic theory of light.

163. **Numerical relations between the electrostatic and electromagnetic units.**—If any one quantity, for example a quantity of energy W, can be expressed in electrostatic and in electromagnetic units, we shall be able to establish the relations between the two systems. In what follows, capitals denote quantities on the electrodynamic system, and small letters electrostatic quantities.

We have already proved that $W = I^2R\,t = i^2r\,t = E\,I\,t = eit = E\,Q = eq = E^2C = e^2c$.

$$\text{Hence: } \frac{q}{Q} = \frac{i}{I}\sqrt{\frac{R}{r}} = \frac{E}{e} = \sqrt{\frac{c}{C}}.$$

Let each of these ratios be expressed by v. The dimensions of v may be obtained from any one of these expressions, for example $\frac{q}{Q}$.

The dimensions of q are $L^{3/2}M^{1/2}T^{-1}$ and the dimensions of Q are $L^{1/2}M^{1/2}$. Therefore the dimensions of $\frac{q}{Q}$ are $\frac{L^{3/2}M^{1/2}T^{-1}}{L^{1/2}M^{1/2}} = LT^{-1}$.

But LT^{-1} is the dimension of a velocity.

In the G.G.S. system the numerical value of v is about 30,000,000,000, the approximate velocity of light in centimetres per second.

It is evident that if this relation exists between the numerical values which express the quantities, the ratios between the *units* in which these quantities are expressed will be the reciprocal of this. If a quantity G measures 300,000 in Γ units and this same quantity g measures one in γ units, it is evident that the unit Γ must be $\frac{1}{300{,}000}$ of the unit γ, while the numerical value of G is 300,000 g.

The relations between the electrostatic and electrodynamic *units* are therefore as follows, q, and Q_1 representing the values of an electrostatic and of an electrodynamic unit respectively.

$$\frac{Q_1}{q_1} = v\ ;\ \frac{I_1}{i_1} = v\ ;\ \frac{e_1}{E_1} = v\ ;\ \frac{r_1}{R_1} = v^2\ ;\ \frac{C_1}{c_1} = v^2.$$

164. **Quantity of electricity and units of quantity in the electrostatic system.**—The unit of quantity is the mass of electricity which when placed one centimetre

from an equal mass will repel it with a force of one dyne (143).

From *Coulomb's* law $F = \frac{qq'}{d^2}$, we get (since $q = q'$) $q = d\sqrt{F}$.

Electric quantity, therefore, is the product of a length (L) by the square root of a force $\sqrt{L\,M\,T^{-2}}$. This gives us the dimensions of the unit of quantity of electricity as $L^{3}/^{2}M^{1}/^{2}T^{-1}$.

The electrostatic unit of quantity must be multiplied by 30,000,000,000 to get the electromagnetic C.G.S. unit. The practical unit, the Coulomb, is $\frac{1}{10}$ of an electromagnetic unit and is therefore equal to 3,000,000,000 electrostatic units.

165. **Unit of Intensity of current.**—The intensity of a current is the quantity of electricity which passes through a conductor in unit time. It is the quotient of a quantity of electricity by a time. Its dimensions in the electrostatic system will therefore be $L^{3}/^{2}M^{1}/^{2}T^{-2}$ and in the electromagnetic system $L^{1}/^{2}M^{1}/^{2}T^{-1}$

The electrostatic unit of intensity is 1/30,000,000,000 of the electromagnetic unit.

The practical unit, the ampere, is one tenth of the C.G.S. electromagnetic unit and is therefore equal to 3,000,000,000 electrostatic units. (9.)

166. **Unit of difference of potential.**—The potential at any point, due to a charge q, is the quotient of the charge q, by r, the distance of the point from the centre of action of the charge. Hence, its dimensions are

$$L^{1}/^{2}M^{1}/^{2}T^{-1}.$$

The same result may be obtained from *Ohm's* law, $e = ir$, whence the dimensions of e are $L^{1}/^{2}M^{1}/^{2}T^{-1}$.

In the electromagnetic system the dimensions of E are $L^{3}/^{2}M^{1}/^{2}T^{-2}$.

In electrostatics, unit difference of potential is defined as the difference of potential existing between two points, when one erg of work is required to bring unit quantity of electricity from one of the points to the other.

This unit is equal to 30,000,000,000 electromagnetic units.

The practical unit or volt, is 1/300 of the electrostatic unit, and is thus equal to 100,000,000 electromagnetic units.

167. **Unit of resistance.**—We have seen that W, the work done by a quantity of electricity Q, is proportional to the electromotive force driving it.

$$W = QE = EIT = I^2RT.$$

Hence $R = \frac{W}{I^2T}$, a relation which is equally true in electrostatic units, $r = \frac{W}{i^2t}$.

Since the demensions of the unit of work are L^2MT^{-2}, we get in the electrostatic system $r = \frac{L^2MT^{-2}}{L^3MT^{-4}xT} = L^{-1}T$, whereas in the electrodynamic system,

$$R = \frac{L^2MT^{-2}}{LMT^{-2} \times T} = LT^{-1}.$$

In other words, a resistance in the electromagnetic system has the same dimensions as a velocity, whereas in the electrostatic system it has the dimensions of the reciprocal of a velocity. This does not imply that resistance *is* a velocity, or the reciprocal of a velocity. We can only say that the dimensions of these two quantities happen to be the same.

The electrostatic unit of resistance is equal to 9×10^{20} electromagnetic units.

The practical unit of resistance, the ohm, is equal to 10^9 C.G.S. electromagnetic units, and is therefore equal to $\frac{1}{9 \times 10^{11}}$ electrostatic units.

168. **Unit of capacity.**—The capacity of a conductor is the ratio of its charge to its potential. $c = \frac{q}{e}$, or $C = \frac{Q}{E}$, since the definition is the same in both systems.

Its dimensions in the electrostatic system are

$$\frac{q}{e} = \frac{L^{3}/{}^{2}M^{1}/{}^{2}T^{-1}}{L^{1}/{}^{2}M^{1}/{}^{2}T^{-1}} = L.$$

In the electromagnetic system the dimensions are

$$\frac{Q}{E} = \frac{L^{1}/{}^{2}M^{1}/{}^{2}}{L^{3}/{}^{2}M^{1}/{}^{2}T^{-2}} = L^{-1}T^{2}.$$

In the electrostatic system, the unit of capacity is the capacity of a conductor in which unit quantity of electricity will increase the potential by unity. A sphere 1 centimetre in radius will therefore have unit capacity.

The electromagnetic unit of capacity is equal to 9×10^{20} electrostatic units.

The practical unit of capacity, the Farad, is equal to 10^{-9} electromagnetic units of capacity, or 9×10^{11} electrostatic units. The farad is the capacity of a conductor whose potential is raised one volt by the addition of one coulomb of electricity.

169. **Table of Practical Units.**

Practical Unit.	Electromagnetic Unit.	Electrostatic Unit.
1 Coulomb . . .	$= .1$	$= 3 \times 10^{9}$
1 Ampere	$= .1$	$= 3 \times 10^{9}$
1 Volt	$= 10^{8}$	$= \frac{1}{300}$
1 Ohm	$= 10^{9}$	$= \frac{1}{9} \times 10^{11}$
1 Farad.	$= 10^{-9}$	$= 9 \times 10^{11}$

IV. Electrostatic Machines.

170. **Types of Static Machines.**—There are two types of electrostatic machines, friction machines and influence machines. The earliest were the friction machines, that of

Otto de Guericke, in 1672, and that of *Ramsden,* 1760. The electricity was produced by rubbing a revolving disc of glass or sulphur with a cushion or the hand.

At the present day influence machines of the *Holtz* or *Wimshurst* pattern are the only static machines used.

171. **The Holtz machine.**—The *Holtz* machine, Fig.

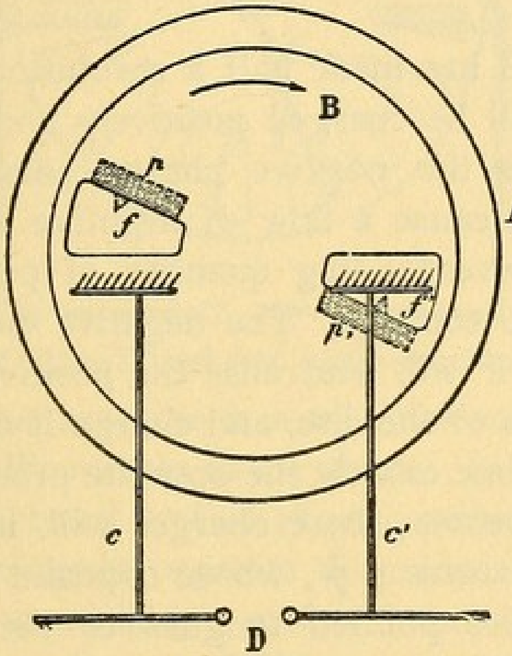


Fig. 32.—Holtz static machine.

32, consists of two parallel plates A and B, one of which, A, is fixed, while the other, B, revolves in front of it.

In the fixed plate are two windows ff', on the edges of which are fixed two paper armatures pp', with pointed tongues projecting across the windows in a direction opposite to that in which the other plate revolves.

Opposite the windows, and on the other side of the revolving plate, are two collecting combs c c',

In order to charge the machine the two balls at D are brought into contact with one another, and a negative charge is given to one of the paper armatures by means of an ebonite rod excited by a catskin.

Suppose the armature ρ be thus supplied with a negative charge. This charge will act on the conductor C by induction, and the positive electricity will flow from the points of the comb on to the glass at B.

Since the balls at D are in contact a corresponding quantity of negative electricity will pass to the other conductor c', and thence through f' to the adjacent portion of the revolving plate.

Thus when B has made half a revolution the upper half of the plate will be charged positively and the lower half negatively. As the positive charge passes through the comb c', it will cause a flow of negative electricity to the plate, and a corresponding quantity of positive electricity will flow to the comb c. The negative electricity flowing from the comb c' will neutralise the positive charge on the adjacent portion of the disc, and charge it negatively.

During this time exactly the opposite proceeding is occurring at c. Moreover, these charges will, in their turn, influence the armatures p p', whose opposite charges will escape through the pointed tongues to the rotating plate. There will thus be a continual flow of negative electricity from C', and of positive electricity from C.

If now the balls at D are separated, the tension between the two sides will increase until it becomes sufficient to cause a spark to pass between the balls.

172. **Wimshurst machine (1883).**—This machine is composed of two glass or ebonite plates mounted on a horizontal axis and rotated in opposite directions. To the outer surface of both plates are attached sectors formed of strips of tinfoil.

At each extremity of the horizontal diameter is placed an insulated metallic comb which acts as a collector. Between these collectors is a detonator or spark gap, as in the *Holtz* machine. Each plate has in addition a metallic rod with two brushes which make contact with opposite sectors on the plate. (Fig. 33.)

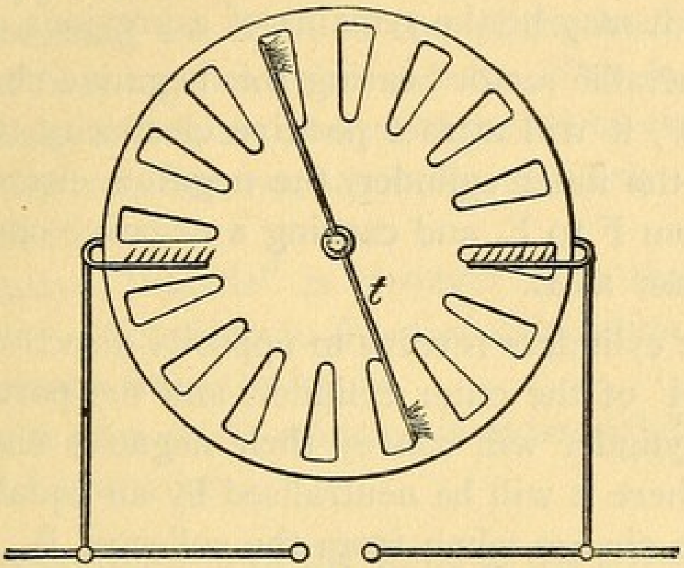


Fig. 33.—Wimshurst static machine.

The *Wimshurst* machine is sometimes made without the addition of metallic sectors to the plates. In *Bonetti's* model the plates are replaced by two ebonite cylinders, one within the other, revolving in opposite directions. This arrangement secures a much larger surface area.

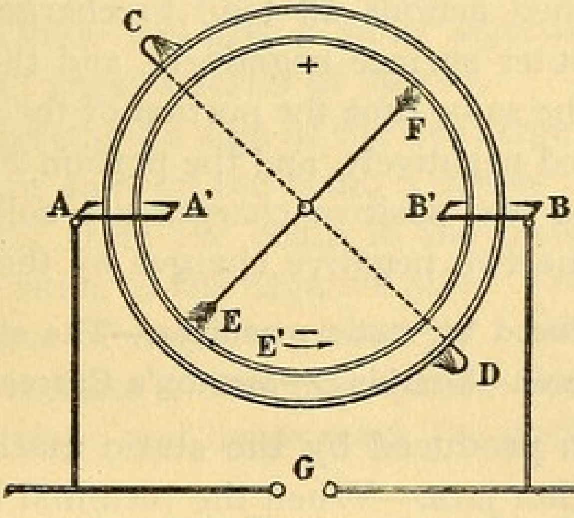


Fig. 34.

To explain the action of a *Wimshurst* machine we will describe a cylindrical instrument (Fig. 34), the cylinders of which are furnished with metallic sectors.

A small charge of electricity is given to the outer cylinder at the point H. This may be produced by friction or by induction, or it may be the remains of a previous charge.

As the metallic sector bearing this negative charge passes the brush F, it will attract positive electricity to the inner surface of the inner cylinder, the negative electricity being repelled from F to E, and causing a negative charge on the inner cylinder at E.

Since the cylinders revolve in opposite directions both the portion HH' of the outer cylinder, and the portion EE' of the inner cylinder will convey their negative charge to the comb B, where it will be neutralised by an equal and opposite positive charge taken from the collector B.

After passing B the portion of the outer cylinder in the position BD will come under the influence of the negative charge on the inner cylinder. It will, therefore, become positively charged, the corresponding negative charge being repelled through the brush D to C, where it will charge that portion of the outer cylinder negatively.

These combined actions all tend to charge the portion HH'B of the outer surface negatively, and the portion IA positively. At the same time the portion of the inner surface EE' B is charged negatively, and the portion FA is charged positively. The two positive charges are collected by the comb A, and the two negative charges by the comb B.

V. Effects produced by static machines.—The static breeze.—Effleuve.—Sparking.—Morton's Currents.

173. **Effects produced by the static machine without the use of Leyden jars.**—When the terminal knobs of the collectors of a static machine are separated, sparks pass between them. When the knobs are near together the spark passes directly, as a single zigzag flash, but when they are further separated it becomes branched.

On still further separating them a violet coloured glow makes its appearance. This is termed the effleuve.

On approaching the hand to one of the knobs a characteristic cool blowing sensation is felt. This is due to the particles of air, which are at first attracted by the knob, and then violently repelled on becoming similarly charged by contact with it.

The negative "Souffle" is stronger than that from the positive pole. According to *Bordier,* this action is reversed at some distance from the knobs.

The output of a static machine is measured by means of *Lane's* unit Leyden jar.

174. **Determination of the signs of the poles of a Static Machine.**—The polarity of a static machine may be determined in several ways:—

1. In the dark the comb connected to the positive pole shews a series of brilliant sparks, while that connected to the negative pole shews a violet aigrette.

2. At the detonator balls an opposite effect is produced. The positive knob will give a violet aigrette, and the negative knob will shew a series of sparks.

A violet aigrette is a sign of the discharge of positive electricity. When seen on the comb it shews the flow of positive electricity from the comb to the plate, and therefore marks the position of the negative pole. The brilliant points indicate a flow of negative electricity. When seen on the combs they indicate a flow of negative electricity from the comb to the plate, and hence mark the position of the positive pole.

3. If the knobs are far enough apart the spark will be branched. The main stem of such a spark is at the positive knob, whilst the branches ramify towards the negative knob.

4. A small piece of ebonite electrified by friction with a cloth or a catskin and suspended by a silk thread will be repulsed by the negative collector.

175. **To charge a static machine.**—Machines with metal sectors will usually charge themselves. Those without sectors may be charged by rubbing the edge of the plate with a dry finger or with a little amalgam.

The positive pole will be the one whose conductor is in advance of the excited region. If the plates are damp an ebonite rod should be charged by rubbing it with a catskin and placed close to one of the plates, just opposite one of the brushes. This will act on the brush by induction through the two plates.

176. **Technique of the Medical Application of Static Electricity.**—(A) *Static Bath.*—The patient is placed on a stool with glass legs. One pole of the machine is connected to the wooden top of the insulating stool, while the other pole is earthed by means of a metal chain.

Loss by leakage along the surface of the glass legs may be reduced by standing them in cups filled with oil. (*Bergonié.*)

(B) *Electric breeze.—Effleuve.*—The patient may be placed either on the floor or on the insulating stool. One pole of the machine is connected to earth, or to the insulating stool.

To give the electric breeze the second pole is connected to a metallic point or brush, or an exciter with multiple points, or *Truchot's* cephalic douche.

To produce an aigrette a wooden exciter must be employed.

(C) *Sparks.*—The same arrangement is used as in the preceding case, except that the pointed electrode is replaced by a metallic ball. This is placed in contact with the skin and then slowly withdrawn, thus gradually increasing the length of the spark.

Electric friction is given by passing this ball backwards and forwards outside the clothes.

(D) *Mediate excitation.—Bergonié's exciters.—Roumailliac's exciters.*—Mediate excitation is also produced by placing the metallic ball directly in contact with the skin, but with the addition of an adjustable sparkgap or exploder in the handle of the electrode, between the ball and the pole of the machine. Fig. 35 shows the arrangement employed in *Bergonié's* instrument.

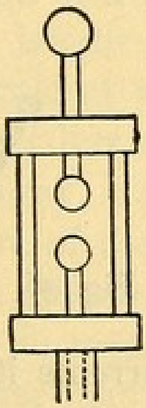


Fig. 35.—Exploder of Bergonié's exciter.

177. **Morton's currents.**—These currents were introduced by *Dr. W. J. Morton* in 1881. To produce them the inner coatings of two Leyden jars are connected to the collectors of the static machine (Fig. 36). The outer coatings are connected, one to earth and the other to the electrode of utilisation. The patient is not insulated.

When a spark passes across the gap between the knobs of the static machine, a simultaneous discharge occurs between the outer coatings of the two jars. This discharge is of an oscillatory character and we are, therefore, really dealing with high frequency currents of rapidly fluctuating intensity.

The muscular contractions, however, are mainly produced by the sudden changes of potential taking place at the passage of each spark, which is a low-frequency phenomenon. The electrode is applied to the motor points to stimulate muscular contraction.

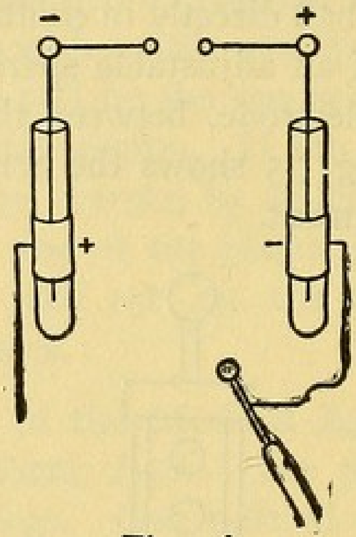


Fig. 36.

When using Morton currents it is advantageous to have condensors of variable capacity, such as those of *Maret* and *Cluzet*. In these the area of the condensor plates is adjusted by sliding two ebonite cylinders one within the other.

CHAPTER VI.

THE RÖNTGEN RAYS.

I.—General Considerations.

178. **Definition.**—The X-rays were discovered by *Professor Röntgen* in 1895. They are radiations, propagated with the velocity of light and the Hertzian waves, and are of much shorter wave length than even ultra-violet light. There is a graduated scale of wave lengths for the X-rays, just as there is a scale of luminous waves of the spectrum. It has been shewn by *Gouy, Haga* and *Wind* that the wave lengths of all X-rays are of the order of one-thousandth to one ten-thousandth of a micron.

The value of X-rays in medical diagnosis is due to two properties. They traverse many substances, such as muscle and skin, which are opaque to ordinary light, and they manifest their presence by their action on fluorescent bodies, or on a photographic plate.

These radiations have also a physiological action on the tissues, which may be either harmful or beneficial. We shall, therefore, have to consider both their danger and their therapeutic use.

179. **Production of X-rays.**—The essential apparatus for the production of Röntgen rays is a vacuum tube called a Crookes tube or Röntgen tube, or focus tube, which is traversed by an electric current of high potential. In practice we make use of two sources of high potential electricity, the Static machine and the Ruhmkorff coil, or alternating transformer.

180. **Use of the Induction Coil or of the Alternating Transformer.**—The same considerations which guided us in the choice of a coil and interruptor for high frequency currents are applicable here. A coil giving a 14 to 18-inch spark should be chosen. We have already described Messrs. *Gaiffe's* transformer for using the alternating current from the public mains. (129.) This apparatus is particularly suitable for driving an X-ray tube.

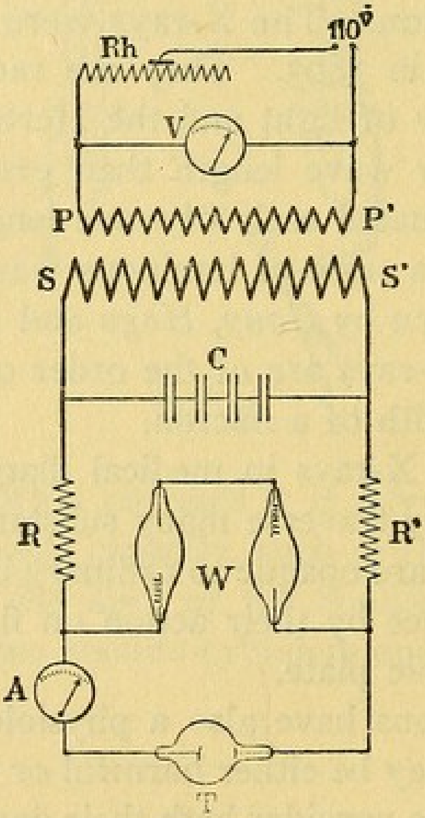


Fig. 37.

The arrangement is shown in Fig. 37. PS is a transformer with closed magnetic circuit, capable of giving a difference of potential of 60,000 volts between the terminals of the secondary circuit.

Between the terminals of the secondary coil SS' and the focus tube T, are interposed the condensors C and the liquid resistances R and R'.

Two Villard valves W are introduced in parallel with the focus tube. These provide an alternative path of lesser resistance for the inverse current and thus prevent it from passing through the focus tube (196).

This apparatus has many advantages. It obviates the necessity for an interruptor, a most unsatisfactory and noisy instrument whose use renders any accurate measurement impossible. It also renders possible the measurement of the current passing through the focus tube by means of a milliamperemeter at A.

The measure of the current passing through the focus tube is a most valuable datum, both for radiology and for radiotherapy. These advantages are so great that the alternating current is now preferred to the constant current for X-ray work, and in some instances even, the constant current supply is converted into an alternating current by means of a rotary transformer in order to permit the use of an alternating current transformer.

181. **Static machines for X-ray work.**—Any static machine having a sufficiently large output may be used to drive a focus tube. The chief disadvantage of static machines is their sensitiveness to any change in the hygrometric state of the air, and the great care necessary to avoid damage to the conductors. On the other hand, they give a steadier illumination of the fluorescent screen, are more portable than a coil and accumulators, and their use greatly lengthens the life of the focus tube.

A Wimshurst machine with two or three plates 50 cm. in diameter, rotated at 800 revolutions per minute is sufficient for most purposes. (*Leduc.*)

182. **Facts to be noted when using a Wimshurst machine in X-ray work.**—There are three different methods of driving a focus tube by means of a static machine.

(A) The tube may be introduced directly into the circuit of the static machine. By this means equality of illumination is assured, but a more powerful machine is required than when either of the following methods is employed.

(B) When the static machine is not powerful enough a sparkgap or detonator may be introduced into the circuit. The current thus obtained is intermittent and does not give the same steady illumination of the fluorescent screen, but this contrivance may often be used with advantage in radiography.

The intermittent current of low frequency obtained by this means is not to be confounded with intermissions of high frequency which originate the cathode rays.

(C) The third method is to connect each pole of the Wimshurst to the inner coating of a Leyden jar, while the outer coatings are connected to the terminals of the focus tube, the anode being joined to the jar on the negative pole of the Wimshurst, and the cathode to the jar on the positive pole. The external armatures of the jars are also connected together by a conductor of great resistance, such as a wooden bar or a Villard valve.

By this method we may in great measure avoid the loss of current due to the leakage from the surface of the conductors.

II.—The Focus Tube.

183. **Definition.—The Crookes tube or focus tube.—** A Crookes tube is a glass globe exhausted of air and provided with two electrodes, an anode, which is connected to the positive pole, and a cathode connected to the negative pole of a source of high tension electricity.

The tube in general use is a bianodic tube (Fig. 38), the two anodes being in electric communication with one another outside the tube. The second anode is inclined at an angle of 45° to the axis of the tube, and is termed the anticathode. This serves to receive and disperse the cathode

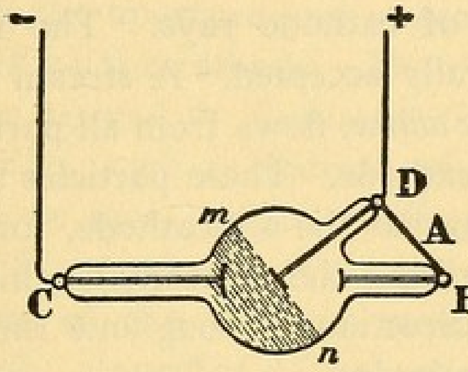


Fig. 38.—Ordinary focus tube with two anodes.

rays issuing from the cathode, and gives out the Röntgen rays, which radiate from it in all directions.

The cathode, C, is made of aluminum, since this metal is least subject to electric evaporation. (189.)

The anticathode, D, is made of platinum iridium, since this is most resistant to heat, a considerable amount of which is generated by the impact of the cathode rays. Moreover, the production of X-rays increases with the atomic weight of the element acting as target for the cathode rays, and platino-iridium is one of the heaviest metals known.

Under the best conditions a live focus tube should shew two distinct hemispheres, which are separated by the plane of the anticathode, m n. The hemisphere in front of the anticathode glows with a brilliant green fluorescent light.

The glass wall bounding the active hemisphere is bombarded by the cathodic projectiles scattered by the anticathode, and is traversed by the X-rays which radiate from the focus of emission on the anticathode. (186.) The hemisphere behind the anticathode is quite dark except when the tube is working irregularly. (197.)

The genesis of the Röntgen rays in a vacuum tube is due to the shock of impact when a stream of cathode rays strikes a target. The first desideratum then is some means of producing a strong stream of cathode rays.

184. **Cathode Rays.**—In 1868 *Hittorff* first described the phenomenon of cathode rays. The following is the theory now generally accepted. A stream of material particles, the *cathodic afflux,* flows from all parts of the vacuum tube towards the cathode. These particles are then repelled by the cathode towards the anticathode, forming the *cathodic beam.* On striking the anticathode this beam is again dispersed in all directions throughout the hemisphere in front of the anticathode.

Cathode rays are, therefore, not due to vibrations, like light, heat, and X-rays, but to a transport of material particles which are probably Hydrogen. These particles travel with a velocity of 20,000 to 50,000 kilometres per second. (*J. J. Thomson, Wiechert.*)

If we watch the electric discharge in a tube which is being gradually exhausted, when the pressure is reduced to about 10 mm. of mercury, we see the so-called *positive light,* a violet glow around the anode, stretching towards, but not reaching, the cathode. The dark space between this glow and the cathode is termed *Faraday's dark space.*

On increasing the vacuum a glow also appears around the cathode, the so-called *negative light* which is separated from the cathode by *Hittorff's dark space.* The colour of this glow depends on the nature of the gas present in the tube.

As the vacuum gets higher this negative light becomes concentrated into the *cathodic beam.* With a sufficiently high vacuum the cathodic beam, by its impact on any obstacle, gives rise to the *Röntgen rays.*

This cathodic beam represents the trajectories of the projectiles driven from the cathode towards the anode or anticathode. It is fed by the afflux of molecules from all parts of the tube. These, on touching the cathode, receive a negative charge, and are repelled, thus forming the cathode rays.

If the cathode is perforated, part of the cathodic afflux will pass through the aperture and appear as a luminous stream at the back of the cathode. These rays behind the cathode have been termed by *Goldstein* the *Kanalstrahlen*,

Radioactive bodies, such as radium, give out radiations analogous to cathode rays, besides emitting radiations similar to X-rays. (*Bécquerél, Curie.*)

185. **Properties of the Cathode rays.**—(a) *Cathode rays are negatively electrified.*—The ratio of the electric charge e to the mass m of the cathodic particles is found to be always constant.

The ratio $\frac{e}{m}$ is the same, whether it is measured in the cathode rays inside the tube or outside the tube in the Lenard rays. It is one thousand times as great as the ratio of charge to mass in the ions concerned in electrolytic conduction. One gramme of cathodic matter would carry a hundred million (10^8) coulombs of electricity.

(b) *The velocity of a cathodic projectile is a function of the difference of potential.*—It therefore increases as the vacuum becomes higher. Since the voltage of the current through a focus tube is constantly fluctuating, every cathodic beam is composed of various cathodic rays travelling with different velocities.

(c) *Cathode rays are deviated and dispersed by a magnetic or an electric field.*—This phenomenon is the direct result of the electric charge carried by the cathodic particles. Following the ordinary laws of projectiles, the deviation of the rays is in inverse proportion to their velocity, so that the deviation is greatest when the vacuum in the tube is lowest. The deviation, moreover, varies for different rays in the same cathodic beam. The rays of high velocity will be less deviated than those travelling more slowly; hence we notice a dispersion as well as a deviation of the beam.

(d) *Electric evaporation.*—The cathode, *i.e.*, the electrode towards which the cathodic afflux flows, and from which the cathode rays originate, undergoes a gradual process of pulverisation or electric evaporation. (189.)

(e) *Production of X-rays.*—The cathodic projectiles give rise to X-rays whenever they strike any material surface. There is, therefore, a production of X-rays at the centre of the anticathode, and on the walls of the focus-tube, which receive the cathode rays dispersed by the anticathode. (186.)

186. **Production of X-rays in a vacuum tube.**—In the earlier Crookes tubes the X-rays were produced by the cathode rays bombarding the glass walls of the tube itself. The surface of emission was large, and shadows formed by the X-rays were ill-defined.

In the modern focus-tube the surface of emission is reduced to a square millimetre or less at the centre of the anticathode, the cathode being concave so as to focus all the cathode rays at this point.

Another great advantage is the substitution of a focus-plate of platino-iridium for the glass wall of the tube, since the intensity of the X-rays emitted increases with the density of the target. Further, since platino-iridium is able to withstand a high temperature, it is possible to concentrate the rays at one point without fear of fusing the target.

The X-rays produced at the anticathode easily traverse the walls of the tube, losing very little of their intensity in the process. The X-rays produced by the impact of the diffused cathode rays on the wall of the focus tube are but feeble, and may be practically ignored. (201.)

187. **Action of a focus tube.**—There are several phenomena of interest to be observed in using a vacuum tube for the production of X-rays.

(A) The electric state of the focus tube and of the vacuum. (188.)

(B) The cathodic evaporation or pulverisation of the cathode. (189.)

(C) The metallisation of the tube. (190.)

(D) The thermic effects. (191.)

(E) The interior resistance. This is a function of the facility of formation of the cathode beam, and therefore of the degree of vacuum. It may be determined by the length of the equivalent spark, or by the quality of the X-rays emitted as measured by *Benoist's* radiochromometer. A focus-tube is said to be "soft" or "hard," according to the degree of its internal resistance. (192.)

(F) The "softening" of a focus tube during use. During the process of exhaustion of a focus tube it becomes softer when a current is passed. This sometimes occurs during use if the focus tube has not been properly exhausted.

(G) The "hardening" of a focus tube during use. When a focus tube has been properly exhausted it always grows harder with use.

188. **Resistance of the focus tube.**—In an electric circuit, the fall of potential between any two points is greater, the greater the resistance between these points; provided that the resistance of the rest of the circuit remains unaltered. It follows, therefore, that the difference of potential between the anode and cathode of a focus tube will be increased by increasing the resistance of the tube. The resistance of a focus tube varies inversely with the facility with which the cathode rays are formed and directly with the degree of vacuum in the tube. (184 and 192.) The re-

sistance of a tube may be measured approximately by the length of the equivalent spark. (193.)

The greater portion of the focus tube is at the same potential as the anode, the drop of potential occurring chiefly at the cathode.

189. **Cathodic evaporation.** — The phenomenon of *electric evaporation* is almost exclusively confined to the cathode of a vacuum tube. During the emission of cathode rays excessively minute particles are torn off from the cathode and strike the glass walls of the tube, producing a blackish discolouration.

Aluminium being less subject to this pulverising action than most other metals, the cathode is almost invariably made of this metal. Platinum, on the other hand, exhibits the phenomenon of electric evaporation in a very high degree. Hence electric evaporation and consequent discolouration of the tube takes place rapidly when a focus tube is driven the wrong way, *i.e.*, when the current is passed from cathode to anode.

190. **Metallisation of the tube.**—The so-called metallisation of the tube is due to the deposit on its walls of metallic particles torn off from the cathode. This gives a characteristic black discolouration to the glass, which is quite distinct from the violet tinge caused by the impact of the cathode rays. These minute particles of metal have a great affinity for oxygen, and by combining with the residual gas in the tube they increase the vacuum and cause the tube to grow "hard." Metallisation should, therefore, be avoided as much as possible, by suppressing the reverse current, for which the platinum anticathode serves as a cathode. (Villard valves, 196.)

191. **Thermic effects.**—Cathodic bombardment is accompanied by an evolution of heat in the target. The anti-

cathode soon becomes red hot, and for that reason it is best made of platinum. The glass walls of the tube also become slightly heated by the impact of the diffused cathode rays. To avoid excessive heating modern tubes are often constructed with a water cooling device around the anticathode.

192. **Internal resistance of the focus-tube.—Hard and soft tubes.**—The resistance of the vacuum in a focus tube is ever varying, depending, as it does, on the ease with which the cathodic beam is formed, and on the degree of vacuum in the tube. These two factors are mutually interdependent.

The greater the resistance the greater will be the difference of potential between the anode and the cathode, the greater will be the velocity of the cathode rays, and the more penetrating the Röntgen rays to which they give rise.

The resistance of a tube may be determined in various ways.

(a) By measuring the length of the equivalent spark. (193.)

(b) By determining the penetration power of the X-rays by means of *Benoist's* radiochromometer. (204.)

(c) By calculation from the voltage in the primary circuit. (*Bergonié.*)

(d) By employing the *d'Arsonval-Gaiffe* alternating current transformer and milliamperemeter, which permits of an exact determination of the resistance and current in the tube. (129 and 180.)

If the internal resistance of a focus tube is above the normal the tube is said to be *hard;* if it is below, the tube is *soft.* When a tube is used for the first time we should note if it grows softer with use. This is indicated by a decrease in the length of the equivalent spark, and by a change in the appearance of the tube. When a focus tube grows softer with use it shows that it has not been properly exhausted.

In the process of manufacture of a focus tube the residual gas has to be repeatedly exhausted, and during the exhaustion a current is passed through the tube to liberate the gaseous molecules absorbed by the glass. Finally the tube is heated in order to liberate any remaining gas.

A focus tube is said to be *formed* when it no longer grows softer during use, even when heated.

If a new tube becomes soft through being over-driven, it may be hardened again by being used repeatedly with a very small current.

193. **Determination of the Resistance of a focus tube —Equivalent spark—Voltage of primary—Milliamperage of the secondary circuit.**—The maximum length of spark which will pass between the balls of a sparkgap mounted in parallel with the focus tube is called the *equivalent spark* length. It gives an approximate measure of the penetration of the X-rays emitted by the tube. Two tubes of the same type, with the same equivalent spark length, will give rays of equal penetration.

The equivalent spark will be longer the greater the resistance and the higher vacuum. Its length will, therefore, increase with any increase in the velocity of the cathodic corpuscles.

Béclère has designed an instrument which he has named *spintermeter,* to facilitate the measurement of the equivalent spark.

It must be remembered that the length of spark will vary with the size of the balls of the sparkgap. This should be one of the data given, in order to render comparable the measurements of different experiments. During an exposure the spintermeter enables us to appreciate one thing only; that is the moment when the tube becomes hard enough to allow a spark to pass between the knobs. If the tube is growing softer we must approach the knobs of the spintermeter until a spark passes, and measure the distance at which this occurs. This interferes with the regularity of emission of X-rays, since it ceases during the passage of a spark across the sparkgap.

Bergonié has devised another means of judging the internal resistance of a focus tube. This is the measurement of the voltage at the terminals of the primary coil. Any increase of resistance in the secondary will increase the self-induction in the coil, and thus alter the resistance to change of flux in the primary.

With a given coil, *if other factors remain unchanged,* we may estimate the change of resistance of the tube by measuring the difference of potential at the terminals of the primary coil, since this will increase as the resistance of the tube increases.

The character of a tube can be determined much more easily by using an alternating current transformer as described in par. 180. A milliamperemeter in the secondary will give the exact measure of the current through the focus tube. Since the intensity of the current is a function of the E.M.F. of the secondary and the resistance of the tube, any change of the latter will be indicated by the milliamperemeter. A comparison of a number of tubes of different makers by means of *Benoist's* radiochromometer has proved the accuracy of this method of measurement.

194. **Hardening of the tube and means of preventing it.**—During its action a focus tube grows gradually harder, *i.e.,* the length of the equivalent spark becomes greater. One cause of this hardening is electric evaporation from the cathode. This may be recognised by the blackish tinge due to metallisation of the glass, which should not be confounded with the violet or brownish discolouration

caused by the direct action of the X-rays and the cathode rays.

The metallic particles thrown off from the cathode have a great affinity for oxygen, and thus reduce the quantity of free gas in the tube.

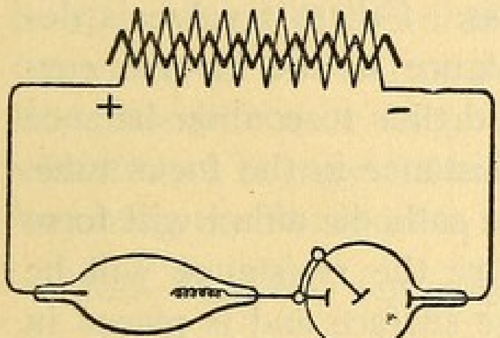
When a tube begins to grow hard it may be restored to its former condition by warming. For this purpose a broad flame from a spirit lamp should be used. Unfortunately, when the flame is withdrawn the tube rapidly becomes hard again. Even during a short exposure the quality of the rays will change, owing to the cooling of the tube.

The use of a Villard valve, which prevents the passage of any inverse current, will in great measure prevent electric evaporation. The degree of hardness of a focus tube may also be regulated by the use of the osmoregulator or other appliance for regulating the vacuum in the tube.

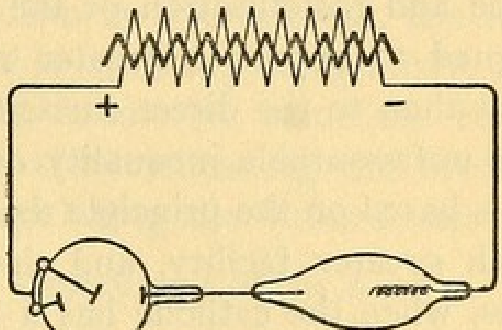
195. **Villard's osmoregulator.** — The osmoregulator consists of a small platinum tube which is sealed into the wall of the focus tube. The outer end of the osmoregulator is closed, while the other end opens into the focus tube. When platinum is heated it becomes permeable to hydrogen gas. The molecules of the gas will tend to pass through the metal from a region where its pressure is higher to one where its pressure is lower, just as liquids do in osmosis.

When the platinum tube is heated in a Bunsen flame, some of the hydrogen molecules present in the flame pass through the platinum into the focus tube, and thus make it softer. If, on the other hand, the osmoregulator be surrounded by a metal sleeve, and this sleeve be heated, there will be no free hydrogen in the region outside the platinum tube, and the hydrogen in the focus tube will diffuse out through the platinum, thus increasing the vacuum in the focus tube and making it harder.

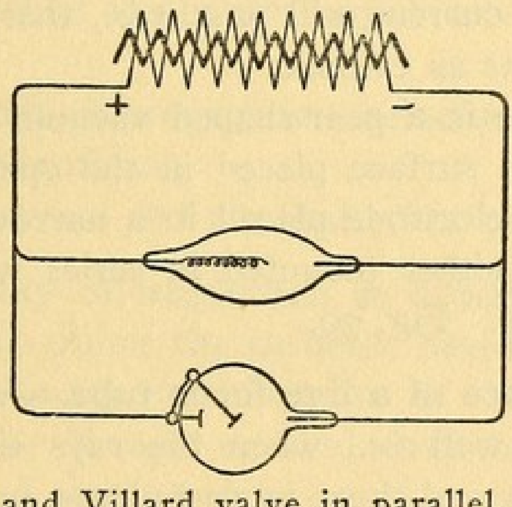
196. **The Villard valve.**—In a focus tube the normal current encounters greater resistance than the reverse current. On account of the position of the anticathode, it is easier for a current to pass in the reverse direction from



A.—Focus tube and Villard valve in series. The small electrode of the valve connected to the positive pole of the coil.



B.—Focus tube and Villard valve in series. The large electrode of the valve connected to the negative pole of the coil.



C.—Focus tube and Villard valve in parallel. The large electrode of the valve connected to the positive pole of the coil, and the small electrode to the negative pole.

Fig. 39

the anticathode to the cathode of the tube than in the normal direction. So much is this the case that the weaker reverse current of "make" will often pass as easily as the stronger "break" current. In this case the focus tube will work badly, shewing patches and striæ—signs of the passage of the inverse current.

Not only does this produce irregular illumination, but it causes metallic evaporation from the platinum of the anti-cathode, since the latter will in alternate phases act as a cathode, with all the attendant evils of hardening of the tube and metallisation of the glass. *Villard's* valve is designed to oppose a greater resistance to the inverse current than to the direct current, and thus to counter-balance the unfavourable inequality of resistance in the focus tube. It is based on the principle that the cathodic afflux will form with greater facility, and therefore the resistance will be less, when the cathode has a large surface and is placed in a free space.

Consider an alternating current with equal phases passing through a vacuum tube with unequal electrodes, the size and position of the electrodes may be so adjusted that only one phase of the current will pass, *viz.*, that in which the large electrode acts as cathode.

A Villard valve is a pear-shaped vacuum tube with an electrode of large surface placed in the open part of the tube and a small electrode placed in a narrow neck at one end. It may be either mounted in series with the focus tube or in parallel. Fig. 39.

197. **Appearance of a live focus tube.**—When a focus tube is working well *i.e.*, when the rays emitted are of medium hardness and there is no inverse current passing through the tube, its appearance is like that already described in par. 183. The chief characteristic of such a tube is the intense green or bluish fluorescence over one half of the tube, the boundary in the plane of the anti-cathode being sharply defined.

When a tube shews striæ and inequalities or spots in the fluorescence, it is either dirty or it is traversed by inverse currents. The first defect can be remedied by washing with soap and water and alcohol; the second may be obviated by interposing a properly adjusted Villard valve.

If a tube is poorly illuminated, or shews a faded yellow colour, it is probably an old tube which had become too hard, whereas if the illumination is intermittent, the interruptor of the coil is probably working irregularly, so that the difference of potential is not the same for each vibration. It may be corrected by adjusting the break, warming the focus tube, or regulating the Villard valves.

III.—Character and mode of employment of the X-rays.

198. **General considerations.**—In the study of X-rays we have to consider,

(A) The intensity of illumination of the different zones of the irradiated area.

(B) The method of illuminating objects in the irradiated area.

(C) The mode of propagation, velocity and wave length of the X-ray vibrations.

(D) The chemical and physical effect of the X-rays.

199. **Intensity of irradiation at different parts of the irradiated area.**—Since the cathodic beam is concentrated on less than one square millimetre of the surface of the anticathode, the X-rays emitted may be considered as radiating from a single point.

The intensity of irradiation is almost uniform over the whole irradiated area, except just at the periphery where the rays are nearly parallel to the surface. The intensity of irradiation is no greater in the centre than on the circumference of the field of irradiation. (*Gouy.*)

There is no advantage in using the rays which issue normally to the anticathode. Indeed it is sometimes advantageous to use other portions of the field.

200. **Illumination of objects by X-rays.**—The laws of illumination applicable to X-rays are the same as the optical laws of illumination from a luminous surface rather than from a point.

In the case of the focus tube, the luminous area is oval, since the anticathode cuts the cone of cathode rays at an angle of 45°. The major axis of this ellipse is in the plane passing through the axis of the anticathode, the cathode and the anode.

Since the source of illumination is an elliptical surface, instead of a point, every object illuminated will show a penumbra around its shadow, and thus we may get all the illusions familiar in optical phenomena.

The apparent diameter of the luminous surface will be greatest when viewed in the direction of the ray normal to the centre of the anticathode. It will appear circular when viewed at an angle with this normal ray equal and opposite to the angle of the cathode ray with the normal ray. Hence, for radiography, we place the body to be illuminated in the direction which the cathode rays would take after reflection by the anticathode, if the cathode rays were rays of light. In this position the penumbra is equal in all directions and therefore it should be chosen for all radiographic work where a clear definition is required.

201. **X-rays emitted by the walls of the focus tube.**—As a rule the X-rays generated by the impact of the diffused cathode rays on the glass walls of the tube are so feeble as to be negligible. In certain cases, however, they may be a source of inconvenience. This may be obviated by interposing a lead diaphragm between the focus tube and the fluorescent screen. The aperture in the diaphragm is so adjusted as to cut off all except the useful pencil of rays.

A penumbra will be visible if the rays are powerful enough, even after all possible precautions have been taken.

202. **Propagation of the X-rays.**—X-rays are propagated in straight lines. They are incapable of reflection, refraction or diffraction.

Secondary X-rays are emitted by all bodies on which the primary X-rays impinge. These secondary irradiations are emitted in all directions, both at the point where the X-rays impinge on a body and at the point where they emerge, after traversing the body. The quality of the secondary radiations varies with the nature of the body interposed, and with the quality of the X-rays giving rise to them.

Secondary rays may further give rise to *tertiary rays,* The production of these secondary and tertiary X-rays is a frequent cause of fogging of the photographic plate in radiography.

203. **Transparency of bodies to the X-rays—Benoist's law.**—*Benoist* has investigated the laws which govern the transparency of various bodies to the X-rays. They are:

(1) The *specific opacity* of any substance is independent of the physical state of that substance. For a given substance, the opacity is merely a function of its mass, and is the same whether the body is in the solid, liquid, or gaseous state.

(2) The *specific opacity* is independent of the molecular or atomic grouping of the substance, whether crystalline or amorphous, or of various allotropic modifications.

(3) The *specific opacity* is the same whether the atoms are free or in chemical combination, and the *transparency equivalent* of a mixture can be calculated from a knowledge of the transparency equivalents of its constituent parts.

Benoist takes as a unit the transparency of a cylinder of paraffin wax 75 millimetres long and one square centimetre in cross section. The *transparency equivalent* of a substance is the mass in decigrammes of a cylinder of the substance one square centimetre in cross section and of such a height that it is of the same transparency as the cylinder of paraffin wax.

(4) For X-rays of any given penetration, the specific opacity of an element is a fixed function of its atomic weight. This is a most important fact. If we take X-rays of definite penetration, a given substance, whatever its form, its state of combination or mixture, will have the same transparency equivalent. A determination of this transparency equivalent may therefore give valuable information as to the composition of an unknown body.

For example, organic matter free from admixture has an equivalent somewhat above 40. If mineral matter is added, this equivalent becomes lowered, since the atomic weight of the mineral is higher than that of any of the constituents of the organic matter.

On the other hand, the quality of the X-rays employed may be determined by comparing the transparency of a body of known transparency with that of different thicknesses of some standard substance such as aluminium. This is the principle of the radiochromometer.

204. **Benoist's radiochromometer.**—*Benoist's* radiochromometer is an instrument which enables us to compare the transparency of a standard plate of silver with that of various thicknesses of aluminium. The plate of silver is .11 mm. thick. For X-rays of medium penetration this has the same transparency as *Benoist's* standard paraffin block 75 mm. in thickness. Around the central silver plate are

placed twelve sectors of aluminium of thickness varying from 1 to 12 mm.

In order to estimate the penetration of the rays given off by a focus tube, the tube is viewed through the radiochromometer and a fluorescent screen. Some two or three sectors will appear of about the same transparency as the silver disc in the centre. The middle one of these is taken to denote the quality of the X-rays under investigation. By this means we are able to measure and give a numerical value to the penetration of the rays emitted by a focus tube.

205. **Holzknecht's chromoradiometer and Sabouraud and Noiré's reagent.**—*Holzknecht* has designed an apparatus which he terms a chromoradiometer, to measure the dose in X-ray treatment. The physiological or therapeutic action of the X-rays is proportional to the quantity absorbed. Highly penetrating rays which pass through the body without being absorbed are almost without therapeutic effect. *Goldstein* found that the colour of certain salts is changed by exposure to the cathode rays. *Holzknecht* observed that the X-rays produce a similar effect, and that the amount of change is proportional to the quantity of X-rays absorbed. Hence he makes use of the colour change of one of these salts to indicate the quantity of rays absorbed.

X-rays, cathode rays, and radioactive bodies have a similar effect on these salts. A solution of chemically pure chloride of sodium is coloured yellow by the rays. The colour effect is the same if it is mixed with pure sodium sulphate, though the latter salt alone is not coloured by the rays. If the two salts are fused together, they will on cooling exhibit a pinkish-violet colour, and the solution of this mixture is stable.

The action of the X-rays on these salts serves to explain the principle of *Holzknecht's* chromoradiometer, although the actual composition of the salt he uses is kept secret. The salt is enclosed in small capsules mounted on a card.

A graduated scale formed of twelve such capsules serves as a standard with which to compare the degree of colouration. *Holzknecht's* unit of measurement is an arbitrary one and is designated by the letter H. A new capsule is required for each case, but the same capsule may be used several times for one patient since if care is taken to exclude light it will preserve its colour from one sitting to the next.

This method of measurement promises to be a very valuable one, when the unit has been clearly defined, and the doses suitable for each case have been determined. It has, however, one drawback. The darkening of the reagent continues for some time after the irradiation has ceased.

In France *Sabouraud* and *Noiré's* discs are generally used for measuring the quantity of radiation. They consist of barium platinocyanide paper similar to that used for the fluorescent screen. The disc is placed 8 cm. from the anticathode, the distance of the patient being 15 cm. Platinocyanide of barium grows darker under the influence of the X-rays, but rapidly regains its original colour on exposure to daylight.

The standard scale used with this instrument gives three tints.

(1) The colour of the unirradiated platinocyanide disc.

(2) The colour of a disc which has absorbed a quantity of rays corresponding to 4 H in *Holzknecht's* units. This is the dose required to give the first degree of radiodermic reaction.

(3) The colour of a disc which has absorbed 5½ H, the maximum dose permissible without injury to the skin.

206. **Ionisation by X-rays.**—X-rays have the property of ionising any gas which they traverse, *i.e.*, of decomposing the molecules of the gas into positive and negative ions. Hence all electrified bodies are discharged when subjected to the influence of the X-rays.

207. **Discharge of electrified conductors.**—*Benoist, Dufour, Righi* and *J. J. Thomson* have investigated the behaviour of charged bodies when subjected to the influence of X-rays. A charged electroscope is at once discharged by a beam of X-rays directed upon it. The rate of discharge increases as the pressure of the ionised gas is increased, and it also varies with the nature of the gas and with the nature of the metallic leaves.

It is not necessary for the beam of X-rays to impinge on the metal leaves; it is sufficient if it passes through the surrounding air, the metal being then discharged by electric convection.

Secondary rays are also capable of discharging an electroscope. (*Sagnac.*)

The same phenomenon is observed when a beam of ultraviolet light is directed on the electroscope, but in this case the instrument is only discharged if the charge which it had received was negative. This may not be a fundamental difference between the two forms of radiation. Indeed, *Lénard's* ultraviolet rays, like the X-rays, are capable of discharging bodies charged with either positive or negative electricity.

208. **Emission of negative charges by metals irradiated by the X-rays.**—*Curie* and *Sagnac* have found that when placed in vacuo metals irradiated by the X-rays emit negative charges as well as secondary X-rays. This is analogous to the negative charges emitted by metals under the influence of ultra-violet light. It is now gener-

ally admitted that when X-rays impinge on a metal in vacuo, the latter emits cathode rays similar to those produced in a Crookes tube, or by a radioactive body.

209. **Condensation of water vapour in supersaturated air.**—*Wilson* found that in common with ultra-violet rays, the X-rays possess the property of condensing the aqueous vapour in supersaturated air.

210. **Velocity of X-rays.**—According to *Blondlot,* the velocity of propagation of the Röntgen rays is the same as that of the Hertzian waves and light waves, *i.e.,* about 300,000 kilometres per second.

211. **Action of X-rays on fluorescent substances.**—Certain substances, such as barium platinocyanide, becomes fluorescent on exposure to the Röntgen rays. If the exposure is prolonged, the platinocyanide becomes brown, and this colour persists so long as the screen is kept in the dark. The discoloured salt is much less sensitive to the X-rays, but its original colour and sensitiveness can be restored by exposure to sunlight. It is therefore advisable always to expose the fluorescent screen to daylight after use.

212. **Photographic action of the X-rays.**—X-rays, like ordinary light, are capable of affecting a photographic plate, which may then be developed in the ordinary way, to give a photographic negative. When a transparent radiograph or *diapositive* is required, it is obtained by taking a photograph of the X-ray negative with the ordinary photographic apparatus.

213. **To obtain a positive radiograph directly.**—The action of light and the X-rays on a photographic plate, though similar, is nevertheless antagonistic. The impression of a radiograph on a photographic plate is destroyed by

exposure to light, even to the infra-red rays of the spectrum. This enables us to obtain a positive directly on the photographic plate. An ordinary radiograph is taken and the plate is exposed to daylight for a sufficient time to destroy the impression caused by the X-rays. The inverse image thus formed is then developed. The shadows on this plate will appear dark, and the portions of the plate which were most irradiated will remain white, owing to the neutralisation of the two effects.

IV. Application of X-rays in Medicine and Surgery.

214. **Radioscopy and radiography.**—I. For ordinary processes of radioscopy and radiography, where great accuracy is not required, the focus tube may be supported by a clamp on any of the ordinary movable stands, and the patient may be placed in whatever position is most convenient for the particular operation required.

II. For clinical radioscopy or radiography, a horizontal or inclined couch should be used, with a support for the focus tube so designed that it can move freely in a plane parallel to the couch. This movable support may be either above or below the couch, and there are numerous appliances designed for this purpose. It is well also to have an arrangement for the examination of the patient in a vertical position. In this case the support for the tube should permit of its being moved in any direction in a vertical plane. The arrangement shewn in Fig. 40, which I devised some years ago, is now very generally adopted. To this *Dr. Béclère* has added an iris diaphragm, which is most useful for clinical work.

III. In all X-ray work it is advisable to interpose a sheet of aluminium between the focus tube and the patient. This metal screen should be connected to earth. By this means any accidental sparking of the patient is avoided, the static field is suppressed, and the injurious effect of the less penetrating X-rays is obviated.

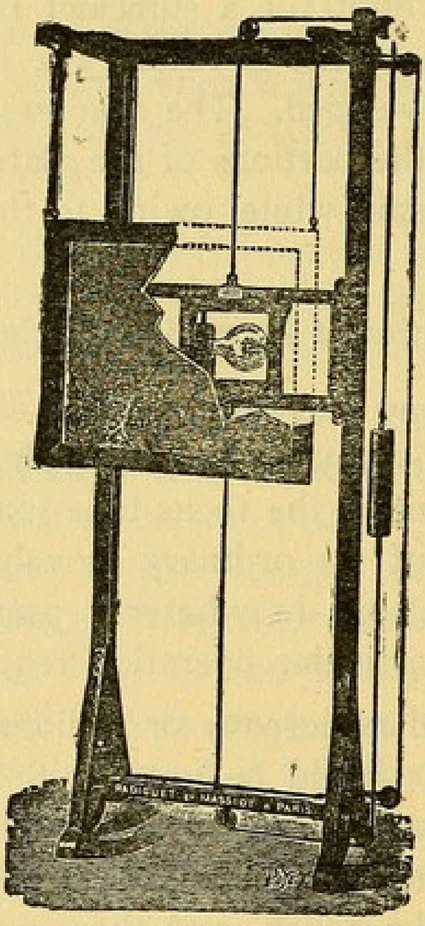


Fig. 40.

215. **Radioscopy and Radiography of Precision.**— When great accuracy is required, as in the determination of the exact position of a foreign body, measurement of the size of an organ, orthogonal projection, etc., we require some means of determining the direction of the incident ray. This is generally accomplished by placing crossed wires in front of the focus tube in the path of the incident ray, usually the ray which is normal to the irradiated surface. In order to place this indicator in position, a pointer is fixed at right angles to the plane of the crossed wires,

and the whole moved about until the shadow of the pointer shews as a circular spot on the fluorescent screen. Instead of the pointer, a second pair of crossed wires may be employed, or the direction of the ray may be marked by a goniometer specially designed for this purpose. The goniometer is the only practicable means of determining the angle of incidence when it is desired to use oblique irradiation.[1]

Normal projection may be obtained directly on the ordinary fluorescent screen, or on a second screen placed parallel to the first or examining screen, as in the orthodiagraph described above.

216. **Sterioscopic projections.**—In sterioscopic radiography we obtain two perspective views of the same object, which, when looked at through an ordinary stereoscope, give the appearance of relief. This gives a better idea of the relative position of the different organs.

It may also be employed in *Steriometry, i.e.,* the quantitative estimation of the position of an opaque body in relation to certain fixed points. (See *Bouchard's* Traité de Radiologie médicale, p. 574.)

The apparatus for stereoscopic radioscopy is designed to give two intermittent images which form two distinct perspective views, so arranged that one shall be observed by the left and the other by the right eye. The right hand image is eclipsed just as the left eye piece is covered. We thus see the two images alternately, the left hand image with the right eye, and the right hand image with the left eye.

[1] The radiogoniometer is an apparatus which measures the inclination of the incident ray on two planes at right angles to one another.—*Traité de radiologie médicale, Bouchard.*

217. **Endodiascopy.**—The process of endodiascopy introduced by *Bouchacourt* consists in introducing a specially constructed focus tube into the various cavities of the body. The walls of the tube are kept at the same electric potential as the earth. The instrument may also be used for radioscopy, with the focus tube in contact with the skin. (Traité de Radiologie médicale, p. 606.)

CHAPTER VII.

GALVANO-CAUTERY.

218. **Electro-cautery.**—An electric cautery consists of a platinum wire or plate of appropriate shape, which is heated by the passage of an electric current, either continuous or alternating.

Electric cauteries have a very low resistance, varying from .4 ohms to .02 ohms, or even less. To heat the cautery to incandescence may require from five up to twenty or even thirty amperes. The voltage at the terminals of the battery must therefore be from 2 to 10 volts. The voltage required for a given cautery may be calculated from its resistance and the current by *Ohm*'s law. $V = RI$.

219. **Source of electricity for the electric Cautery.**—Since a cautery needs a large current at a low potential, it is best heated by means of accumulators, galvanic batteries with large plates, or dynamos of low voltage.

As a rule, we use the most available source, which is probably of higher voltage than that required for the cautery.

Usually the choice lies between the use of a galvanic battery or accumulators and a current of high voltage as supplied from the public main.

220. **Galvanic cells and Accumulators.**—Galvanic cells are very useful when no other source of electricity is available. Cells with large plates should be chosen, and these should be joined up in series and parallel so as to give a pressure of 2 to 6 volts and a current of 5 to 20 amperes, according to the cautery employed.

Whenever practicable, accumulators should be preferred as they are much more convenient. Two accumulators in series are usually sufficient for a cautery. A portable accumulator, yielding 25 ampere hours, is a useful size for this purpose.

An accumulator is, however, more likely to be damaged by using it for the cautery than in any other way, since the current is generally greater than the accumulator is able to supply with due regard to the life of the plates.

221. **Use of the current from the public mains for the electric cautery.**—This is the most convenient source, but it is the most difficult to employ satisfactorily. If we use a current of 110 volts directly to heat a cautery which requires 6 volts and 10 amperes, we must expend 104×10, or 1040 watts, of which only 60 watts are used in the cautery. For this reason the use of a transformer is much more economical. On the other hand, a current of high voltage is often very convenient, and we will therefore proceed to enumerate the best methods of utilising it.

(a) *Alternating current from the mains.*—In this case a transformer with closed magnetic circuit specially designed for use with the cautery must be employed. The apparatus is light, cheap and very efficient. A small current of about one ampere in the primary, with a pressure of 110 volts, is transformed into a large current of low voltage, 10 amperes at 10 volts.

This is the ideal form of transformer. When it is used the only other apparatus required is a low resistance rheostat in series with the cautery.

(b) *Continuous current from the mains.*—When employing a continuous current at high potential for electro-cautery, a method much practised in Germany is to use a transformer with open magnetic circuit. The transformer is in fact a Ruhmkorff coil in which the thin wire acts as a primary, and the thick wire as secondary. This is, however, expensive, and necessitates the use of an interruptor—always a source of difficulty. Rotary transformers are also subject to the same objection.

It is better to resign oneself to the waste of energy, and to use the current directly, with the interposition of high resistances. The ordinary rheostat in series with the cautery is not sufficient. A shunt circuit must be employed as a "potential reducer," the arrangement of the resistances being that already described in par. 88.

Suppose, for instance, we were using a cautery of .3 ohms resistance, requiring a current of 10 amperes with the resistance in series with the cautery. If the pressure in the mains is 110 volts a spark would pass across the interruptor in the handle of the cautery on breaking the current. This spark would have an energy of 1100 watts, enough to destroy the terminals of the interruptor, or to produce continuous sparking if the insulation were defective.

This energy of the extra spark will be greatly reduced if the cautery is introduced into a shunt circuit. Suppose we have a resistance of 10 ohms in the main circuit, and the cautery of .3 ohms in the shunt circuit. Let that portion of the main resistance placed in parallel with the cautery be so adjusted that a current of 10 amperes will pass through the cautery when one ampere passes through the main circuit. When the cautery is in use, the total energy passing through the circuit will be $11 \times 110 = 1210$ watts. When the current in the cautery is cut off the total resistance will be increased from 10 ohms to 12.73 ohms, and the energy of the current will drop from 1210 to 948 watts.

The break spark will therefore in this case only correspond to an energy of 262 watts.[1]

This spark moreover will find an alternative route through the main circuit, and its effect on the interruptor will therefore be reduced to a minimum.

The usual method of arrangement in the potential reducer is to use an invariable resistance of 10 to 20 ohms in the main circuit, and to place the cautery in parallel with an adjustable resistance of 3 to 5 ohms.

[1] Let I^c be the current through the cautery and R^c its resistance,—I^s the current through the shunt, and R^s its resistance. In the above example $I^s R^s = I^c R^c = 3$ volts, since the current I^c is 10 amperes and the resistance R^c is .3 ohms. If I^s the current through the shunt is 1 ampere, R^s must be 3 ohms. R, the equivalent resistance of R^s and R^c, is therefore .273 ohms.
The resistance of the rest of the circuit is $10 - .273 = 9.727$ ohms. If to this be added the resistance $R^s = 3$ ohms, we get a total resistance of 12.73 ohms when the cautery is not in use.

CHAPTER VIII.

OZONISATION.

222. **Method of producing ozone.**—Ozone (οζη, odour) is an allotropic modification of oxygen. Whereas the oxygen molecules O_2 consists of two atoms of oxygen, the ozone molecule O_3 contains three such atoms. The earliest observations on ozone were made by *Van Marum* in 1779, and *Schoenbein* in 1840.

Ozone, which exists in small quantities in the atmosphere, may be produced artificially by several methods, the most practical of which is electricity. The effleuve discharge, in air or oxygen, of conductors charged to a high potential is accompanied by a production of ozone.

Berthelot's ozone generator is the one generally used in the laboratory. It consists of a glass tube filled with dilute sulphuric acid, surrounded by a second tube dipping into a shallow vessel filled with the same solution. The space between the two tubes is traversed by a current of air or oxygen. A current from an induction coil is passed through the apparatus, one terminal being connected to the solution in the inner tube, and the other to that in the shallow vessel. Electric discharges occur across the space between the tubes and thus convert part of the oxygen into ozone.

The generators of ozone used in medicine are of three types, the *Houzeau* generator, electrostatic generators, and high frequency generators.

223. **Ozone generators of Houzeau, Labbé, and Oudin.**—All these make use of the discharges from an induction coil for the production of ozone. A glass tube covered with

aluminium foil or aluminium wire, is connected with one terminal of an induction coil. An aluminium rod connected

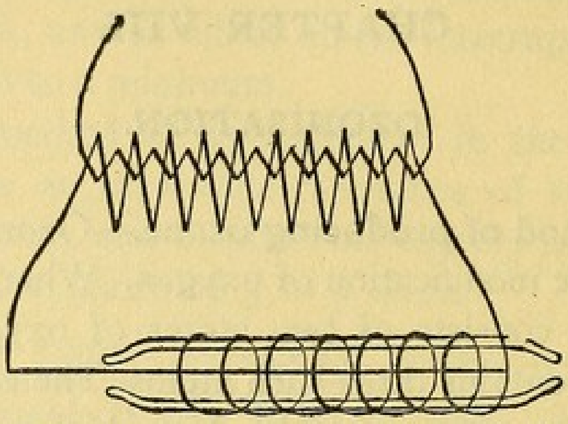


Fig. 41.—Ozone generator, Houzeau-Oudin type.

to the other terminal of the coil passes down the centre of the tube. Aluminium is chosen, since it is less readily oxidisable than most metals.

The output of ozone is very small. *Bordier* has shown that although the presence of ozone can be distinctly recognised by the smell, the amount is so minute as to be practically useless for physiological or therapeutic work.

224. **Electrostatic ozone generators.**—There is a noticeable production of ozone at the poles of an electrostatic machine. *Bordier's* experiments, however, show that with a Wimshurst machine of medium size, only a fraction of a millegramme of ozone is generated in an hour. The same quantity is produced at both poles, and is proportional to the output of the machine.

In *Weill's* electrostatic ozonator a metallic rod furnished with a number of radiating points is enclosed in a barrel-shaped glass vessel. The latter is covered with tin-foil to about three-quarters of its height. A current of air is passed through the vessel.

The central rod is connected to the outer armature of the Leyden jar on the negative pole of a Wimshurst machine. The outer tin-foil covering of the ozonator is earthed, as is also the external armature of the Leyden jar on the positive pole of the static machine. The arrangement, therefore, unites the advantages of electrostatic and of high frequency ozonators.

225. **High frequency ozone-generators.**—*Bordier's* investigations have proved the superiority of high frequency currents for the production of ozone. The effleuve from an Oudin resonator, or from a flat spiral, is used to convert the surounding oxygen into ozone.

When an Oudin resonator is used, it is covered with a glass globe within which the air or oxygen circulates. The more rapid the flow of air through the glass the greater will be the production of ozone. (*Bordier.*) When high fre-

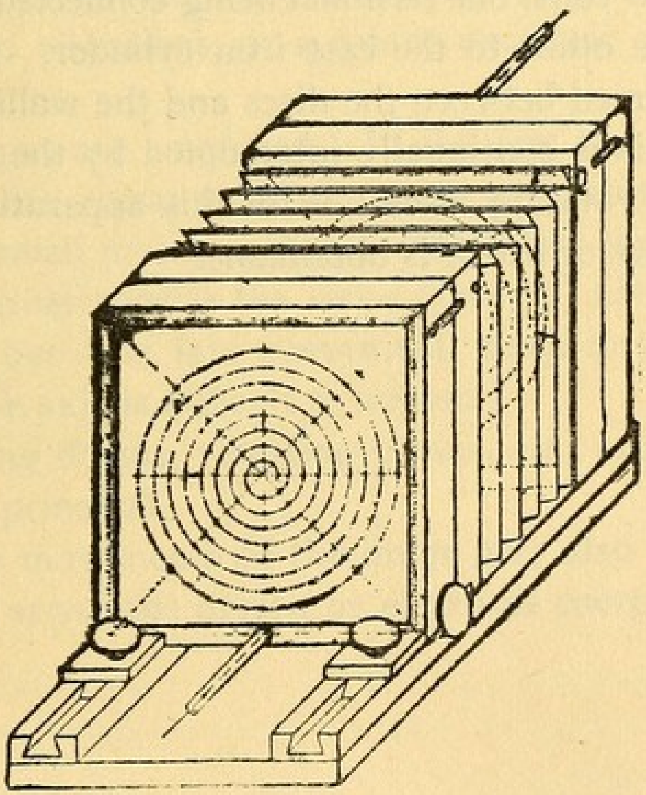


Fig. 42.—Guilleminot's Ozone generator.

quency spirals are used the bipolar arrangement is employed, the coils being enclosed in a box having glass ends and collapsible sides, as in Fig. 42.

The silent effleuve should be used and sparking should be avoided in order to prevent the production of nitrous acid. The nature of the interruptor has a great influence on the efficiency of the apparatus. *Wehnelt's* interruptor, as modified by *Bordier,* gives most excellent results.

226. **Otto's rotary ozone generator.**—At the meeting of the French Society of Civil Engineers in 1901, *Otto* described a rotary ozone generator with movable electrodes. It consists of a cylindrical vessel of cast iron, closed at both ends by plates of glass. Within this vessel a number of thin steel discs with gaps cut in their edges are mounted on an insulated axis.

An alternating current transformer is used, giving a current of 20,000 volts, one terminal being connected to the steel discs and the other to the cast iron cylinder. An arc discharge is formed between the discs and the walls of the cylinder, but this is continually interrupted by the gaps in the edges of the rotating discs. With this apparatus a considerable quantity of ozone is obtainable.

CHAPTER IX.

ELECTRICITY AS A GENERATOR OF MOTION—VIBRATORY MASSAGE—PASSIVE GYMNASTICS, ETC.

227. **Vibrotherapy.**—Electricity is also used to produce the various forms of movement used in vibrotherapy and sismotherapy. The latter term was introduced by *Jayle* and *Lacroix* to designate the mode of treatment by means of an apparatus producing mechanical vibrations. The apparatus consists either of a tuning fork with electrically maintained vibrations, or a rotary excentric vibrator driven by a dynamo.

Two types are employed. In the first the motion is conveyed to the vibrator by means of a flexible axis. In the second a small motor is placed within the vibrator itself.

The former type is the more powerful and more easy to regulate, but it is less convenient, since in many positions the flexible axis is difficult to adjust.

Vibrating drums, vibrating chains, etc., are all worked on the same principal.

Passive movements of the limbs may also be obtained by means of apparatus driven by electrical energy.

CHAPTER X.

PHOTOTHERAPY AND THERMOTHERAPY.

228. **Apparatus.**—In this chapter we shall omit all mention of apparatus in which light or heat are obtained by other than electrical means.

The different varieties of phototherapeutic apparatus are all derived from *Finsen's* original apparatus. In France *Lortet* and *Genoud's* modification of the *Finsen* light is much used. More recently *Marie* has introduced an arrangement which unites the advantages of lightness and convenience with increased power.

229. **The Finsen Light.**—Phototherapy was introduced into medicine by *Prof. Neils R. Finsen,* of Copenhagen, who employed a powerful arc lamp of 50 to 80 amperes at about 50 volts. The voltaic arc is formed by the passage of the current through a small air gap between the extremities of two carbons connected to the terminals of the electric source. The hot air heats the carbons to incandescence, and since the carbons are thus gradually burnt away they must be re-adjusted either by hand or by some automatic process. In *Finsen's* apparatus four condensors are placed around the central arc, each consisting of a telescope with wooden tubes, furnished with lenses of rock crystal. By this means the diverging rays of the electric arc are refracted and condensed into a parallel beam. A current of water is introduced between the two lower lenses in order to arrest the passage of heat and infra-red rays. The telescope is also kept cool by a current of cold water circulating through a sleeve at its lower end.

The parallel beam from the condensor is again cooled by passing through a compressor formed of two discs of rock crystal between which flows a second stream of cold water. This compressor is used not only to cool the tissues by contact, but in order to render them anæmic by pressure. When the blood is thus driven out the luminous rays are found to penetrate deeper into the tissues. When the electric arc is used the lenses should be of rock crystal. With sunlight glass lenses will do equally well. Glass is opaque to all rays less thon 300 μ in length, whereas rock crystal is transparent to shorter wave lengths of 200 μ. The electric arc is rich in ultra-violet rays between 200 μ and 300 μ in length, which are the most potent for therapeutic purposes. Sunlight, on the other hand, has been already deprived of most

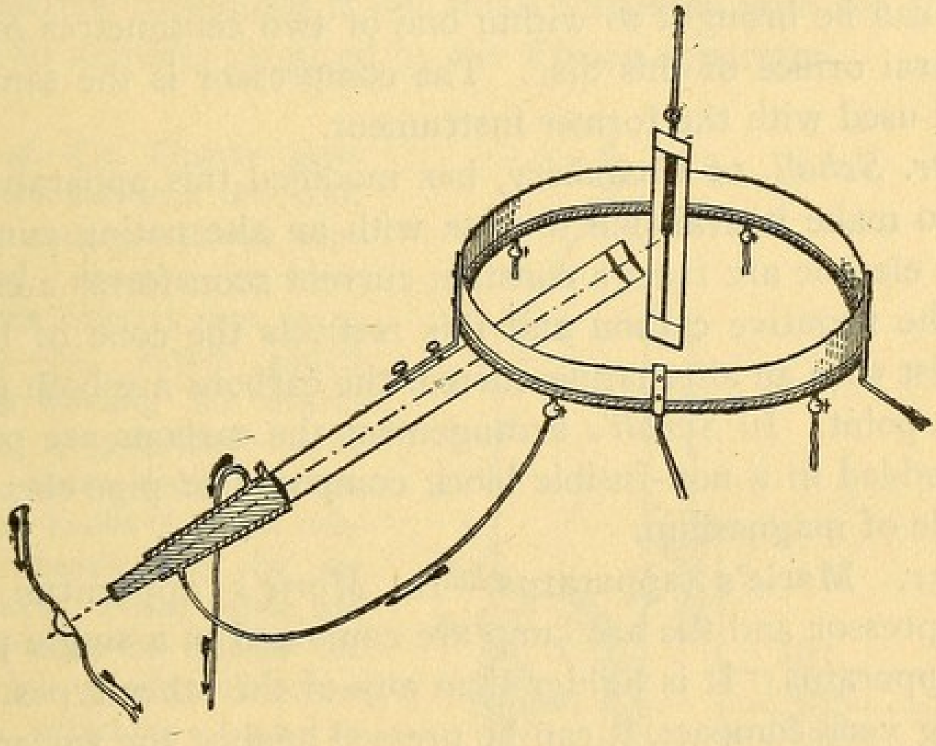


Fig. 43.—Finsen light.

of these short wave vibrations during its passage through the atmosphere, and therefore suffers but little diminution of its efficacy by being passed through lenses of glass.

Finsen's apparatus is very complicated and very expensive. Only a small fraction of the light is available, since the patient is some four or five feet from the source of light, much of which is also lost by absorption and reflection at the surface of the lenses.

230. **Lortet and Genoud's Arc Lamp.**—The first modification constructed by *Lortet* and *Genoud* had an arc lamp enclosed in a lantern. A glass globe filled with cold water served at once to cool and condense the rays and a compressor similar to that used by *Finsen* was employed.

In their second pattern the condensor was omitted. The angle of the carbons is so adjusted that the cone of the rays from the incandescent crater on the positive pole passes through an aperture in a shallow chamber 6 millimetres thick, within which a current of cold water circulates. The arc can be brought to within one or two centimetres of the central orifice of this disc. The compressor is the same as that used with the former instrument.

Dr. Schall, of Chambéry, has modified this apparatus so as to make it available for use with an alternating current. The electric arc from a constant current soon forms a crater in the negative carbon and this restricts the cone of light, whilst with an alternating current the carbons are both worn to a point. In *Schall's* arrangement the carbons are partly imbedded in a non-fusible block composed of pipe-clay and oxide of magnesium.

231. **Marie's apparatus.**—In *Marie's* apparatus the compressor and the arc lamp are combined in a single piece of apparatus. It is lighter than any of the other types, and being very compact, it can be pressed against the surface to be treated with considerable force. It is the simplest, and, in our opinion, the most practical and powerful lamp available at the present time.

The carbons are adjusted by hand, and are enclosed in a case which may be suspended at any height above the patient and attached to the surface to be treated by means of india-rubber bands. A total pressure of nearly 20 pounds may be applied by these bands in order to compress the tissues.

A number of quartz objectives of different sizes are supplied, any of which will fit into the condensor. The water cooling takes place between two quartz plates. The positive carbon is placed perpendicular to the skin, so that the crater may act as a reflector. The negative carbon is smaller, and is placed at right angles to the former, so as not to interfere with the irradiation. (Fig. 44.)

To the clinical advantages of lightness, facility of movement and steady compression, this apparatus adds those of relative cheapness both in initial cost and in upkeep, since the current it requires is but small compared with the 50 or even 80 amperes required by the *Finsen* apparatus.

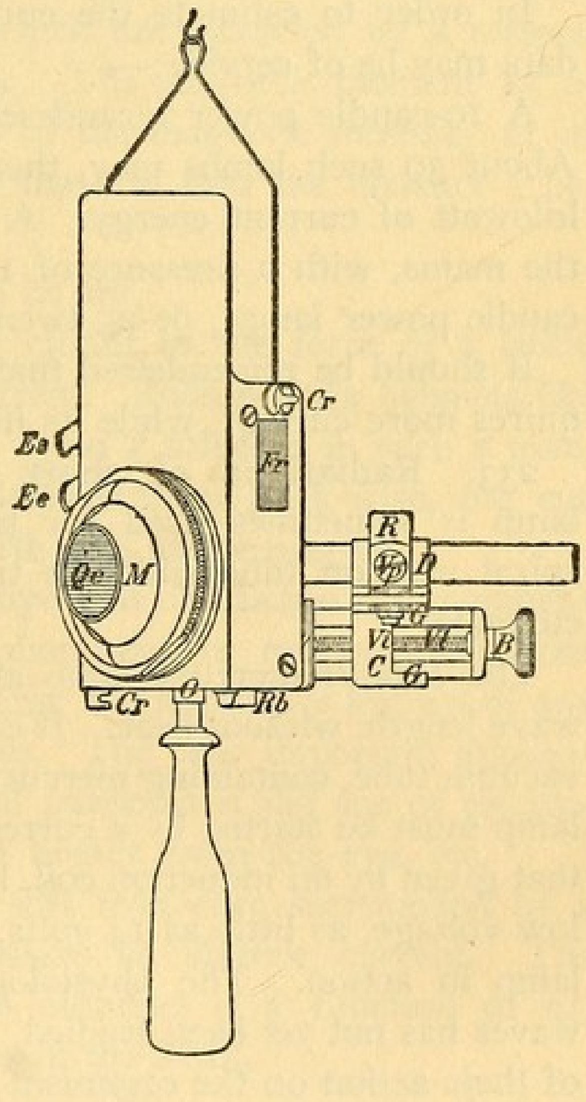


Fig. 44.—Qe. Quartz plate in contact with the skin. Six such plates are supplied, ranging in diameter from 15 mm. to 40 mm.—M, nickel plated ring holding the quartz lens in position.—Ee & Es, water cooling tubes. —Cr, knobs to which rubber bands may be attached. These bands are tightened by means of ratchet wheels.—O, screw for attaching handle when compressor bands cannot be used.—Fr, window of red glass for observing the light.—C, horizontal carrier moved by the screw B.—D, socket for the carbon.—Vp, screw for fixing the carbon.—R, five metallic plates forming radiator to keep the carrier cool.

232. **Heat Baths.—Local applications of heat.**—Heat baths, or light baths, as they are sometimes called, consist of cages of various shapes, supporting some forty or fifty incandescent lamps. The illuminating and heating power, and also the colour of the light, can be varied at will, either by altering the lamp or by a multiple system of lighting. Such baths often require as much as 30 amperes, and therefore care should be taken that the wires and apparatus used are adapted to withstand so large a current.

Small local heat baths are also used. A small cylindrical lamp enclosed in a roller, used after the manner of a laundress' flat iron, is of great service in the treatment of rheumatism and similar affections.

In order to estimate the current required the following data may be of service:—

A 10-candle power incandescent lamp requires 33 watts. About 30 such lamps may, therefore, be supplied for each kilowatt of current energy. A current of 5 amperes from the mains, with a pressure of 110 volts, will supply 50 ten candle power lamps, or 25 twenty candle power lamps.

It should be remembered that as a lamp grows old it requires more current, while its illuminating power decreases.

233. **Radiations of short wave length.**—The *Tesla* lamp is sometimes used for treatment. It consists of a spiral vacuum tube which is traversed by high frequency currents.

The *Hewitt* mercury lamp also gives out light of short wave length, without heat. It consists of a straight or spiral vacuum tube, containing mercury vapour instead of air. The lamp must be started by a current of high potential, such as that given by an induction coil, but once started a current of low voltage, as little as 14 volts, is sufficient to maintain the lamp in action. The physiological effects of these short waves has not yet been studied. A methodical investigation of their action on the organism should be of interest.

CHAPTER XI.

MAGNETS AND ELECTROMAGNETS.

234. **General considerations.**—The general theory of the magnetic flux and of the magnetic field has already been given in par. 101 of this work. The use of magnets and electromagnets in medicine is very restricted.

The north pole of a magnet is that end which points towards the north when the magnet is free to move, as in a compass needle. Bodies which are attracted by a magnet are said to be *paramagnetic*. The magnetic moment m of any magnet is the product of the magnetic intensity of its pole—that is, its magnetic mass m into the distance l between its poles.

$$m = ml.$$

A solenoid is a metallic circuit in the form of a helix, traversed by an electric current. Such a helix behaves like a bar magnet. If we look down a solenoid in such a manner that the current circulates counter-clock-wise, the end nearest to us will be the north pole of the magnet.

235. **Magnets employed in medicine.**—Permanent magnets are occasionally employed in nervous affections such as hysteria and neuralgia, but nothing is known of any physical action in such cases. The only important application of magnets for medical purposes is the use of electromagnets to extract foreign bodies from the eye, etc.

An electro-magnet is a soft iron core surrounded by a solenoid through which passes an electric current. The magneto-motive force thus obtained is a function of nI, the number of ampere-turns in the helix.

Large magnets are required to move even a small spicule of iron at some distance. The magnetic force decreases with the square of the distance, and unless the magnetic mass of the pole is very large, only a very small body can be moved. Hence huge electro-magnets have been constructed, of which that designed by *Haab* may be taken as an example.

236. **Haab's electromagnet.** — This apparatus was primarily devised to extract foreign bodies from the eye. In spite of its great weight, 272 kilos, it can readily be adjusted in any position by means of levers.

It is driven by a continuous current at 110 volts and produces a very strong magnetic field. A piece of iron weighing one gramme, when held 5 millimetres from the magnet, will support a weight of 337 grammes; at a distance of 10 mm. it will support 173 grammes, and at 15 mm. only 105 grammes.

SECOND PART.

PHYSIOLOGY.

237. **General division of the subject.**—The study of the various forms of electric energy used in medicine has already given us some notion of the wide extent of its physiological action. The effects are manifold and vary according to the forms employed. They may, however, be grouped under one or other of the following categories.

1. Physiological effects of the continuous current in its steady state.

2. Physiological effects of the variations of current. This category includes the variable state during the make and break of a galvanic current, the extra current, the faradic current, the sinusoidal and undulatory current, and in general all the electrical conditions which may be grouped under the heading of *the variable state of low frequency and low tension currents.*

3. Physiological effects of currents of high frequency and high tension.

4. Effects of static electricity.

5. Action of the various radiations, caloric, luminous, ultra-violet and the X-rays.

In addition we shall rapidly pass in review the action of ozone, of vibratory massage, and of magnets.

We shall also have a word to say on the electric phenomena having their origin in the action of living tissue. This will appear as an appendix to the article on the continuous current, as the explanation of the phenomena depends on the theory of ions.

CHAPTER I.

PHYSIOLOGICAL ACTION OF THE CONTINUOUS CURRENT IN ITS CONSTANT STATE.

I. Definitions.

238. **General considerations.**—In order to apply the continuous current to the human body, we require the intervention of special appliances termed electrodes (98).

The smaller the surface of the electrode in contact with the skin, the more the lines of electric flux are concentrated in passing through the tissue immediately subjacent to the electrode (Fig. 45).

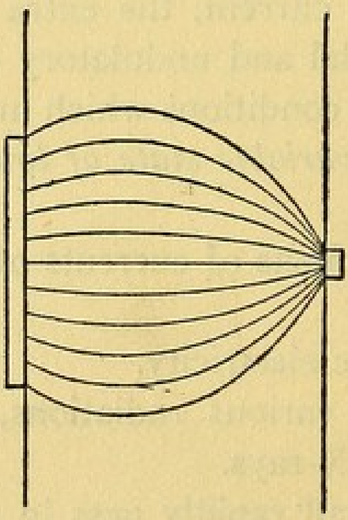


Fig. 45.

When two electrodes are employed, one of large surface and the other of small surface, the former is said to be the *indifferent electrode,* and the latter the *active electrode.*

The terms *anode* and *cathode* are applied to the electrodes connected to the positive and negative poles respectively.

The indifferent electrode usually consists of some spongy substance, such as felt or cotton wool, covered with gauze and moistened either with pure or with salt water.

The active electrode may be either metallic, or of the same nature as the indifferent electrode. A metallic electrode may be made either of some inoxydisable metal such as platinum, which is used in the construction of the hysterometer, or it may be formed of some oxydizable metal chosen for a special purpose. When an active electrode of a spongy nature is used it is usually soaked in pure water, or it may be moistened with various solutions for the production of ionisation or cataphoresis.

239. **Polar action and Interpolar action.**—The action which is set up in the immediate vicinity of the electrode is termed polar action. It differs from ordinary interpolar action in two respects.

1. In its greater intensity, due to the concentration of the lines of flux at the electrode.

2. In the ionic exchanges which occur between the integuments and the electrode. These vary according to the pole employed (250).

240. **Action of the continuous current on the human body.**—The effects of the continuous current on the human body may be placed in two groups.

1. Electric effects, comprising all the physico-chemical phenomena due to the passage of the current, including cataphoresis.

2. Physiological effects due to living tissue, and in particular to the action of the nerves.

II. Physico-chemical action of the constant current.—Electrolysis—Cataphoresis.

241. **General considerations.**—The physico-chemical effects of the passage of a constant current through the living body consist of electrolysis and of cataphoresis.

Electrolysis is the phenomenon of the transport of electric charges through certain solutions which are called electrolytes.

It is one of the most important divisions of medical electricity, since all the liquids of the organism are electrolytic. Cataphoresis is of much less importance and its very existence has been denied. It consists in the transport *en masse* of non-dissociated molecules, either of the solvent or the solute, in the direction of the current.

242. **Electrolysis.**—Electrolysis is the phenomenon which takes place when certain solutions are traversed by a continuous current. The conduction of electricity by solutions differs entirely from the conduction we have studied in the chapters devoted to electrical physics.

There are two modes of conduction for the continuous current. The first is that which is met with in metal conductors. It consists in the propagation of a dynamic state or condition. There is no transport of matter. The state or condition is propagated from one portion of matter to its neighbour by mere continuity or contiguity. This may be termed metallic conduction.

The second mode of conduction is by the transport of matter; conduction by convection. It is characteristic of a certain class of solutions which are called electrolytic.

An electrolytic solution is one in which the solvent by itself is not a conductor of electricity, but becomes so by the solution of certain substances called *electrolytes.*

All soluble substances are not electrolytes. Thus pure water, which by itself is a non-conductor, becomes a conductor when it holds in solution a salt, an acid or a base, whereas it remains a non-conductor when it holds in solution albuminoids, fats, glycerine or sugar. Electrolytes consist only of salts, acids and bases.

The reason for this difference, and the true nature of the phenomenon of electrolysis, has been made clear by a comparison of the osmotic, cryoscopic and tonometric properties of electrolytic and non-electrolytic solutions.

A clear idea of the intimate phenomena of electrolysis is indispensable for a due comprehension of the physico-chemical action of the continuous current on the organism.

243. **Electrolytic solutions—The Theory of Ions.**—The theory of the ionisation of the molecules in solution explains completely all the phenomena of electrolysis. It was observed that solutions have certain properties in common, which vary in intensity according to the strength of the solution. The osmotic pressure, the lowering of the freezing point and the vapour tension are all functions of the *number of molecules* in solution. This law being established, it was noticed that certain solutions formed an exception, *viz.*, solutions of bases, and of salts. On further investigation it was found that this exception was only apparent. The explanation of the anomaly is that the molecule is dissociated in the process of solution, each portion acting as if it were an entire molecule. These dissociated portions of a molecule are called *Ions* (ιωv—ιον travelling).

Conduction by convection thus became comprehensible. The molecules of an electrolyte—a salt, an acid or a base—become dissociated in the process of solution into two ions, which may be either monatomic or polyatomic. One of these ions possesses a positive and the other a negative charge, quite independent of any external electric influence. If now we plunge the two terminals of an electric circuit into such a solution, the electro-negative ions will naturally be carried to the positive pole, and the electro-positive ions will be similarly attracted by the negative pole. The electric current is the product of this procession of charged carriers. This is the electrolytic theory of *Clausius* and *Arrhenius.*

An electrolytic solution may be thus defined. It is the solution in a non-conducting liquid of a substance whose molecules become dissociated during solution into two portions called ions, one the *cathion* carrying a positive charge and moving towards the cathode, the other the *anion* carrying a negative charge and travelling to the anode.

For example, Na Cl by the process of solution is broken up into $\overset{+}{\text{Na}}$ and $\overset{-}{\text{Cl}}$; the cathion Na being attracted to the cathode, and the anion Cl to the anode.

In the same way K_2SO_4 is broken up into an anion, SO_4, and a cathion, K_2. The anion SO_4 is an example of a polyatomic ion.

244. **The Theory of Ions—Constitution of matter—atom—molecule—atomic weight—molecular weight—chemical equivalent—specific heat.**—Matter is an agglomeration of very minute particles called molecules. Each molecule is a complete entity, remaining unaltered whether the substance is in the solid, liquid or gaseous state. We know from *Avogadro's* law that all gases, whatever their nature, will, at the same temperature and pressure, contain the same number of molecules per unit volume.

In the same way all solutions, whatever the nature of solute and of solvent, will at the same temperature and osmotic pressure, contain the same number of dissolved molecules per unit volume (*Pfeffer, de Vries, Van t'Hoff*). These two laws, relating to gases and substances in solution, demonstrate the individuality of the molecule or primitive particle of matter. This particle is indivisible so long as the substance retains its identity, but it may be split up into its consistent elements.

The molecule NaCl, for instance, cannot be divided without destroying the chloride of sodium as a salt. It can, however, be split up into an atom of Na and an atom of Cl. An atom is usually considered the last possible division of matter, but it would seem to be very probable that the atoms themselves are further divisible. Their differences in specific weight and specific heat lead us to believe that each atom is an agglomeration of a certain number of centres of energy, the so-called *electrons* of *Laurenz.* Up to the present time, however, it is impossible to pass beyond the atom without entering into the realm of pure hypothesis.

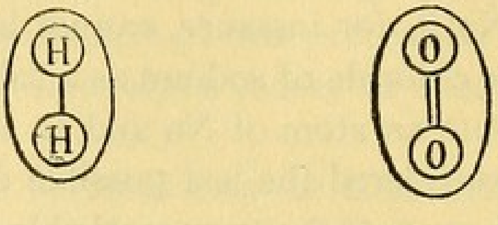
Most elements are composed of molecules consisting of two atoms. The molecule of hydrogen, for example, is composed of two atoms, as is that of oxygen, chlorine and sodium. Mercury and zinc, however, have a monatomic molecule, and under certain conditions selenium has a triatomic molecule.

Elementary atoms in uniting to form molecules obey fixed laws, the most important of which is that of *Valency.*

In order to form a molecule of water, H_2O, we must furnish two atoms of H to satisfy the affinity of one atom of O; whereas to form a molecule of hydrochloric acid, HCl, we only need one atom of Cl. Hence Cl is said to be monovalent, and O is said to be divalent, whereas N is trivalent.

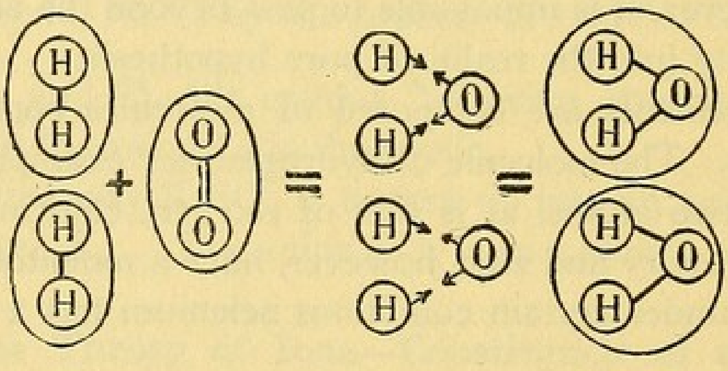
We may conceive that when the molecule of an element such as oxygen is composed of two atoms, these two atoms are united in such a manner that the double valencies of each atom are satisfied.

We may suppose the molecule of an element arranged thus



Molecule of H. Molecule of O.

The combination of these to form a molecule of water may be figured thus



This diagram will enable us to understand the meaning of the term chemical equivalent, as well as atomic and molecular weights.

The *molecular weight* may be deduced directly from the vapour density of a gas. Since under similar conditions a litre of any gas contains the same number of molecules, each molecule must have a weight proportional to the weight of a litre of the gas in question.

In those elements whose molecule is monatomic, the *atomic weight* will be equal to the molecular weight. With diatomic elements the atomic weight will be one-half the molecular weight. The molecular weight of a compound is the sum of the atomic weights of its components. Thus the molecular weight of water, H-O-H, is 18, since the molecule of water contains an atom of oxygen weighing 16, and two atoms of hydrogen, each weighing 1.

Theoretically we may take any one of the constituent atoms out of the molecule of a composite body and replace it by another elementary atom, on condition that we conform to the law of valency. Thus from the composite body H_2SO_4, we may remove two atoms of H, each of which weighs 1, and replace them by two atoms of K, each weighing 39, or by two atoms of Na, each weighing 23. It is evident that the weights 1 of hydrogen, 39 of potassium and 23 of sodium are mutally equivalent, hence these numbers are called the *chemical equivalents* of the elements H, K and Na respectively.

It is a fact of great theoretical importance that the specific heat of a gas is inversely proportional to its molecular weight, or to its vapour density. The heavier the molecule, the less is the quantity of heat required to raise the temperature of a given weight of the substance one degree. Thus one molecule of any substance requires the same amount of heat to raise its temperature one degree.

245. **The Theory of Ions—Electro-chemistry—Theory of solutions.**—It has been seen that molecules are the smallest particles into which a substance can be divided without altering its constitution. These molecules may be further divided into atoms, which are the ultimate particles of matter. The atoms have a definite weight, which is characteristic of each element, and the specific heat of the element is inversely proportional to this atomic weight. A molecule cannot be resolved into its component atoms without satisfying the chemical affinities and valencies of these atoms. Even when we dissociate a molecule such as HCl containing two atoms, we are unable to isolate the atom H or the atom Cl, since the molecule of each of these elements, H_2 and Cl_2 is diatomic.

In electrolytic solutions, that is, solutions of acids, base and salts, a particular form of dissociation takes place. Thus the molecule K_2SO_4 is split up into an acid radicle SO_4 and K_2, each of which acts as a molecule in its osmotic, cryoscopic and tonimetric relations. These two portions are the *ions*. According to the theory of *Arrhenius*, these ions, so long as they carry an electric charge, do not behave as chemical entities. As soon, however, as they lose their electric charge, they become subject to the chemical laws of affinity and valency.

When two electrodes of a circuit are plunged into an electrolytic solution, a current passes. The theory of the origin of this current was not at first understood. In 1845 *Clausius* shewed that a current would pass with a very feeble electromotive force, and thence concluded that the dissociation was not produced by the current. This observation was not destined to bear fruit until the study of osmosis, vapour pressure and the lowering of the freezing point resulted in *Arrhenius'* theory. According to this theory the electromotive force only sorts out the ions which are already separated; and the electric current itself is but the transport of the anions to the anode and of the cathions to the cathode.

The following are the arguments for this theory: Just as the gaseous pressure is a function of the molecular concentration of the gas in a closed space, so the osmotic pressure of a solution is a function of the molecular concentration of the solute. With the same number of molecules in solution, the osmotic pressure is the same whatever the solute, and whatever the solvent. Solutions of acids, bases and salts are an exception to this law; in dilute solutions each molecule is dissociated into two ions, each of which behaves like a molecule. In stronger solutions some of the molecules are dissociated, while others remain intact.

This view is supported by cryoscopy, *i.e.*, the study of the point of congelation. Pure water freezes at 0°, whereas water freezes at a lower temperature if it contains any substance in solution. The lowering of the freezing point is a definite function of the degree of molecular concentration of the solution, so that a knowledge of the freezing point will enable us to determine the number of dissolved molecules in a solution. The study of cryoscopy, like that of osmosis, proves that in a dilute electrolytic solution the molecules of the solute are dissociated, each behaving as two distinct molecules.

246. **Rôle of the ions in electrolytic conduction.**—In dilute electrolytic solutions the molecule of the solute is dissociated into two ions, each acting as a molecule in its osmotic, cryoscopic and tonometric relations. When the molecule breaks up into ions, each ion carries an equal and opposite electric charge.

When the two electrodes of a galvanic circuit are plunged into an electrolytic solution, the ions are attracted according to the laws of static electricity, those possessing a positive charge going to the negative pole, and those possessing a negative charge to the positive pole. On coming into contact with the electrode the ions abandon their charges, and this continual importation of static electric charges constitutes the current itself. This is *Arrhenius'* theory of electrolysis.

As soon as the ions have lost their electric charges they return to their rôle of chemical elements, with chemical affinities, and attack the water or the electrode, according to the ordinary chemical laws. For instance, Na and Cl, as long as they are ions and carry a charge, remain free, but directly they have given up their charges to the electrodes they combine with water to form NaOH and HCl.

The electric resistance of an electrolytic solution is a function of the number and the velocity of the ions engaged in transporting the electric charges.

The velocity with which the ions move varies according to their nature. *Hittorf* has shewn that the velocity of the anions differs from that of the cathions. This may be proved by the following experiment: A solution of sulphate of copper is placed in an electrolytic cell with a porous partition, the solution being identical on both sides of the partition. After passing a current for some time the solution is found to be more concentrated on one side of the partition. The anion SO_4, has travelled faster than the cathion Cu, although the number of ions liberated at the electrodes is the same.

—	SO_4 SO_4 SO_4	SO_4 SO_4 SO_4	+
	Cu Cu Cu	Cu Cu Cu	

Before the passage of the current.

—	SO_4	SO_4 SO_4 SO_4 SO_4 SO_4	+
	Cu Cu Cu Cu	Cu Cu	

After the passage of the current.

The ratio of the degrees of concentration on either side of the porous diaphragm enables us to estimate the relative velocities of the anions and cathions respectively.

The molecules of the solution, or of any dissolved substance except the electrolyte, are obstacles to the passage of the ions, and diminish their velocity. *Leduc's* experiments prove that the rapidity of diffusion in a gelatinous solution varies with its concentration. The velocity of the ions follows the same law; the greater the concentration of the gelatinous solution, the less the velocity of the ions. We must bear in mind, however, that the smaller the traveller the less it is influenced by obstacles, so that the smaller ions are less retarded than the larger complex molecules.

The *mean molecular conductivity* of a liquid is the ratio of its conductivity to the number of molecules in the liquid, the liquid being contained in a cubic cell, one centimetre in length, with the electrodes on two opposite sides. The molecular conductivity increases with the temperature, and also with the degree of dilution of the solution.

Whereas cryscopy indicates the total number of particles in a solution, whether molecules or ions, the electric conductivity enables us to estimate the number of ionized molecules.

247. **Quantity of Electricity carried by the Ions.**—The *gramme molecular weight* of any substance is the molecular weight of that substance expressed in grammes. Since the molecular weight of hydrogen is 2, the gramme molecular weight of a substance is the weight of a quantity of that substance which contains the same number of molecules as 2 grammes of hydrogen. Thus the gramme molecular weight of glycerine is 92 grammes.

The quantity of electricity carried by the ions is 96.537 coulombs per gramme molecular weight set free at the electrodes, for each valency of the ionic radical (*Faraday*). In other words, in order to set free one gramme molecular weight of any radical we require 96.537 coulombs of electrictiy for each valency of that radical.

Thus 35 grammes of chlorine or 23 grammes of sodium will each carry 96.537 coulombs of electricity, since Na and Cl are both monovalent.

248. **Electro-chemical equivalent.**—Since each chemical equivalent E carries 96.537 coulombs, one coulomb is carried by $\frac{E}{96.537}$, which is the electro-chemical equivalent of a substance, or weight required to transport 1 coulomb of electricity. A coulomb of electricity therefore sets free $\frac{1}{96.537}$ of the chemical equivalent of a substance in grammes.

The following are some of the electro-chemical equivalents in milligrammes:

Silver	1.117
Chlorine	.36728
Copper	.32709
Hydrogen	.01038
Iodine	1.313
Lithium	.07268
Mercury	1.37
Oxygen	.08286
Potassium	.40539
Sodium	.23873

By multiplying the electro-chemical equivalent *e* by the number of coulombs passed through an electrolytic solution we obtain at once the total weight of the substance set free.

The number of coulombs is given by It, the product of the intensity of the current by the time.

Thus with a current of .020 amperes passing for 1000 seconds, we have It = 20 coulombs. The weight of mercury carried across by this current will be

$$1.37 \times 20 = 27.4 \text{ milligrammes.}$$

The weight of other substances will be

Iodine	26.26	milligrammes
Lithium	1.4536	"
Copper	6.6	"
Silver	2.234	"
Sodium	4.76	"

249. **Conduction in the living body.**—From the point of view of electric conductivity, the body may be regarded as a number of electrolytes separated by porous diaphragms. These porous partitions, the membranes separating the elements of the various tissues and organs, are the seat of the electrolytic exchanges; the anions going against the current towards the positive pole and the cathions following the current in the opposite direction.

There is thus every reason for the distinction between polar and interpolar action. In the interpolar region there is merely an exchange of ions in the substance of the tissues, whereas in the neighbourhood of the poles, immediately beneath the electrodes, the phenomena are more complex. With electrolytic electrodes there will be an exodus of the ions of the body, and an entrance of the ions of the electrodes.

The liberated ions, in their capacity of chemical elements, produce secondary and tertiary effects (*Bergonié*). The importance of this from a therapeutic point of view is considerable. (251.)

In all observations on the action of electric currents unpolarisable electrodes should be used. Those of *d'Arsonval* are best adapted for local application. They consist of a tube of glass drawn out to a point and filled with normal saline solution, in which is immersed a silver wire coated with chloride of silver.

250. **Polar action in living tissue.**—Polar action falls into two classes, according as the electrode is metallic, *i.e.*, possessing metallic conductivity, or electrolytic. The metallic electrodes may be further divided into oxidisable and non-oxidisable metallic electrodes.

251. **Polar action of non-oxidisable metallic electrodes.**—When the electrode is formed by a substance such as platinum or charcoal, which is not attacked by the chemical bodies set free at the electrodes, we have the following phenomena.

Primary effects.—The anions, hydroxyl (OH), acid or halogen radicals, set free by the electrolytic decomposition of organic liquids, appear at the anode. The alkaline metals, or cathions, appear at the cathode.

Secondary effects.—Both anions and cathions lose their charge by contact with the electrodes, and then act like ordinary chemical elements in a nascent state. The anions act as anhydrides, attacking the tissues, seizing on the hydrogen and setting free the oxygen.

$$2Cl + H_2O = 2HCl + O.$$

The cathions take from the tissues an atom of hydroxyl radicle and liberate hydrogen.

$$2\,Na + 2(H_2O) = 2\,NaOH + H_2$$

Tertiary effects.—The compounds thus formed, HCl and Na OH, for example, act in their turn on the tissues, and behave in the same way as electrolytic solutions of HCl and of Na OH, causing the subsequent effects described by *Bergonié* under the name of tertiary effects.

For this reason a needle electrode should be made of platinum if the needle is positive, so as to do away with the tertiary effects. In certain cases the tertiary effects may be desired, as when we use needles of copper, which is readily attacked, so as to take advantage of the action of the chloride or oxy-chloride of copper formed at the anode.

In the conduction of the current through the body, it is the NaCl that plays the most important rôle. For each coulomb of electricity transported from one electrode to the other, $\frac{1}{96.573}$ of an electro-chemical equivalent of NaCl is electrolysed. Thus for each coulomb .238 gr. of Na and .372 gr. of Cl are set free at the electrodes. The other salts held in solution may be neglected, as they form but an insignificant part of the organic liquids.

By secondary action this .238 grammes of Na and .372 grammes of Cl combine with water to form .412 grammes of NaOH and .383 grammes of HCl.

It is this NaOH and HCl that acts on the tissues, producing at the cathode a soft and feebly contractile clot, the soda clot; while at the anode it produces one that is hard and more retractile, the acid clot.

The negative clot is of greater extent than the positive one, probably in consequence of the greater velocity of the anion OH formed by the action of Na at the cathode (*Guilloz*). If blood be electrolysed by means of two platinum needles, a large hard clot is formed at the anode, while the clot at the cathode is soft and but slightly adherent. The special coagulating power of the positive pole depends on the coagulating effect of Cl on the albumins of the blood. This action may be increased by employing an iron electrode, the chloride of iron thus formed having a strong coagulating power. It is used more particularly in the treatment of aneurism.

252. **Polar action of the oxidisable metallic electrodes**—When the electrode is made of an oxidisable metal, the acids set free at the anode attack the metal, forming salts which act as electrolytes, thus producing the so-called tertiary effects.

253. **Polar action when an electrolytic solution is employed as an electrode.**—The phenomena are somewhat modified when the current is applied by means of a spongy electrode soaked in an electrolytic liquid, or when an electrolytic solution, a foot bath or hand bath for example, is applied.

At the anode there is a stream of anions passing out of the body, while a stream of cathions, furnished by the electrode, traverses the integuments and penetrates into the body.

At the cathode a stream of cathions leaves the body while the anions of the electrode pass into it.

If R represents an acid radicle or halogen, and M a metallic base, the molecule of acid may be represented by the ionic formula $\overset{-}{R}\ \overset{+}{H}$, that of the base in solution by $\overset{+}{M}\ \overset{-}{OH}$, and that of the salt $\overset{-}{R}\ \overset{+}{M}$.

This formula indicates the fact that the cathion of all acids is H, and the anion of all bases is the hydroxyl group OH.

In the neighbourhood of the anode, therefore, the action of all acids will be the same, and will consist in the reduction of the salts of the tissues by hydrogen. $NaCl + H = HCl + Na$. At the cathode, the action of all bases will be the same, consisting in the substitution of hydroxyl for the halogen or acid radicle of the salts of the tissues.

$$NaCl + OH = NaOH + Cl.$$

With a dilute acid or electrolyte, whatever the nature of the acid employed, it is the production of HCl which dominates the action at the anode. With a base, whatever the nature of the base, it is the action of the sodium that is noticeable.

The table on the next page shews the nature of the reaction at the anode and cathode, with acids, bases and salts. (*Leduc* and *Gonzalez Sanchez.*)

254. **Demonstration of the Penetration of the Ions through the Integument.**—*Leduc* proved the penetration of the ions by a classical experiment. He took two rabbits and placed them in series in the same galvanic circuit, the electrodes being applied to the flanks, which had previously been shaved. The current was conducted to the first rabbit by an electrolytic solution containing 2% of sulphate of strychnine, it then passed out by a cathode of pure water, entered the second rabbit by an anode of pure water and passed out by an electrolytic cathode of cyanide of potassium.

A current of 60 to 100 milliamperes was passed, and after a period varying from one to twenty seconds it was observed that the reflexes of the first animal became greatly exaggerated. Tetanic convulsions and death speedily supervened, while the second rabbit suddenly became stiff, fell down senseless and soon died. In the first case the symptoms were those of strychnine intoxication, while in the second they were those of hydrocyanic poisoning.

Acids.

	Anode.			Body.				Cathode.		
Before the current passes.	+H / −R	+H / −R		+Na / −Cl	+Na / −Cl	+Na / −Cl	+Na / −Cl	+H / −R	+H / −R	
After	−R	−R	+H / −Cl	+H / −Cl	+Na / −Cl	+Na / −Cl	+Na / −H	+Na / −H	+H	+H

Bases.

	Anode.			Body.				Cathode.		
Before	+M / −OH	+M / −OH		+Na / −Cl	+Na / −Cl	+Na / −Cl	+Na / −Cl	+M / −OH	+M / −OH	
After	−OH	−OH	+M / −Cl	+M / −Cl	+Na / −Cl	+Na / −Cl	+Na / −OH	+Na / −OH	+M	+M

Salts.

	Anode.			Body.				Cathode.		
Before	+M / −R	+M / −R		+Na / −Cl	+Na / −Cl	+Na / −Cl	+Na / −Cl	+M / −R	+M / −R	
After	−R	−R	+M / −Cl	+M / −Cl	+Na / −Cl	+Na / −Cl	+Na / −R	+Na / −R	+M	+M

If the current was passed in the reverse direction, the strychnine being made the cathode and the cyanide the anode, neither animal was affected in the slightest degree.

This experiment proves the penetration both of the acid cyanide anion and of the basic strychnine cathion, and contraverts the idea that the results are due to ordinary absorption.

Another proof is furnished by the penetration of coloured ions. When a solution of permanganate of potash is used as a cathode, the anion, the permanganic acid radicle, penetrates the skin and colours it, whereas no such result occurs when the permanganate solution is used as an anode. (*Leduc.*)

By examining the urine it is equally easy to demonstrate the penetration of the salicylic anion into the organism.

255. **The Glandular Orifices are the parts by which the ions penetrated the skin.**—The use of coloured ions proves that the glandular orifices are the site of the coloured deposit, and that they are the natural channels by which the ions and the electric current penetrate the body.

256. **Polar effects produced by electrolytic electrodes.**—The polar effects of an electrolytic solution used as an electrode vary according to the nature of the active ion.

The introduction into the skin of each variety of ion is accompanied by a special sensation. The anions Cl, Br and I cause merely a slight sensation of heat, the cathions K and Na provoke a painful, burning sensation, whereas Lithium produces only a slight fomication. Ba, Ca, Mg, Zn, Fe, Cu, As_2, O_3, AsO_4, PO_6 and S are all painful. The ions of the heavy metals Zn and Cu, etc., coagulate albumen and destroy the skin; NH_4, Sn, Au, Pb, Ag are almost painless. The cathion H and the anion OH are exceedingly painful and cause rapid alteration of the skin. (*Leduc* and *Gonzalez Quijano.*)

Usually there is slight redness of the skin, due to vasodilation, disappearing some hours after the application.

This may or may not be accompanied by pruritus. Occasionally the glandular orifices are congested, giving a dotted appearance to the skin, especially with the ions Br, Li, Au, Fe, So_4, S and Mn O_4. The redness or pruritus may remain for some time; in the case of the Calcium ion for as much as 18 days.

257. **Electrical Resistance of the Human body.**—The resistance of the body cannot be satisfactorily compared with that of a metallic conductor. The resistance depends on the degree of polarisation and the number of free ions in the tissues. With electrolytic electrodes, the resistance varies with the greater or less facility with which the ions penetrate the skin. The determination of the resistance of the body is therefore a very complex problem, depending on an analysis of the various phenomena which have an influence on the total resistance.

The following is the order of conductivity of the animal tissues: nerve, blood, muscle, skin, tendon, fat, bone. (*Alt, Schmidt.*)

In consequence of this variation of conductivity the lines of electric flux are unequally distributed in the space between the electrodes, being denser in the tissues with less resistance. It is for this reason that the nerve responds so readily to excitation, even when the electrode is placed at some distance from its point of stimulation.

The blood plays an important rôle in the conductivity of the body. Like the other fluids of the body, it is composed of a solution of electrolytes, salts, acids and bases, and of non-electrolytes, albumens, sugars and fats. When a current is passed through the body, the index of the milliamperemeter rises rapidly, indicating a corresponding diminution in the resistance of the body. This diminution has been shewn to be due to coagulation. Formerly it was supposed to be due to the afflux of blood to the skin at the electrodes. When a moistened electrode is properly applied, the greatest resistance is in the epidermis itself, which offers an obstacle to the passage of the current incomparably greater than that of all the other tissues. On passing the current the skin becomes red, in consequence of the dilatation of the smaller vessels. It was natural to suppose that the diminished resistance was a consequence of this vasodilatation. *Leduc*, however, has shewn that this congestion in the vicinity of the electrodes does not modify the resistance of the skin, and that the phenomena of ionisation are quite sufficient to explain the fall in the curve of resistance.

258. **Modification in the resistance of the body caused by polarisation of the tissues.**—By suitable precautions we may obviate the polarisation of the electrodes, which seriously affects the resistance of the body. There is, however, another polarisation which cannot be avoided, *viz.*, that which is produced in the substance of the tissues themselves. *Weiss* has devised the following arrangement for measuring this internal polarisation.

The hands of the patient are immersed in two separate vessels, each containing a saline solution in communication with the pole of a battery. By means of a key, the battery can be suddenly cut out, and the two vessels placed in communication with the armatures of a condenser, one of which is earthed. The condenser will take a charge proportional to the electromotive force of polarisation, and this charge may be measured by a ballistic galvanometer.

In this way *Weiss* found a potential of .2 to .25 volts, due to polarisation of the tissues of the body.

259. **Practical method of measuring the electrical resistance of the body.**—The importance of this measurement in electro-physiology and in electro-diagnosis is so great, and the errors in its estimation have been so enor-

mous, that it will be well to study the methods of operation somewhat in detail.

We may measure the resistance to the galvanic or to the faradic current. With the galvanic current we may employ *Weiss'* procedure by means of the Wheatstone Bridge, *Mergier's* by means of the Ohm-meter, or *Bergonié's* method as modified by *Bordier.*

260. **Weiss' Wheatstone Bridge method of measuring the resistance of the human body.**—This arrangement is shewn in Fig. 46. The hands or the feet of the subject are

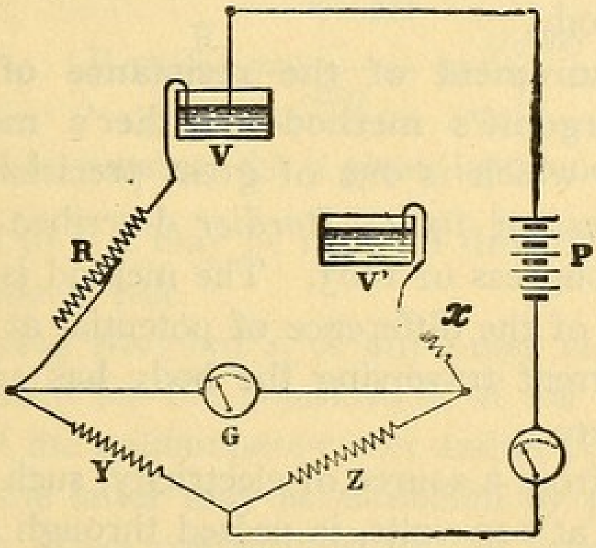


Fig. 46.

immersed in the vessels V and V'. The patient, VV', and a resistance of 500 ohms, X, are introduced into one of the upper arms of the Wheatstone Bridge, a rheostat, R, being interposed in the opposite arm. In the two lower arms are two resistances, Y and Z, each of 50 ohms. In order that the galvanometer, G, may mark zero, the resistance, R, must balance the resistance X, plus that of the patient. The resistance of the patient will therefore be R-X. Polarisation phenomena at the electrodes are equal on the two sides. The polarisation of the deeper tissues may be measured by the method already described in par. 258.

261. **Measurement of the Resistance of the body by means of the Ohm-Meter** (*Mergier*).—Two separate coils of wire are wound on two cards placed at right angles to one another. These are joined up in parallel, and connected to the poles of a galvanic battery. When these movable coils are hung up in a magnetic field, the equilibrium of the whole will vary according as the intensity of the galvanic current is greater in one or the other circuit. The resistance to be measured is introduced into one of the circuits, and a rheostat in the other. The apparatus may be graduated empirically by inserting known resistances in place of the body.

262. **Measurement of the resistance of the human body by Bergonié's method—Bordier's modification.**—This method, which is one of great precision, was shewn at the Congress of 1902. *Bordier* described his modification at the Congress of 1903. The method is based on the measurement of the difference of potential at the terminals when the current traversing the body has an intensity of one milliampere.

A current from a source of electricity, such as a constant current main at 110 volts, is passed through a circuit consisting of a fixed resistance of 50 ohms and the variable resistance of a rheostat. This latter is regulated until the amperemeter included in the circuit indicates exactly 1 ampere. When 1 ampere of current passes, we know from Ohm's law that the difference of potential between the ends of the fixed resistance must be 50 volts, since the resistance is 50 ohms.

This fixed resistance of 50 ohms is composed of a nickel wire of length L stretched along a millimeter rule. The body whose resistance is to be measured is introduced into a shunt circuit in parallel with a part or the whole of this wire. For this purpose one electrode is attached to the extremity of the wire and the other to a movable key sliding along the millimetre scale. A milliampere-meter reading to $\frac{1}{10}$ milliampere is included in this circuit.

The sliding key is now adjusted until the current registered in the shunt circuit is exactly 1 milliampere. Let the distance on the scale between the points of attachment of the electrodes be *l*. The difference of potential between these points will be $\frac{50v}{L} \times l$ volts. The resistance of the patient's body may be calculated from *Ohm's* law

$$R = \frac{E}{C} = \frac{\frac{50}{L} \times l}{.001} = \frac{50000}{L} \times l.$$

$\frac{50000}{L}$ will be constant for a given instrument. Since R is proportional to *l*, it may be read off directly from the scale on the millimetre rule.

In employing *Bergonié's*, or any other method, we must make allowance for the polarisation of the tissues and the resistance of the milliampere-meter and electrodes. The resistance of the latter may be estimated by placing the two electrodes in direct contact without the intervention of the body. It should be remembered that the resistance of the body varies for the first few seconds after the current is turned on. This variation is due to progressive ionisation at the electrodes. Finally the resistance of the epidermis varies with the region to which the electrode is applied. It varies also considerably in different subjects quite independently of any pathological condition.

263. **Measurement of the resistance of the human body by means of the Faradic current.**—For the completion of this subject we will now proceed to describe a

method of measuring the resistance of the body, based on the use of the faradic current. Clinically, the results so obtained shew marked divergencies from those obtained when using the galvanic current. The simplest method is that adopted by *Bergonié*.

One branch of the faradic current passes through the body whose resistance is to be measured, and the other through a regulating rheostat, both circuits being connected to a differential telephone. No sound will be heard in the telephone when the resistances of the two circuits are equal. The only thing required, therefore, is to alter the resistance of the rheostat until all sound in the telephone ceases. *Bergonié* employs a liquid rheostat graduated in ohms.

The study of the resistance of the human body to the faradic current shews that there is no diminution of resistance during the course of the experiment, such as we find when continuous currents are employed. With the faradic current the phenomena due to ionisation and congestion are reduced to a minimum.

264. **Electrolytic resistance of the fluids of the body.** —The ions are the carriers of the electric current through the blood and the other electrolytic liquids of the body. The conductivity of these liquids is therefore a function of the number and velocity of the ions. In fluids containing dissolved substances other than electrolytes, the non-ionised molecules act merely as obstacles to the motion of the ions. Hence gelatinous electrolytic solutions are not such good conductors as pure solutions. One gramme of hæmoglobin added to 99 grammes of serum reduces its conductivity by .8 per cent (*Stewart*), whilst 1 per cent of albumen reduces the conductivity of serum by 2.5% (*Tangl* and *Burgasky*).

The recent experiments of *Leduc* of Nantes have completely elucidated the influence of the non-electrolytic molecules on the velocity of diffusion of the ions. Further, in a gelatinous solution of given concentration, all ions have not the same velocity. Just as the smaller vehicles can worm their way more quickly through a crowd of large obstacles, so the small ions of simple structure can travel faster through the obstacles formed by the presence of the gelatinous molecules, than can the large complex ions. (*Leduc.*)

The same consideration explains why the blood becomes a better conductor when its temperature is raised; the ions have greater freedom of movement when the atoms of the conductor are further apart.

The conductivity of ox blood serum at 25° Centigrade is the same as that of a .7 per cent solution of chloride of sodium. The conductivity varies slightly in different subjects (*Oker-Blom.*)

265. **Influence of the ions of the liquid electrode on the resistance of the body.**—The difference of conductivity due to various ions may be measured by using a small electrode of 10 to 12 square centimetres area, soaked in the solution we desire to investigate; a large indifferent electrode being applied to a distant part of the body. It may thus be shewn that each variety of ion has a characteristic curve of conductivity. A description of the interesting experiments of *Leduc* and of *Gonzalez Quijano* on this subject may be found in the thesis published by the latter in Paris in 1902.

The resistance of the human body depends chiefly on the nature of the mobile ions which enter the tissues. For instance, with the same electrodes, we may get a resistance of 700 ohms when chlorine is the active ion, and of 4000 ohms when the active ion is quinine. These numbers were obtained by *Leduc* when using a solution of hydroclorate of quinine as active electrode. The active ion was chlorine or quinine, according as this solution was made the cathode or the anode.

Leduc's investigations have had an enormous effect on clinical electrology. Previous to this the application of the measurement of resistance to electro-diagnosis was of the vaguest character. It was indeed known that in exophthalmic goitre the electrical resistance was diminished, while it was increased in certain mental and nervous affections, becoming normal as the disease disappeared. When, however, it was desired to obtain definite measurements, and to compare the work of different observers, no adequate data were forthcoming. This is not to be wondered at when we consider that the older observers reported neither the size of the electrodes nor the voltage, nor the part of the body explored, and that the whole apparatus used consisted usually of a voltmeter and an amperemeter.

266. **The Interpretation of the measurements of resistance of the human body.**—The resistance of the body is a function of the resistance of the skin, and more especially of the epidermis. The electric resistance is principally determined by the ionic state of the tissue traversed by the current. The diminution of the resistance is due to the penetration of the ions into the skin, and not to the saturation of the skin by the liquid of the electrode, nor to the increased vascularity of the integument.

The following are *Leduc's* reasons for this assertion:

(a) The conductivity differs according to the nature of the active ion.

(b) The resistance is not modified by liquid impregnation of the skin when once the electrode is in good contact. This may be proved by the following experiment. The two electrodes being in position, the galvanic current from a large accumulator is turned on just long enough to enable one to read the milliamperemeter. If this operation is repeated at longer or shorter intervals, we find that the current intensity remains the same, although the skin becomes more and more saturated. With high voltages a slight difference may be noted, but this is due to the phenomena of ionisation during the time the current is turned on.

(c) The vascularity of the skin has no effect on the resistance. This may be proved in the following way. The patient is placed in a galvanic circuit, so that one of the electrodes, consisting of a saline hand bath at 50°, may be instantaneously replaced by a similar bath at 0°. The conductance of the system does not alter, showing that the resistance of the skin is not affected by any amount of vaso-dilatation due to heat.

Leduc proves this in another way. A small anode, impregnated with a solution of chlorhydrate of adrenalin, is applied to the skin, the large cathode being soaked in a solution of KCl. Under the influence of the current the skin becomes blanched, but the resistance, instead of being increased, is rapidly diminished.

The following is a summary of the facts relative to the resistance of the body to a continuous current.

The resistance of the whole body, and more especially of the skin, depends on the degree of ionisation.

The resistance diminishes as the skin becomes ionised. The degree of vascularity has hardly any influence on resistance.

As long as ionisation is not complete, the resistance of the body is variable, and decreases with the length of time the current has been passing.

All measurements are useless which do not take into account the curve of ionisation.

Each variety of ion has its characteristic curve. This curve varies with the subject and with the voltage, since ionisation occurs more rapidly with high voltages.

The following is *Leduc's* technique for measuring the resistance:[1] The indifferent electrode is formed of eight thicknesses of absorbent cotton wool, 20 cm. by 10 cm. This is soaked in a one per cent solution of KCl, this liquid being chosen because the conductivity due to the K ion and the Cl ion is the same. The moistened lint is rolled around the calf of the leg, and covered by a sheet of lead foil and a metal plate. The metal plate is attached to the rheophore and the whole is kept in place by a bandage. The smaller electrode is formed of eight thicknesses of absorbent lint impregnated with the solution it is desired to investigate. This is covered by a metallic disc and fastened to the front of the forearm by an elastic band. The E.M.F. of the current used should be 6 volts.

Such then is the present state of the inquiry into the electrical resistance of the human body. From the clinical point of view the investigation must be commenced afresh. The scope of electro-diagnosis will be vastly extended when, for any given pathological condition, we can determine the characteristic curve of conductivity for each variety of ion. *Leduc's* experiments have not as yet given us the absolute resistance, but we hope it will shortly be possible to construct the absolute ohmic curve of the human body.

267. **Application of electrolysis for the transport of medicaments.**—Treatment by electrolytic transport has taken an important place in medicine since *Prof. Bouchard's* work drew attention to this method of local treatment, which brings the medicament to the spot where it is most wanted. It was first mentioned by *Palaprat* in 1833, then

[1] Archives d'Electricité Médicale, Jan. 25, 1904.

by *Bruns* in 1870, by *Munch* in 1873, *Lauret* in 1885, *Gärtner* in 1884, and *Wagner* in 1886. Since 1890 it has been taken up by a number of investigators. *Edison* experimented with lithine, *Aubert* with pilocarpine and *Labatut, Weiss, Guilloz, Leduc* and *Frankenhaüser* with various other solutions.

The recent work of *Leduc* and *Gonzalez Quijano* has brought together the results of previous experimentors.

As long as due precautions are taken the mode of operation is simple and certain. The instrument consists of the ordinary apparatus for the application of the continuous current. The electrodes are the ordinary electrolytic foot-baths or hand-baths, or pads of cotton wool or other spongy tissue impregnated with a solution of the electrolyte.

When we desire to act locally, avoiding as far as possible the dissemination of the active ions through the organism, the skin under the electrode should be compressed, so as to cause anæmia and reduce the circulation of blood at the point of treatment to a minimum. Under these conditions, however, the skin just around the electrodes, which is not compressed, is the better conductor. The lines of force are therefore denser and the transport of ions greater at the periphery. It is therefore advisable to place a sheet of gutta-percha, with a central aperture for the application of the electrode, on the region to be treated. The edge of this aperture may be thickened, so as to press with greater force on the subjacent tissues and thus concentrate the lines of force in the central region. The solutions vary in strength, from one to three per cent being usually employed. The degree of concentration of the solution has no effect on the ionic penetration. The number of ions carried into the body depends merely on the number of coulombs passed through the electrode.

268. **Cataphoresis.**—If an electric current is passed through the liquid in two vessels united by a capillary tube or a porous membrane, there is a transport of the liquid *en masse* in the direction of the current; the liquid passing from the positive vessel into the negative vessel. This phenomenon is termed *Cataphoresis.*

In certain cases there appears to be a transport from the cathode to the anode, or *anaphoresis.* Thus, according to *Lindner* and *Picton,* certain colloidal substances are subject to anaphoresis. Hydrate of iron, silver hydrate, and oxyhæmoglobin are transported towards the anode, whereas aniline blue and sulphide of arsenic are carried towards the cathode. In general, bases are subject to cataphoresis, acids to anaphoresis. Probably, when we understand the phenomenon better, we shall find that both cataphoresis and anaphoresis are due to the transport of ions.

We sometimes meet with a physiological phenomenon due to cataphoresis. If the circulation in a limb is interrupted, and the limb is submitted to the action of the continuous current, a portion of the organic liquids is transported *en masse* from the anode to the cathode, hence the region under the anode shrinks and shrivels up, whilst that under the cathode swells up and becomes œdematous.

The phenomenon is not so marked if the circulation is not interrupted, as the circulation continually compensates the transport of liquid due to cataphoresis.

III. Physiological Effects of the Continuous Current.

269. **General Considerations.**—Besides its physico-chemical action, the galvanic current produces certain physiological effects on living nervous tissue. We cannot separate these physiological effects from the phenomena of ionisation. Ionic phenomena are of the very essence of the current, and the effect on the nerves is but a consequence of these ionic changes.

270. **Sensory Effects.**—There is a special sensation accompanying the passage of a current. According to *Volta's* expression, it is a "burning pricking," becoming more violent as the current rises in intensity. The sensation differs at the two poles, as might be expected from the different electro-chemical effects.

At the negative pole the sensation is deeper and more painful. Each pole moreover produces a sensation *sui generis*, which cannot be defined in words, but can be easily recognised after once experiencing it. The electric sensation is attenuated with time, so that by increasing it gradually patients are able to bear a current which would have been extremely painful at the commencement of the sitting.

271. **Action of the continuous current on motor and sensitive excitation—Electrotonus.**—We are obliged to consider here a phenomenon which would come more naturally in the chapter on the variable electric state. Both sensory and motor nerves respond to excitations of the variable electric state, whether galvanic or faradic, alternating or undulatory. This excitation obeys certain laws which we shall study presently. What interests us here is the fact that the continuous current introduces a profound modification into the reaction of the nerve to excitations of the variable state.

This modification in the condition of a nerve while carrying an electric current is called *electrotonus*. Before studying it, it may be well to recall the modern theory of the constitution of the nervous system, the theory of the *neurone*.

272. **Theory of the Neurone.**—The neurone is the fundamental element of the nervous system, the nerve cell with all its prolongations. These prolongations are of two sorts.

1. *Protoplasmic prolongations,* cellulipetal prolongations conducting nervous impulses from their extremities towards the cell. They are terminated by arborisations which are called dendrites.

2. *The axis cylinder or axone,* the cellulifugal prolongation, conducting the nervous flux away from the cell towards the extremity of the axone.

In studying the function of the neurone we have to consider two separate arcs.

1. The reflex arc pure and simple, which deals only with an external excitation followed by movement. This arc consists of two peripheral neurones, without any participation of the nerve centres.

2. The central arc, which sets in action the neurones of the central nervous system.

We shall see further on the importance of this distinction,

1. *Simple Reflex Arc.*—The simple reflex circuit consists of two peripheral neurones, the sensory neurone and the motor neurone. Each neurone is in direct communication with the external world, one by means of its protoplasmic prolongations, the other by means of its axis cylinder. The cells of the sensory neurones are found in the ganglions on the posterior roots of the spinal nerves. The cells of the motor neurones are found in the anterior cornua of the spinal cord.

The dendrites of the motor neurones interlace with the arborisation of the axis cylinder of the sensory neurone. There is no anastomosis, as was at one time believed to be the case.

2. *Central Arc.*—Fig. 47 is a diagram of the central nervous mechanism. A B H G is the simple reflex arc. The impression is received at K, a sensory organ, at the extremity of the sensory nerve, and translated immediately

into motion at i, a muscle at the extremity of the motor nerve. Let us now add a branch circuit M L, so that part of the nervous flux along G may pass through M to a sensory neurone in the central nervous system, from thence to a central motor neurone, and return through L to the dendrites of B. A number of such branch circuits will represent the central nervous system. These derived circuits are of different kinds, according to the position of the neurones which constitute them. They are termed *central neurones,* in contra-distinction to the peripheric neurones which are in immediate relation with the external environment. Thus there is a cerebellar circuit, and a cerebral circuit. The cerebral circuit in its simplest form is composed of a central sensory neurone and a central motor neurone, the cells of the former being situated in one of the nuclei of *Goll* and *Burdach,* those of the latter in the pyramidal psychomotor area of the cerebrum.

There are other circuits in the central nervous system derived from the central circuits. These consist of neurones of association, which are found in the grey matter of the cerebrum and cerebellum.

The rôle of the cell-body of the neurone is that of a trophic centre.

According to *Morat,* the nervous influx is not elaborated at the site of the cell itself, but at the junction of the dendrites of a neurone with the aborisation of neighbouring neurones. The part played by this synapsis, or by the cell itself, in the production of nervous action, is not as yet fully determined.

When a nerve is divided, the peripheric end degenerates: the so-called Wallerian degeneration. If the section is made through the posterior nerve roots between the ganglion and the cord, the axis-cylinder ED which is cut off from its cell degenerates. If on the other hand the section is made at G, the sensory nerve G K degenerates. The sensory nerves have their trophic centres in the spinal ganglia, and the motor nerves in the anterior cornua.

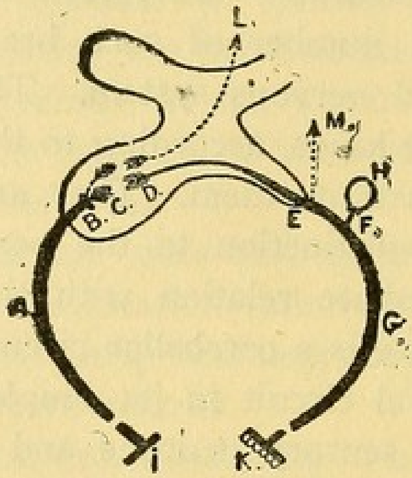


Fig. 47.—A, Cellulifugal axis cylinder of a peripheral motor neurone. —B, Cell of the motor neurone in the anterior cornua.—C, Dendrites of the motor neurone.—D, Arborisation of the axis-cylinder of the sensory neurone.—E, Cellulifugal axis-cylinder of the sensory neurone.—H, Cell of the peripheral sensory neurone in the posterior spinal ganglion.—I, Muscle.—K, Epithelium.—M, L, Branch central circuit.

273. **Normal function of the Neurone.**—1. During the period of repose there is formed in the cell-body of the neurone a substance which, on account of its avidity for colouring matters, has been termed *Chromophil.* When the neurone is submitted to functional excitation the Chromophil is used up and disappears. This exhaustion of the Chromophil occurs whether the excitation is normal or experimental, as under the stimulus of the variable electrical state. The Chromophil therefore appears to be a substance which is kept in reserve for the supply of nervous energy. On awakening in the morning the cells of the nerve centres are found to be charged with Chromophil, while it almost entirely disappears after the day's work.

2. Phenomena of great importance occur where the neurones articulate one with another, *i.e.*, at the synapsis of the dendrites of one neurone with the aborisation of the axis-cylinders of another neurone. The terminal filaments of the dendrites and of the aborisations are endowed with amœboid movements.

The labours of *Mlle. Stefanowska* and of *Oudier* have proved this amœboid movement beyond the reach of doubt.

It has been found, moreover, that when the peripheral neurones are subjected to prolonged faradisation, their prolongations retract and disappear within the body of the cell.

274. **Structure of the Nerve.**—The nerve is composed of a bundle of nervous filaments, cellulipetal or cellulifugal prolongations of the neurone. This nervous filament, formerely called the axis-cylinder, is surrounded by a sheath of myelin and an external membrane, the white substance of *Schwann.* The nervous filaments are grouped into bundles united by connective tissues, the neurilemma, in which run the nutrition vessels of the nerve.

275. **Function of the Nerve.**—The principal rôle of the nerve is that of conduction. The nervous filaments may be compared to multiple insulated electric conductors.

The velocity of conduction of the nervous flux along a nerve is some 30 to 60 metres per second. We must not conclude from the difference of velocity of the nervous flux and of an electric current that there is no analogy between the two phenomena. The propagation of electricity through non-metallic conductors is often extremely slow.

Anatomically, the nerves are divided into motor, sensory and mixed. To these must be added nerves of special function such as secretory nerves.

A nerve may be composed entirely of cellulifugal or of cellulipetal fibres, or it may contain a mixture of the two. A nerve filament possesses no special conductivity for a special sensation, or a special nervous influx. Its connection with the nerve centre alone determines the functional specialisation of a nerve fibre. Moreover, the nerve centres themselves are not exclusively specialised for one definite function. An organ which has been specialised by habit for a given function may take on another function. The equilibrium of the organism is such that this mutation of function may frequently occur, to the great profit of the general economy.

Although the topography of the various nervous territories, whether motor or sensory, is mapped out for us in our works of anatomy, we must remember that their boundaries are far from being well defined. In consequence of anastomosis between different nerves, especially at their terminal plexus, each nerve includes fibres belonging to an adjacent territory. In this way may be explained the persistence of sensibility or mobility in a territory whose nerve has been divided, and also the occasional rapid restoration of its functions, although the regeneration of the nerve trunk is not complete for many months.

276. **Electrotonus.**—When a nerve is submitted to the action of a constant current, it becomes the area of various phenomena which are united under the name of electrotonus.[1]

Electrotonus comprises two distinct phenomena.

1. Electrotonic currents. According to some authorities, the formation of electrotonic currents is a purely physical phenomenon, whilst others regard it as entirely physiological.

[1] According to Wiazemsky, it was not du Bois-Reymond who discovered electrotonus. The true discoverers were the French physiologists, Longet and Gerard, who gave at the same time the theory of the phenomena. (Soc. des Natur. de Moscow, Dec., 1900, Archives d'Electricité Médicale, April, 1902.)

2. The modification of the phenomena of excitation of a nerve while traversed by an electric current.

277. **Electrotonic Currents — Anelectrotonus — Cathelectrotonus.**—Let A B, Fig. 48, be a nerve, of which a segment a b is galvanised by means of polarisable electrodes. If two unpolarisable electrodes be placed at a' and b' and connected by a wire passing through a galvanometer, it will be found that there is a current passing through a' b' in the same direction as that through a b. In the same way it may be demonstrated that there is a similar current passing through a" b". These currents are called electrotonic

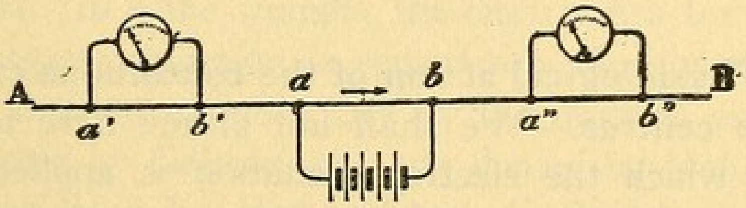


Fig. 48.

currents. The cathelectrotonic current a" b", on the segment of the nerve below the cathode, is stronger than the anelectrotonic current, a' b', on the segment of the nerve above the anode. When the current of excitation is suddenly broken, the electrotonic currents are reversed for a moment and then cease.

278. **Modification of the excitability of a nerve in a state of Electrotonus.**—In the nerve A B in Fig. 48, it is found that the portion a" b" in a state of cathelectrotonus is more irritable than the portion a' b' which is in a state of anelectrotonus. As long as the current flows through a b, the excitations of the variable state are stronger on the side of the cathode than on that of the anode. In the region of cathelectrotonus, a stimulus *less* than the minimum normal stimulus is sufficient to cause excitation, either

sensory or motor, whereas in the region of anelectrotonus a stimulus *greater* than the minimum normal stimulus is required in order to produce any response.

279. **Nature of Electrotonus.**—The nature of these phenomena is still under discussion. One view is that electrotonic currents are purely physical, the condition of the nerve being similar to that of a platinum wire plunged in an electrolytic solution. (*Herman, Mateucci.*) On the other hand *du Bois-Reymond* regards the phenomena of electrotonus as inseparable from the vital properties of the nerve. We shall return to this question when we come to consider the phenomena of auto-electricity produced by living cells.

280. **Physiological action of the continuous current on the nerve centres.**—We shall not allude here to experiments in which the electric excitation is applied directly to the cerebral cortex. The results of these experiments are due to the action of the variable electrical state, as evidenced by contraction of various muscular groups, which correspond with the precise cortical area which is stimulated.

Mediate galvanisation of the cerebrum is carried out by applying large electrodes to the forehead, temporal regions and neck. When a current is passed with an electrode on each temporal region, there is a sensation of vertigo. The subject seems drawn towards the cathode, and in order to oppose the sensation leans to the side. When the anode is placed on the forehead and an indifferent electrode on the neck or body, the patient experiences an increase of intellectual lucidity, whereas if the frontal electrode is a cathode, there is a sensation of somnolence. (*Leduc.*)

APPENDIX.

Electric Phenomena proper to living tissue. Animal Electrogenesis.

281. **General Considerations.**—Just as in the inorganic world, alteration of molecular energy is manifested by electric phenomena, so in the living organism the work of the cell is accompanied by a production of electricity.

This production of electricity, which is very slight under ordinary circumstances, may occasionally attain considerable proportions. In some animals, the electric fish for example, this electrogenic function is remarkably developed.

The production of electricity by the muscles and nerves was suspected by *Galvani,* but was denied by *Volta;* it was further elucidated by *Matteuci* and *du Bois-Reymond.* It was, however, as a result of *Lippmann's* experiments on electro-capillarity that *d'Arsonval* was able to build up his theory of animal electrogenesis.

The production of electricity by muscles and nerves may be studied under two conditions, with the tissues in a state of action and in a state of repose.

282. **Auto-Electric Phenomena of muscle in a state of repose.**—I. If we test a portion of a cylindrical muscle, bounded at either end by a section at right angles to its length, we shall find the following electrical conditions:

1. Any point of its external longitudinal surface is positive when compared with any point of the transverse sections. If by means of unpolarisable electrodes we connect any point on the longitudinal surface with any point on the transverse section, there will be a current through the wire from the surface to the section.

2. The positive potential of the external longitudinal surface becomes higher as we approach the middle of the muscle. On the transverse section the point becomes more electro-negative as we approach to the centre of the section.

II. If the sections at the ends of the cylindrical muscle are oblique, instead of at right angles to its axis, the maximum positive potential will be found at the obtuse angle, while the most electro-negative region will be at the acute angle. The gastrocnemius muscle of the frog has this rhomboidal form, the insertion of the muscular fibres into the tendon forming the oblique transverse section. Hence there is always a great difference of potential between the oblique and the acute angle. This muscle is very convenient for demonstrating the difference of potential, since whatever points of the muscle are joined up a current is produced.

III. The difference of potential between different points of a muscle explains the contractions which result when any two non-equipotential portions of a muscle are joined up. This may be done by a metallic conductor, as in *Galvani's* experiment, or by another muscle, or by immersion in a liquid conductor.

IV. The electromotive force of a muscle, *i.e.*, the difference of potential between the positive and negative areas, may be some hundredths of a volt (.03 to .07 volt).

283. **Auto-electric Phenomena of the nerve in repose.**—In a state of repose the nerve presents the same currents as the muscle. These are, however, more feeble, and on account of its small size it is difficult to demonstrate the difference of potential between points on the transverse section of a nerve.

1. For a nerve, as for a muscle, there exists a difference of potential between the longitudinal surface, which is positive, and the transverse section, which is negative.

2. In a nerve, as in a muscle, the potential increases as we approach the middle point of the segment.

3. In the nerve there is an additional current, *the axial current,* which is shewn when any two transverse sections of the nerve are joined by a conductor. This axial current in a centrifugal nerve is *ascending,* whereas it is *descending* in the case of a centripetal nerve. The axial current is therefore in the opposite direction to the physiological nervous flux. The axial current is also more intense in the more important nerves, as for instance, the vagus, in which the electromotive force is considerable. (*Mendelssohn.*)

These currents of repose are found in all nerves, in those without as well as those with a myelin sheath, although in the former they are much more feeble.

284. **Auto-electric Phenomena of a muscle in action.**—If we measure the current of repose on the galvanometer, and then cause the muscle to contract, we shall see the current fall at once to half its former intensity. The contraction of the muscle has therefore produced an electromotive force in a direction contrary to that of the current of repose.

Du Bois-Reymond calls this phenomenon "The negative variation of the current of repose," considering it as a simple diminution in this current. *Hermann,* on the other hand, considers it to be an added electromotive force, a *current of action.*

The negative variation, or current of action, takes place before the actual occurence of contraction. When a muscle is stimulated, a certain time elapses before it contracts. It is during this interval that the negative variation of the current is produced.

The negative variation which accompanies the physiological contraction of the heart in systole may be easily demonstrated.

285. Auto-electric Phenomena of nerves in action.—The current of repose in a nerve is diminished by any stimulus, whatever the mode of excitation, electric, mechanical or cerebral. The result is the same for fibres with or without a myelin sheath, although in the latter case the variation is less apparent.

The negative variation may be observed in a nerve for 12 to 48 hours after death or removal from the body.

When a portion of the length of a nerve is excited by a continuous current, the nerve is traversed by electrotonic currents, which may be regarded as currents of action, set up by the stimulus of the galvanic current.

286. External manifestations of auto-electric phenomena in living beings.—On account of the great resistance offered by the skin, it is exceedingly difficult to demonstrate the current of repose in a muscle *in situ* in the living subject. *D'Arsonval,* however, has been able to demonstrate it by making an incision in the skin and introducing an unpolarisable electrode at either end of the muscle. The wound made by either electrode having an equal effect, the difference of potential observed must be the measure of the current of repose.

The negative variation, or current of action, is more easy of demonstration. The following experiment is due to *du Bois-Reymond.*

Two vessels containing sulphate of zinc solution are connected with a galvanometer, and one hand of the subject is placed in each vessel. As long as the arms remain at rest the galvanometer will register 0. If now the muscles of the hand are contracted by a voluntary effort, the needle will deviate, shewing an ascending current in the contracting arm. The difference of potential is of the order or $\frac{1}{1000}$ of a volt.

It has been objected that the current might be due to the excretion of sweat in the contracted limb. *Du Bois-Reymond,* however, shewed that the current due to perspiration was not an ascending one. The clinical observations of *Mendelssohn* confirm *du Bois-Reymond's* opinion. In patients suffering from unilateral hydrosis of nervous origin, there is a current due to the secretion of sweat. There is, however, no difference in the intensity of the current of contraction when the patient contracts the two arms alternately. Moreover, in patients suffering from ichthyosis, in which perspiration is absent, the current of contraction is equally well marked. In certain paralytic patients with exaggerated sweat secretion, *Mendelssohn* observed that there was no true ascending current produced by the effort to contract the paralysed muscles. The effort was followed by increased sudation, but not by any muscular movement. The needle of the galvanometer shewed only a few vague and feeble oscillations. The experiment of *du Bois-Reymond* is therefore conclusive, the current is the negative current due to muscular contraction.

The currents due to muscular contraction of the heart may be also observed through the integuments. *Waller* has shewn that there is a difference of potential due to this cause between the right hand and the left hand, and between the back and the front of the thorax.

Independently of these special variations of potential, the general surface of the body is electro-positive. This electric tension explains the phenomena sometimes observed in hysterical girls, in whom the electric tension may sometimes become high enough to produce sparks. It must be remembered that all cell action produces electricity. The electric currents due to glandular action, and especially to that of the sudoriparous glands, are very appreciable.

287. **Auto-electric Phenomena.**—There are two opposite explanations of auto-electric phenomena.

1. *Du Bois-Reymond* believes that the living molecule is the original cause of the difference of potential, and that the currents of repose in muscle, nerve and gland are the manifestations of this electro-genesis.

2. On the other hand *Hermann* considers that the animal electricity is caused by lesion of the tissue during the course of preparation, each point which has been injured becoming electro-negative in comparison to a surface which is intact.

Du Bois-Reymond considers each element of a muscle or nerve to be a reduced image of the whole, with a positive external equatorial region and a negative axial region. The resultant of these electrical tensions in the elements of a muscle would be the electrical tension of muscular repose. The negative variation or current of action would result from any perturbation in the arrangement of the muscular elements at the moment of contraction.

In *Hermann's* view the current of repose is due to alteration of the tissue by injury, the negative variation of contraction being caused by a true current of action, any point of stimulation becoming negative when compared with the rest of the organ. The controversy is far from being settled, and quite recently *d'Arsonval* has brought forward a new theory.

288. **D'Arsonval's theory of animal electro-genesis.**—*D'Arsonval's* theory depends upon the electric phenomena associated with alterations of surface tension in liquids.

1. Each molecule of matter exercises a force of attraction on those in its vicinity. The attractive force is only exercised through a very short distance, so that each molecule may be considered as surrounded by a limited "sphere of influence." The radius of this sphere is the range of mole-

cular attraction. In a liquid the molecules are placed within this radius of molecular activity, whereas the molecules of a gas are outside the range. Let us consider a single molecule of a liquid. Its sphere of influence will be spherical so long as it is at a distance from the surface of the liquid. If, however, the molecule is near the surface, the field of action is no longer symmetrical. When it is part of the superficial layer, it has no molecule above it on which to exercise an attractive force. In this asymmetrical field then the attraction between the laterally situated molecules is increased. By this means a sort of elastic skin is formed on the surface which bounds the liquid mass. The force which unites the molecules of the upmost layer is called the *surface tension.*

This surface tension of a liquid mass is the cause of a number of interesting phenomena. A steel needle can be floated in water if the surface of the skin is not broken. Insects can walk on the surface of a pond. The various phenomena of soap bubbles and soap films are due to the same cause. The best liquid to exhibit these phenomena is one composed of 300 grammes of sugar and 15 grammes of soap in a litre of water (*Terquem*) or a 30% to 50% solution of castor oil in collodion. (*Imbert.* Traité de Physique Biologique.)

Surface tension is measured by the resistance which a liquid surface offers to rupture and is stated in milligrammes per unit length.

Other phenomena are exhibited by the modification of the surface tension, due to the contact of two liquids which do not mix, or to the contact of a liquid and a solid. The presence on the free surface of a liquid of the molecules of another liquid tends to re-establish the symmetry of the molecular sphere of action, and thus to diminish the surface tension. Suppose we place a drop of liquid A on the free surface of another liquid B, with which it will not mix. The surface tension of A will be diminished. If the surface tension remains sufficiently strong, it will prevent the spreading of the drop. On the other hand the surface tension may be entirely annulled, or even reversed, so that the attractive force of the superficial layer is less than that of the central molecules, in which case the surface of A will tend to spread. The greater this "negative tension" the more rapidly a drop of liquid A on coming into contact with B, will spread over the surface of B. This explains the spreading of a drop of oil on the surface of water. The same diminution of surface tension occurs when a liquid comes into contact with a solid. When a liquid does not moisten the solid, it is because its surface tension is not reduced to zero by contact with the solid. When a liquid moistens a solid, it is because its surface tension has become negative by contact with the solid surface. This is the cause of the phenomena of Capillarity, the ascension of liquids which moisten, and the depression of those which do not moisten the capillary tube, the formation of a concave meniscus on the surface of a liquid that moistens the walls of the vessel, and of a convex meniscus in the surface of a liquid that does not moisten the walls of the vessel in which it is contained.

II. *Lippmann* has shewn that all changes of surface tension give rise to electric phenomena. A globule of mercury, in dilute acid, becomes electro-positive when deformed by mechanical means so as to inscrease its surface area. On the other hand, it becomes electro-negative when its surface area is diminished. This may be shewn by placing the mercury and the acid in communication with the poles of a galvanometer.

Conversely any modification of the electric state will change the surface tension of a liquid.

This is the principle on which *Lippmann's* capillary electrometer is based.

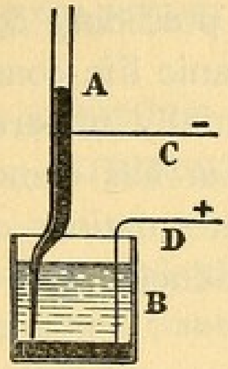


Fig. 49.—Lippmann's Electrometer.

The capillary electrometer consists of a glass tube A, drawn out into a slightly conical capillary at one end. The tube is filled with mercury and its extremity is immersed in a vessel B containing dilute acid with a small quantity of mercury at the bottom. The height to which the mercury rises in the tube A is a function of the surface tension where the mercury is in contact with the dilute acid. If now a current be passed from the mercury in the vessel to that in the tube by means of the electrodes C and D, the position of the meniscus of separation will alter, owing to changes in surface tension due to the current. This is a most sensitive apparatus, enabling us to appreciate variations of potential of the order of $\frac{1}{10,000}$ of a volt.

III. These facts led *d'Arsonval* to formulate his theory of animal electro-genesis. This theory he supported by a series of experiments, the most interesting of which is that of the artificial muscle. This consists of an india-rubber tube, divided into a series of compartments by means of porous discs. Each compartment is filled by a layer of mercury and one of dilute acid. When the tube is suddenly stretched a current is produced which can be easily detected by the ordinary apparatus. Experiments on this artificial muscle, together with his observation on animal muscle, have enabled *d'Arsonval* to explain the current of repose as well as the negative change preceding contraction.

The processes of organic life consist of molecular movements which are essentially imperceptible. By means of the telephone, *d'Arsonval* has demonstrated the reality of these infinitely small deformations of liquid surface, which are quite capable of producing the observed electrical phenomena.

A priori one would expect that the elongation of a muscle by a mechanical force would produce an electrical manifestation opposite to that of contraction, viz., an augmentation of the current of repose.

This is in fact the case, and has been proved by experiment. No other hypothesis offers any explanation of this observation.

289. **Rôle of the Ions in Organic Electro-genesis.**—As *Mendelssohn* has pointed out, some of the manifestations of animal electro-genesis may be explained by the movement of the ions in the organism. This is certainly an important source of the electric phenomena going on in the living body, and together with electro-genesis by variation of surface tension is sufficient to afford a rational explanation of animal electricity in its various manifestations.

CHAPTER II.

PHYSIOLOGICAL EFFECTS OF VARIATIONS OF CURRENT.

Variable state of opening and closure—Induced Currents—Extra Currents—Alternating sinusoidal Currents—Undulatory Currents.

I. General Considerations.

290. **The Variable State.**—Any variation of current has two principal effects on the organism.

1. It causes *sensation*. This is propagated to the nerve centres by means of the sensory nerves.

The sensation produced by current variation cannot be traced further, since the intimate phenomena of perception are still unknown. We shall allude to this again when we come to study the laws which treat of sensory impressions.

2. It produces a *motor excitation*. This is followed by muscular contraction, whether the stimulus be applied directly to the muscle or to the nerve which supplies it.

The study of motor excitation requires some knowledge of its mechanism. Muscular contraction is the index of physico-chemical excitation and of both reflex and central stimulation. We must therefore investigate the mechanism of muscular contraction and the architecture of the muscular elements.

291. **Constitution of Muscle—Mechanism of contraction under the stimulation of the variable state.**—Contractility is not the exclusive property of muscle. Other

organic elements, such as leucocytes and the cells of ciliated epithelium, are contractile and respond like muscle to external stimuli. We also find entire organisms such as the amœbæ and ciliated infusoria, in which the contractile tissue has not been differentiated, and which respond *en bloc* to external stimuli.

It is interesting to notice how simple and rudimentary are the primitive muscular elements in animals like the hydra, in which we can examine the commencement of differentiation of contractile tissue.

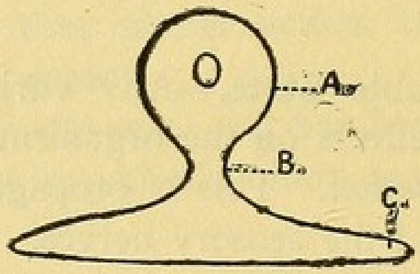


Fig. 50.—A, Ectodermic cell.—B, Peduncle.—C, Contractile portion of the cell.

In these animals the cells of the ectoderm are furnished with expansions, which penetrate more deeply into the mesoderm. This expansion, which is attached to the ectodermic cell by a peduncle, is alone endowed with contractility.

The cell is a rudimentary neurone, the peduncle being the future nerve, and the expansion the muscle fibre. A nucleus soon makes its appearance in this contractile portion, and it then speedily takes on an independent existence.

This rough sketch of the development of the nerves and muscular tissues shews very clearly the relationship between the neurone and the muscle fibre, a relationship which in the higher animals has become so complex.

We may now pass on to consider the two varieties of muscular fibre, the final stages in the development of the primitive contractile plasma. These are the striated and the non-striated muscular fibre.

The striated muscular fibre is characterised by the rapidity of its contraction. It constitutes the muscles of voluntary action,—the muscles of relation and of animal life.

Non-striated or smooth muscular fibre is characterised by the slowness of its contraction, recalling that of the primitive plasma. It is an element which is less highly differentiated and at a lower stage of evolution.

We may proceed to study the architecture of the striated and of the smooth muscular fibre, omitting for the present the special musculature of the heart.

292. **Architecture of Striated Muscle.**—Voluntary muscles are formed of striated fibres, bound together by connective tissue. The contractile element, the muscular unit, is the striated fibre. It is a cell of fusiform shape, 4 to 5 cm. in length and 40 to 50 μ in diameter. It contains several nuclei and is surrounded by an envelope, the sarcolemma or myolemma, which is the original cell wall.

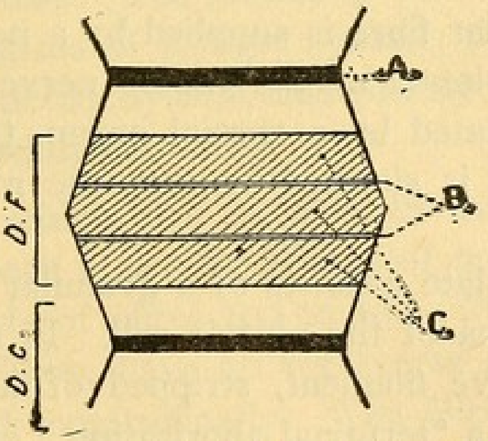


Fig. 51.—A, Thin disc. Amici's band.—B, Clear band, single or double. Hensen's band.—C, Thick disc divided into two or three layers of Hensen's bands.—D.C, Clear disc.—D.F, Opaque disc.

This striated fibre is composed of cylindrical fibrillæ, 1 μ to 3 μ in diameter, which pass from end to end of the fibre.

This division into fibrillæ is marked by a longitudinal striation which is often as noticeable as the transverse striation.

When in repose, each fibrilla is formed of a number of clear and dark discs superposed one upon the other. The clear disc is traversed by a dark stripe, the stria of *Amici.* The dark disc is traversed by one or two striæ, the bands of *Henson.* The clearer portions are probably formed of liquid muscular juice.

Amici's disc is probably the membrane limiting what *Krause* calls a muscular case. The opaque segments of the thick disc are the contractile portions of the fibre. (*Engelmann, Ranvier.*)

Carnoy and *Van Gehuchten* regard the muscular fibre as a system of transverse and longitudinal trabeculæ, which form a network, the meshes of which are filled with muscular juice, the myositic enchylème. In their opinion the network is the contractile element, the liquid remaining passive.

We must now turn our attention to the mode of termination of the nerve fibres, the conductors of stimulation to the muscle.

Each muscular fibre is supplied by a nerve filament from the terminal plexus of the motor nerve. This nerve filament is terminated by a special organ, the motor plate of *Rouget,* which is situated beneath the myolemma. (*Ranvier.*)

The motor plate consists of a granular substance formed from the plasma of the muscle cell. In this granular substance the nerve filament, stripped of its myeline sheath, breaks up into a "terminal aborisation," each twig of which is in connection with a muscular fibrilla. The nerve twig is lost on the surface of the fibrilla and the microscope does not shew if there continuity between the nervous and muscular tissue, although embryology would lead us to suppose this to be the case, the motor expansion of the cell being originally a portion of the plasma of the ectodermic cell.

293. **The Phenomena of Contraction.**—The phenomena of contraction are not as yet well understood, since the constitution of the striated muscular fibre itself is still a matter of doubt. The opaque discs are usually considered to be the seat of contraction.

According to *Engelmann* there is absorption of the clear liquid at the moment of contraction. Accordiing to *Ranvier* there is an exodus of clear liquid when the muscular segments contract and become spherical, whilst *Carnoy* and *Van Gehuchten* hold that there is contraction of the trabeculæ of the dark coloured network.

Whatever the mechanism of contraction, we may say that in the evolution of striated muscular fibre, certain specially contractile elements have been differentiated from the plasma of the contractile cells. These are probably the dark discs, or the trabeculæ of *Carnoy* and *Van Gehuchten.* The contractive elements are in intimate relation with the conductors of nervous impulse. The remainder of the cellular plasma, the granular plasms of *Rouget's* plates, the clear segments, and the myosytic enchylème, has merely a nutrient action, or acts as a packing material.

294. **The architecture of smooth muscle.**—The non-striated or smooth muscular fibre is of much simpler structure. It consists of fibres 100 to 200 μ long, and 4 μ to 6 μ in diameter. These have no transverse striæ, but are frequently striated longitudinally. The fibrillæ, which extend the whole length of the fibre, are placed round the periphery. The centre of the fibre is occupied by plasma, the sarcoplasm, which has only a passive or nutritive rôle.

In the development of smooth muscular fibres, the plasma has been differentiated into a more contractile portion, the fibrillæ, and a passive portion, the sarcoplasma. The nerve supply consists of the axis cylinder, the cellulifugal process of the neurone. The nervous filaments terminate in the middle of the fibre in the "tache motrice." (*Ranvier.*)

295. **Explanation of the phenomena of contraction by the laws of surface tension.**—We have already seen in par. 288, how *d'Arsonval* explains the electric phenomena exhibited by living tissue by alterations of surface tension. In the same way he explains the mechanism of muscular contraction. The semi-liquid particles of the muscle are in a state of equilibrium between the forces of surface tension and the various external forces acting on the muscle. Any alteration in the electric condition will disturb the equilibrium, since it changes the surface tension. The following is *M. Imbert's* explanation of the phenomena.

a. *Contraction of smooth muscle.*—From an electrical point of view, the fibrillæ may be considered as consisting of a semi-fluid substance bathed in a fluid plasma. Their form of equilibrium is the sphere. Any alteration in surface tension would not alter their form if the fibrillæ were in this state of spherical equilibrium. But if they have been previously distorted by external forces, the nervous influx, like an electric impulse, will tend to restore them to their primitive spherical shape.

b. *Contraction of striated muscle.*—The explanation of the contraction of striated muscle is associated with the fact observed by Ranvier that there is an exudation of liquid from the dark disc segment at the moment of contraction. The nervous influx causes an alteration of equilibrium at the surface of contact between the clear and the dark discs, and a consequent change of their form.

The explanation of *d'Arsonval* and *Imbert* presupposes the similarity of a nervous and an electric influx. It would, however, be premature to conclude that the two are identical.

There are many facts which seem to support this view. The difference in the velocity of propagation of nervous and electrical impulses is not conclusive. The recent labours of *d'Arsonval* and *Weiss* on the propagation of electric waves in muscle and nerve seem to indicate a similarity in the mode of transmission of nervous and electrical impulses.

II. Effect of the Variable State of opening and closure of a Continuous Current.

296. **General considerations.**—We may now proceed to consider the varying electric conditions which obtain during the time of opening and closure of an electric current. The variation of the current may be expressed by the graphic

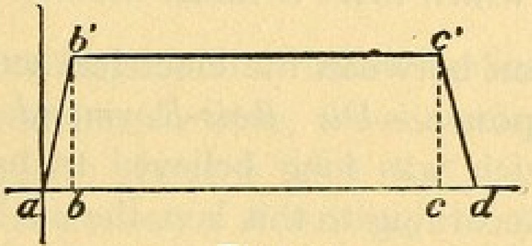


Fig. 52.

method. Fig. 52 is a diagram of the varying intensity of a continuous current at "make" and "break," the abcissæ on the axis representing the time, and the ordinates the intensity of the current. In this case there is no rheostat resistance such as is sometimes used to increase the current gradually from zero to its maximum intensity. The diagram represents the variation in intensity which occurs when we apply the electrode suddenly to the skin, or what is better, close the circuit by means of a key after the electrode has been placed in position. In this way at the moment of closure, the maximum E.M.F. is applied to the circuit. Similarly at the moment of opening the circuit, the rupture of the circuit is instantaneous, whether this is done by means of a key or by the sudden removal of the electrode.

During the period of closure a b, the current increases rapidly, attaining its maximum value at b'. The intensity of the current is then represented by b b'. During the period of opening, c d, the current decreases rapidly, its intensity falling to zero at d. We are not in a position to measure the exact duration of the periods a b and c d, nor can we determine the forms of the lines a b', c d'. In studying the effects of opening and closing the circuit, we need only take into consideration the maximum intensity of the current.

We may now proceed to investigate the relation between the electrical excitation and the physiological response,—a question about which there is much debate.

297. **Relation between the electrical excitaton and the muscular response.**—*Du Bois-Reymond* formulated a simple law which was long believed to be general in its application. According to this law, the excitation is a function of the rapidity with which the strength of the current varies.

Thus if Δ is the strength of the current, and $d\Delta$ its variation during an infinitely short time, dt, the expression for the corresponding excitation will be $f\left[\frac{d\Delta}{dt}\right]$.

Hence the more gradual the rise of the curve of closure, the feebler will be the excitation. The time of closure may be prolonged by the employment of a rheostat with decreasing resistance, or by increasing the self-induction of the circuit. In order to get the same degree of excitation with a more gradual increase of current, the total change of intensity must be augmented in proportion to the time which the current takes to attain its maximum value. We may suppose for the moment with *du Bois-Reymond,* that the total excitation is the integral sum of the elementary excitations.

Fick shewed that *du Bois-Reymond's* law was not universal, and that it does not hold true when the curve of closure is at a very small angle with the axis, or when it is almost perpendicular to the axis[1].

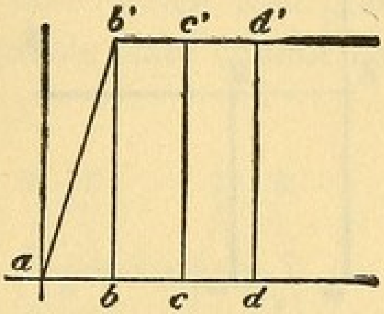


Fig. 53.

He found that when a b' is almost vertical, *i.e.,* when the time a b approaches to zero, the duration of the current in its continuous phase b' c' d' has an influence on the intensity of excitation. According to *du Bois-Reymond's* law, the curve at a b' is the only portion which needs to be taken into consideration. The periods b' c', b' d', etc., during which the strength Δ of the current does not vary, should have no influence on the value of the excitation since during that time $\frac{d\Delta}{dt}$ is zero.

Weiss has recently directed his attention to the same question. His results are not in accordance with *du Bois-Reymond's* laws, at all events in cases where the waves are of short duration, less than .003 of a second. His work is so important that we shall give a description of his experiments[2].

[1] Fick. Beiträge zur vergleichenden Physiologie der irritabelen Substanzen, 1863. Braunschweig.

[2] Weiss Arch. Italiennes de Biologie de Mosso., 1901, t. XXXV.

298. **Weiss' experiments—1st Law.**—*Weiss* proceeds in the following manner. The two points A and B (Fig. 54) are connected to an electric source. A nerve preparation from the leg of a frog E is connected to the points B and D. A wire C D places D in connection with C A. A

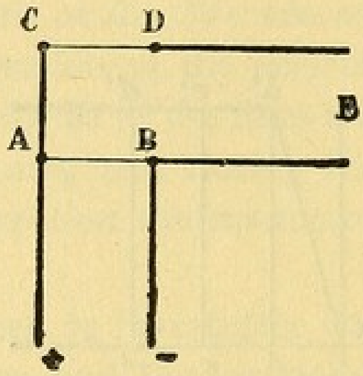


Fig. 54.

and B are united by a wire A B of negligable resistance. When A B and C D are in place, the whole current passes through A B. If A B is cut, the whole current passes through the nerve, and if C D is cut, the current through the nerve is arrested. The current passes through the nerve only during the interval between the rupture of A B and C D. In *Weiss'* experiments the wires are ruptured by means of a gun loaded with liquid carbonic acid, having an equable velocity of 130 metres per second, so that each centimetre of distance between the wires A B and C D corresponds to .000077 of a second.

The first question was to determine how long a time elapsed after the rupture of A B before the permanent state was obtained, *i.e.*, what time was necessary for the current to attain its maximum value. *Weiss* found that this was quite negligable. He used a *Thompson* galvanometer with high self-induction and found that the duration of the varying state was imperceptible, even when the establishment of the current was retarded by the self induction of the instrument.

Since we may neglect the duration of the varying state, we are in a position to estimate the influence of the duration of the permanent state on the organism. This may be done by a comparison of the muscular contractions, corresponding to different intervals between A B and C D. Fig. 55.

A difficulty arises here which was pointed out by *Fick*. The current in its equable state cannot be arrested without

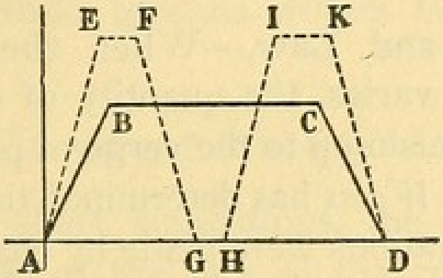


Fig. 55.

producing a curve of "break" following the rupture of the second wire C D. What will be the influence of this varying current on the preceding equable current?

In order to answer this question, *Weiss* made a series of experiments to determine the influence on muscular contraction of successive electrical waves. For this purpose he made an arrangement in which there were four wires connecting A B and C D of Fig. 54. By the introduction of suitable resistances he obtained two undulations,—AEFG and HIKD of Fig. 55, in the place of the single one ABCD, in the same time AD. This experiment was of great interest. It was found that any interval produced in the undulation ABCD diminished the excitation of the organism, *i.e.*, a greater intensity of current was required in order to attain the required degree of physiological excitation. Thus the summits, EF and IK, of the shorter waves are higher than the summit BC of the longer undulation.

It was found, however, that the total quantity of electricity necessary to raise the organ to the verge of excitation was exactly equal in both cases. The area ABCD in the first case was equal to the areas AEFG and HIKD in the second case.

Weiss therefore enunciated the following law: "With the same duration of electric stimulus, the same quantity of electricity is required to raise the organism to the verge of excitation."

299. **Weiss' 2nd Law.**—When the duration of the electric stimulus varies, the quantity of electricity required to bring the organism up to the verge of physiological excitation also varies. *Weiss* has determined the law of this variation. The observations were made by changing the distance between the wires in his experiment, so as to alter the total duration of his single and multiple undulations. He found that the quantity of electricity necessary to bring the organism up to the verge of physiological excitation may be considered as composed of a fixed quantity, a, and a quantity, bt, which varies with the time. $Q = a + bt$, where t is the duration of the electrical discharge. The value of the coefficients a and b depend on the conditions of the experiment, the ratio a/b varying according to the animal under observation.

From these observations *Weiss* deduces his second law. "In order to produce a minimal response in an organism, the electric stimulus of the nerve or muscle consists of a quantity of electricity which is constant, plus a quantity which is proportional to the duration of the discharge.

"The result," he says, "is as if a definite quantity of electricity were required to excite the nerve, but that an additional quantity of electricity proportional to the duration of the action was required to neutralise the continual tendency of the organ to return to its original condition."

The coefficients a and b are easily determined by making two successive experiments in which the time of excitation t and t' is varied. We get

$$Q = a + bt$$
$$Q = a + bt'$$

which enables us to obtain a and b.

Dubois of Berne and *Hoorweg* have also investigated the subject and their formula differs but little from that of *Weiss.*

Since $Q = It$, we get $It = a + bt$, whence $t = \frac{a}{I - b}$

Hence for short undulations, the excitation is not simply a function of the rate of the current variations, but the duration of the equable current must also be taken into account during a time $t = \frac{a}{I - b}$ This is found by experiment to be nearly equal to the latent period of muscular contraction. *Weiss* remarks that this fact seems to indicate that the excitation takes place only during the latent period, after which the organ passes into a sort of refractory phase.

We have hitherto studied the action of successive waves passing in the same direction. *Weiss* has also determined the reciprocal effect of waves travelling in opposite directions. The following are his conclusions.

When a wave, capable of producing contraction, is preceded or followed by an opposite wave of less amplitude, the second wave diminishes the effect of the first, but this effect is independent of the amplitude of the second wave and cannot therefore be regarded as simply subtractive in character. It seems merely to produce perturbation at the moment of the current-reversal.

Recently *M.* and *Mme. Lapicque* have slightly modified *Weiss'* formula, which becomes

$$Q = A + bt - \gamma V$$

where V is the difference of potential between the electrodes. A second variable depending on the potential is thus introduced into *Weiss'* formula.

300. **Action of the variable state on striated muscles.**—The study of muscular contraction is complicated by the phenomenon of polarisation, which appears to modify the results.

We shall first study the effects of the variable state on non-polarised muscle and nerve, and shall afterwards discuss the accessory changes due to polarisation.

The muscle may be excited directly. It is not necessary for the excitation to pass through the motor nerve. In animals which have been curarised, thus destroying the excitability of the nerve, the muscle contracts directly under electrical stimulation. After death, the muscle remains excitable, while the nerve ceases to be so. *Schiff's* phenomenon, the so-called idiomuscular contraction, is another proof of the auto-excitability of muscle. When a muscle is struck, the shock causes a localised contraction, which forms a sort of persistent swelling of the muscular substance.

Opinions are divided as to the part played by the terminal nervous filaments when a muscle is made to contract by a stimulus applied at its point of election, *i.e.*, at the point where the motor nerve enters the muscle.

Doumer and others consider that when a muscle is stimulated at its point of election, the muscular reaction is due to the excitation of the nervous filament which supplies it, the various pathological anomalies of reaction being explained by anomalous reactions of the nerve filaments. *Huet* is of contrary opinion.

301. **The Muscular Response to the excitation of the variable state.**—When a muscle, or the motor nerve of a muscle, is stimulated by a rapid change in its electrical state, such as occurs at the "make" and "break" of a galvanic circuit, a momentary contraction of the muscle occurs. This "secousse musculaire" is much shorter than any possible voluntary contraction.

Fig. 56 shows the classical diagram representing this secousse.

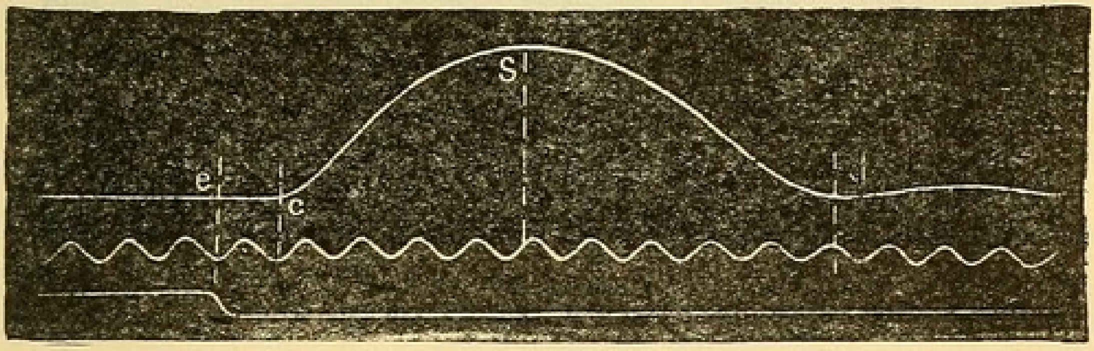


Fig. 56.

On the lower line is seen the electrical signal, e, at the instant of excitation. The sinuous line gives the vibrations of a tuning fork marking hundredths of a second. The upper line is the graphic representation of a single muscular secousse.

It will be seen that the muscle does not begin to contract until after the lapse of a certain time ec, after excitation. This interval of about one hundredth of a second between the excitation and the commencement of the secousse, is called *the latent period of excitation,* or the *lost time* of contraction.

It will be remembered that it is during the latent period of excitation that the negative variation in the stimulating current is produced (284).

The latent period is succeeded by the *period of increasing energy* of contraction, the duration of which is about $\frac{5}{100}$ of a second.

This is followed in turn by the period of *decreasing energy*, which is slightly longer. These figures are not absolute, the duration of a secousse varying with conditions of heat and cold and muscular fatigue.

Figure 57, borrowed from *Marey*, shews the alteration

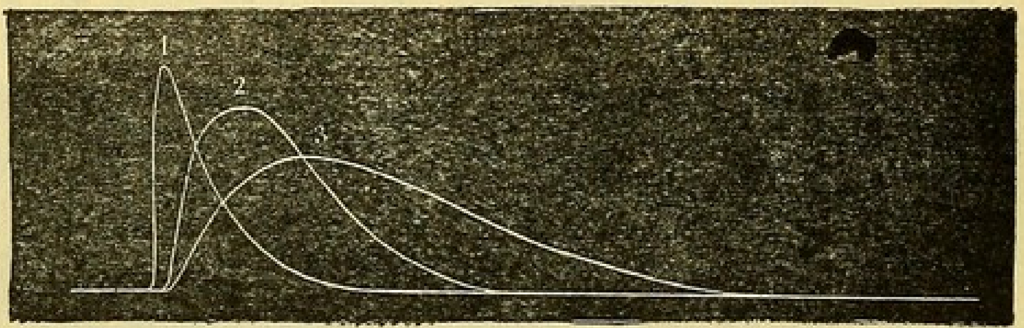


Fig. 57.

in the diagram of the muscular secousse under the influence of fatigue. 1 is the trace of the muscle in its normal state, 2 and 3 representing the muscle as it becomes more and more fatigued, the contraction becoming less in extent and slower.

We may notice here, that the duration of the latent period varies with the mechanical resistance to contraction. The length of the latent period is in proportion to the inertia of the mass moved, just as the delay in starting a train increases in proportion to the weight the locomotive has to move.

302. **Muscular wave of contraction.** When a muscle is stimulated at a point near its extremity, an elevation is formed at the point of stimulation. This raised portion or knot is caused by a zone of contraction which may be seen

to travel towards the other end of the muscle as a sort of undulation. (*Aëby*, 1862.)

Aëby and *Marey* estimate the velocity of propagation of this wave of contraction at one to two metres per second. During the ordinary physiological action no such wave is produced, the contraction taking place through the whole mass at the same instant. Physiological muscular contraction is in no way analogous to the undulatory contractions observed in the muscles of insects at the moment of death, or after death. *Laulanié* has shewn that at the approach of death, muscular waves frequently coexist with physiological contraction *en masse*.

303. **Laws of Muscular Contraction.**—The order in the appearance of the contraction following opening and closure of the exciting current vary according to the sign of the active electrode and according to whether the muscle is polarised or not.

In muscle testing the indifferent electrode may be placed on any part of the body. The small active electrode should be applied to the motor nerve or to the point of excitation of the muscle. The apparatus should be furnished with a current-reverser so as to make the active electrode positive or negative at will.

The muscular contractions appear in the following order as the intensity of the current is raised. (*Erb.*)

KCC. Contraction on closure when the active electrode is a Cathode.

ACC. Contraction on closure when the active electrode is an Anode.

AOC. Contraction on opening when the active electrode is an Anode.

KOC. Contraction on opening when the active electrode is a Cathode.

Suppose, for example, we apply a current of .5 milliamperes to the motor point of a muscle. There will be no contraction either at "make" or "break," whether the active electrode be positive or negative.

If the intensity of the current be raised to .6 ma, KCC will be produced. On closure of the circuit there will be no contraction if the active electrode be an anode. There will be no contraction in any case when the circuit is broken.

If the current be raised to 1 milliampere there will be strong KCC, a very appreciable ACC, and slight AOC.

On increasing the intensity of the current still further KOC will appear, KCC will be very strong, whilst ACC and AOC will be fairly strong.

304. **Influence of Polarisation on the Law of Contraction.**—It may be said in general that contractions on closure (CC), are diminished by polarisation, whereas the contractions on opening (OC) are increased. In other words, the contraction on opening (OC) are produced earlier and those on closure (CC) are produced later, than they would appear normally when the current is gradually increasing in intensity.

The observations of *Chauveau* and *deBoudet* shew that as the exciting current is increased the tissues become more and more polarised, the KCC, which is at first superior, becomes successively equal to, inferior and again superior to ACC.

305. **Effect of the variable state on Sensation.**—Sensory effects follow the laws of motor effects. *Bordier,* using an electrode of 12 square centimetres, obtained the following results. The sensation on closure when the active electrode is a cathode (KCσ) is the first to appear.

KCσ	.9	milliamperes
ACσ	1.1	"
AOσ	1.2	"
KOσ	2	"

These results are not in complete accordance with those of *Erb,* who places AOσ before ACσ.

306. **Motor effects produced by several successive periods of the variable state.**—Let us examine first the result of two successive muscular contractions. If the second secousse arrives during the phase of increasing muscular energy, the curve of contraction is not reduplicated, but its amplitude is increased. There is but a single contraction of increased strength.

If the second secousse arrives in the period of decreasing muscular energy, the descending curve ascends again to a greater height than before. Two distinct but barely separated curves of contraction appear, the second being stronger than the first.

If the second secousse takes place after the termination of the first, the two contractions are independent, but the second is stronger than the first, although the excitation was the same.

This phenomenon, "the summation of stimuli," is of great importance. If we subject a muscle to a series of successive excitations, the contractions become gradually stronger until we reach a maximum. The effects are superimposed, so that a current which at the first "make" is incapable of causing a secousse, is at last able to produce contraction after a succession of attempts which appear to have been made in vain.

When the series of excitations is so rapid that one secousse follows the other during the phase of increasing energy, a permanent contraction of the muscle follows. This contraction, although permanent, is made up of a series of successive contractions. We may recognise this by auscultation, the ordinary muscular bruit being continuous. The more frequent the secousses, the more permanent is the muscular contraction. The number of excitations cannot, however, be raised above a certain limit, 1100 to 1200 per second. The muscle no longer responds to the excitation, when the interruptions or inversions exceed 10,000 per second, as is the case in high frequency currents.

When the muscular contraction is in this apparently permanent condition, the muscle is said to be tetanised. The number of excitations necessary to produce tetanus, is 100 per second in birds, 60 per second in the guinea-pig, and 40 per second in man, 15 to 30 per second in the frog, and 3 per second in the tortoise. (*Richet.*)

During voluntary contraction the muscle is in a state of physiological tetanus, with successive secousses. The pitch of the muscular bruit heard on auscultation indicates a frequency of 36 to 40 vibrations per second. (*Helmholtz.*)

307. **Action of the variable state on smooth muscle.**—Smooth muscle has certain pecularities in its relation to the variable electrical state. To produce tetanus in unstriped muscular tissue, the shocks of the variable state must be separated by longer intervals. This is due to the slower rate of contraction of unstriped fibres. Another peculiarity is, that ACC is more efficacious than the KCC.

With rhythmic galvanic currents, it is easy to obtain peristaltic contractions of the digestive tract, or other organs such as the bladder or gall bladder, actuated by unstriped muscular fibres.

Unstriped muscle has another peculiarity, *viz.*, that it will contract under the influence of the steady, continuous current, quite independently of the period of variable state.

The vaso-motor phenomena produced in the vicinity of the electrodes are a manifestation of the excitability of the smooth fibres in the walls of the smaller blood vessels. These vaso-motor phenomena occur with the continuous current as well as with variations of the electrical state.

III. Physiological action of the Faradic Current.

308. **General considerations.**—The laws of the muscular secousse caused by the variable state give us a clue to the action of alternating currents.

Let us consider first the faradic current. The form of the two induced undulations is given graphically in Fig. 58, in which the abscissæ represent intervals of time. The varying intensity of the secondary current is represented by ordinates, positive when the secondary current is in the same direction, and negative when it is in an opposite direction to the primary current.

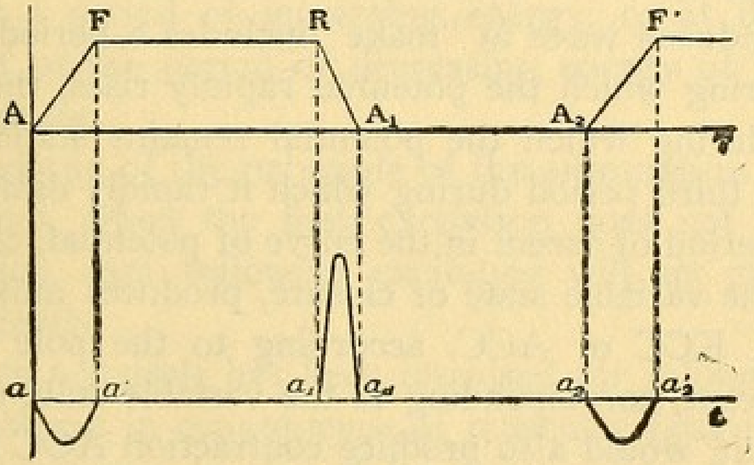


Fig. 58.

The wave a a' is the wave of "make," induced at the moment of closure of the primary circuit. The stronger wave a_1 a'_1 is the wave of "break," produced at the moment of rupture of the primary circuit.

The duration of each of these induced waves is equal to the duration of the variable state of closure and of opening in the primary circuit. The induced wave at "make" is of longer duration and more spread out than the wave at "break." The duration of the variable state at "make" is increased by increasing the self-induction in the primary.

309. **Analysis of the effects of the induced current of**

"break."—The induced wave $a_1\, a'_1$ at "break" is the one that has the greatest physiological effect.

The total quantity of electricity passing in each of these waves is the same, as may be proved by using a ballistic galvanometer. The wave of "break," however, gains in potential what it loses in duration. Whether we use *du Bois-Reymond's* formula $Q = f\left(\frac{d\Delta}{dt}\right)$ or *Weiss'* formula $Q = a + b\,t$, it is evident that in order to produce the same physiological effect, the quantity Q would have to be greater in the wave of longer duration. This is contrary to the conditions since, as we have seen, the quantity of electricity in the two waves is the same.

The induced wave at "make" includes a period of ascension, during which the potential rapidly rises, then a short period during which the potential remains stationary, and finally a third period during which it rapidly diminishes.

The period of ascent in the curve of potential, corresponding to the variable state of closure, produces muscular contraction, KCC or ACC, according to the pole employed. The descent, corresponding to the variable state of opening the circuit, would also produce contraction AOC and KOC, if its action on the muscle were isolated.

310. **Analysis of the induced waves of "make."**—The height of this wave is less, and its length is greater, two reasons why its effects are neutralised and overborne by the "break" wave, which with the same quantity of electricity has a greater maximum intensity and a shorter duration.

The "make" wave has a similar but less marked effect on the muscle than the "break." There is a fusion of the two secousses, due to the varying state of ascent and descent in the potential curve of intensity.

In the faradic coil the wave of "make" is effaced by the wave of "break," so that we may say that we are using *positive faradisation* when we use the positive pole of the "break" current as active electrode, whereas when the negative pole of the "break" current is used we are applying *negative faradisation*. These are commonly referred to as the positive and negative pole of the coil.

311. **Physiological effects of faradisation.** We have now to inquire into the effects of a succession of induced shocks on the organism, since faradisation consists in the application of a series of such shocks.

We may recall what was said in par. 306 on the effects of the successive applications of the variable state.

1. Tetanus is produced if the secousse reaches the muscle during a period of increasing energy, or at the commencement of the period of decreasing energy of the preceding secousse.

2. By virtue of the principle of the summation of electrical stimuli, when the first excitation does not produce a contraction, each following excitation will act more and more efficiently.

3. When a muscle has been tetanised for a long period, it finally relaxes in consequence of muscular fatigue.

The physiological results of faradisation have been studied and formulated by *Debédat.*[1]

The results are due to local gymnastic action on the muscle, which increases the normal development of its elements.

In order to avoid the fatigue due to tentanisation, *Debédat* used the rhythmic faradic current. He experimented on rabbits.

After 20 applications of 4 minutes each, he found a marked increase in weight of the femoral muscle on the side which had been faradised. This increase was as much

[1] Archives d'Electricité Médicale, 1894, p. 69.

as 50% of the original weight of the muscles. Histological examination shewed that the increase was due to development of the active muscular elements, not of the interstitial tissues.

On the other hand, he found that prolonged tetanisation produced an opposite effect, and led to a diminution of the muscle weight. Physiological fatigue had a similar action. After excessive fatigue, microscopical examination shews an atrophy of the muscular fibre itself, which may even undergo degeneration.

This explains the importance of applying the faradic current in a proper manner. While excellent results may follow careful electric treatment, an opposite effect may be produced if the muscle is tetanised so as to produce fatigue. Hence the value of instruments such as *Bergonié's* rhythmic interruptor. (113.)

312. **Effect of the Faradic Current on Sensation.**—A variety of sensations are produced by the application of the faradic active electrode. Special sensations of pricking and tickling are felt, together with a sensation of warmth due to vaso-dilatation, and a sensation of muscular contraction.

The painful sensations are the more intense, the finer the wire of the secondary coil. In order to produce strong muscular contractions without pain, a large wire should be used for the induced currents.

IV. Galvano-faradic currents.

313. **Physiological action of the galvano-faradic current—Characteristic mode of excitation.**—The galvano-faradic or *Watteville* current is obtained by combining the galvanic current with a succession of shocks from the induction coil. The apparatus consists in an induction coil placed in series with a galvanic battery. (114.) The

positive pole of the battery is connected to the negative pole of the coil, and the positive pole of the coil with the negative pole of the battery. The patient may be placed in any part of the circuit thus formed.

The apparatus is sometimes connected up in a different manner, the positive pole of the battery being joined to the positive pole of the coil, so that the two currents pass in opposite directions.

Lewandowski places the battery and the coil in parallel. One electrode is connected to the positive pole of the battery and to the positive pole of the coil, while the other electrode is connected to both negative poles. The galvanic circuit will act as a shunt for the faradic circuit, and in the same way the faradic circuit will act as a shunt for the galvanic circuit, so that it is difficult to say what would be the curve of excitation under these circumstances.

The physiological action of these currents is difficult to analyse, and this for several reasons. The amplitude of the faradic waves is altered, those in the same phase as the galvanic current being increased, and those in the opposite phase being decreased. Moreover, the excitability of the muscle is modified by electrotonus; an electrotonus diminishing and cathelectrotonus increasing the excitability. Finally the ionising effect of the continuous current is added to the action of the induced current.

The labours of *Leduc, Bordier* and *Cluzet* have thrown new light on this subject. We shall proceed to study the physiological action of the Watteville current.

314. **Action of the Watteville current on striated Muscle.**—When the galvanic and induced currents are in series two cases may be distinguished.

a. The active electrode is the anode both of the galvanic and induced currents. In this case the secousse produced at each shock will be stronger than with the faradic current alone.

b. The active electrode is the cathode both of the galvanic and induced currents. In this case also the secousse is stronger than when the faradic current is used alone.

In the latter case, the augmentation of the secousse is due to the increased excitability of the nerve due to cathelectrotonus. In the former case a virtual cathode is produced in the peripolar region around the anode, and this virtual cathode sets up cathelectrotonus. (*Leduc.*)

The increase of intensity may also in part account for the increase in the strength of excitation when the two currents are in the same direction. When the currents are in *opposite directions* the secousses are greatly decreased, which may be accounted for by the change in the intensity of excitation, the continuous current reducing the effect of the faradic current.

Whichever pole is employed, when the two circuits are connected in series, the secousse is stronger than when the faradic current alone is used. On the other hand, when the circuits are joined up in opposition, the strength of the secousse is diminished.

315. **Action of the Watteville current on unstriated muscle.**—What has been said of striated muscle applies equally to smooth muscle, with the exception that unstriated muscular fibre is more sensitive to ACC than to KCC. (*Laquerrière* and *Delherm, Bordier* and *Cluzet.*)

The faradic current from a thick wire coil has but little action on unstriped muscular fibre. To stimulate it effectually a fine wire coil must be used. This is, however, a very painful procedure. The great advantage of the Watteville current is that it produces contractions as well with a thick wire coil as with a thin wire coil.

316. **Action of the Watteville Current on Sensation.**—The addition of a galvanic to the faradic current has the same effect on sensation as it has on muscular contraction. When the two currents are in opposition, the painful sensation is diminished as the galvanic current is increased.

317. **Physiological Effects of the Watteville Currents.**—The most marked effect of the combined current is a rapid increase of muscular growth. With rhythmic galvano-faradisation, *Bordier* obtained an enormous increase in the muscles of the arm and forearm, giving seances of 10 minutes every other day for two months. This explains its beneficial action in the treatment of paralysis, myopathy and atony of internal organs actuated by unstriped muscular fibres.

V. Physiological Action of the Sinusoidal Current.

318. **The distinctive physiological action of sinusoidal currents.**—With a sinusoidal current, the increase and decrease of intensity occurs gradually, and not in the sudden manner which characterises the other forms of the variable state.

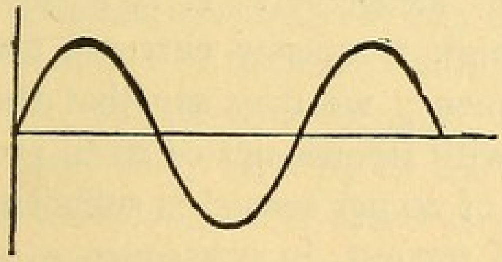


Fig. 59.
Sinusoidal Current.

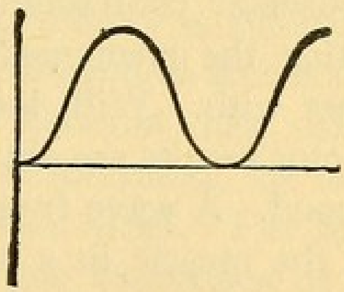


Fig. 60.
Undulatory Current.

With low frequency, when each wave is broadened out, sinusoidal currents have but little action on volunatry muscle. The effect is augmented as the frequency is increased.

In addition to their action as currents of the variable state, sinusoidal currents have an electrolytic action, which brings them into relation with the continuous current.

In studying the physiological action of sinusoidal currents we have to consider three points.

1. Their action on voluntary and on involuntary muscle.

2. Their electrolytic action.

3. The physiological results of their prolonged application.

319. **Action of Sinusoidal Currents on Striated and on Unstriated Muscle.**—The excitation due to sinusoidal currents varies according to two principal factors, the frequency and the amplitude of the undulations. (118.)

In order to attain the verge of excitation with a sinusoidal current of given intensity, a certain frequency is required, below which no contraction results. Up to a certain point the degree of muscular response increases with the frequency.

Beyond this point, *i.e.,* above 1000 to 2000 alternations per second, the increase of muscular response with added frequency ceases; and beyond 10,000 alternations per second muscular contraction ceases altogether. It is at this point that the phenomena of high frequency currents are first met with. With low frequency we may say that the best motor results are obtained with frequencies of 20 to 150 per second. A wave frequency of 20 per second is sufficient to put the muscle in a state of tetanus, in consequence of the fusion of the individual contractions. With weak currents a somewhat higher frequency is required to produce tetanus.

Non-striated muscle responds in a most marked manner to the excitation of the sinusoidal current, which leads to its therapeutic application in various directions. Sinusoidal currents also appear to have a special action on the sensory nerves, and are particularly useful in the treatment of certain forms of neuralgia.

320. **Transport of Ions by the sinusoidal current.**—*A priori* we would imagine that there could be but little ionic transportation, when we take into consideration the slowness of ionic motion and the rapid alternation of the current. Experiments, both physical and physiological, have, however, demonstrated the electrolytic action of the sinusoidal current.

The experiments of *Ayrton, Perry, Maneuvrier, Chapuis, Labatut* shew that for a given current the ionic action is greater when the alternations are slow. *Labatut* demonstrated the penetration of the pilocarpine ion at both electrodes, which leads us to suppose that the sinusoidal current sets up ionic exchanges in the substance of the tissues, comparable with those produced by the continuous current. This explains the physiological action of the sinusoidal current, which had been already established clinically by *d'Arsonval.*

321. **Physiological action of the sinusoidal currents on the general system.**—When the entire body is submitted to the action of these currents, there is a general acceleration of the nutritive exchanges. As *d'Arsonval* has shewn, the respiratory capacity of the blood is increased, the blood cells absorbing 20% more oxygen than usual. The urine also indicates an increase in the organic exchanges of the body. The circulation is accelerated, an effect which may perhaps be due to the special action of the sinusoidal current on unstriped muscular fibre.

322. **The Undulating Sinusoidal Current.**—From the physiological point of view, the undulatory current may be considered as a combination of the sinusoidal with the continuous current, analogous to the combination of gal-

vanic and faradic currents in the Watteville current. As is shewn in Fig. 60, the curve of excitation is entirely on one side of the axis X. The most important point from a physiological point of view is the electrolytic action of the superimposed continuous current, which is added to the excitation due to the variable state.

CHAPTER III.

HIGH FREQUENCY CURRENTS.

323. **Physiological action of High Frequency Currents.**—The currents of high frequency consist of isochronous oscillations which rapidly die down, as shewn in Fig. 61.

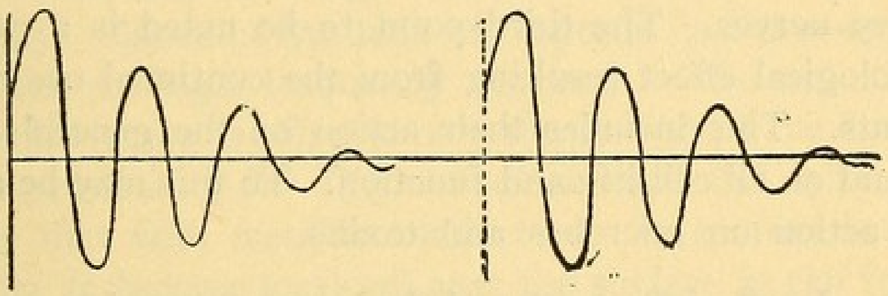


Fig. 61.

There are various modes of carrying out high frequency treatment.

1. The currents may be applied *directly* by means of two electrodes in series with the *d'Arsonval* helix or other high frequency circuit. A high frequency circuit may be defined in general terms as any circuit of considerable self-induction connecting the external armatures of two condensors.

2. The patient may be treated by *auto-conduction* or by means of the condensing couch.

3. In order to produce local effects, the patient may be exposed to electric radiations, consisting of *effleuves,* or spark discharges in their different forms.

In whatever way the high frequency treatment is applied, whether by auto-conduction or by radiation, the patient is exposed either directly or by induction to enormous differences of potential of an oscillatory character. What impresses the physiologist most strongly is the fact that the neuro-muscular system does not in any way respond to the currents of high intensity and tension which traverse the patient's body. His muscles do not contract and his nervous system does not register any impression. The first point then is the complete absence of excitability. The second point is the production of anæsthesia, due to a special inhibitory action of the high frequency currents on the sensory nerves. The third point to be noted is a general physiological effect resulting from the continual use of the currents. This includes their action on the general nutrition and on all cell-life and function. To this may be added their action on microbes and toxins.

324. **Lack of Response of the neuro-muscular, and the neuro-sensitive system to high frequency currents.**—When a body is submitted to the direct action of high frequency currents, or exposed to auto-conduction, or to radiation by means of the effleuve, it is traversed by direct or induced currents of considerable intensity. These currents may be demonstrated by the classical experiments of *d'Arsonval.* When one or more persons are placed in a circuit in series with a high frequency helix, they are traversed by a current capable of illuminating a 100 candle power lamp, introduced into the circuit by being held between the hands of two persons. In the same way when the subject is placed in a field of auto-conduction, he may light up an incandescent lamp by means of the currents of auto-conduction which pass between his hands.

Moreover, when a part of the body is exposed to high frequency effleuves, sparks may be drawn from any portion of the integument, proving that the whole body is subjected to oscillatory variations of potential. In all these cases, notwithstanding the strength of the currents which traverse the body, there is neither muscular contraction nor sensation of shock. If any sensation is felt, it is due to shocks of low frequency caused by faulty conditions of experiment. The spark-gap may be imperfectly regulated, or the balls rough and unpolished, the spark may be in fault, or there may be bad contact in the circuit, or between the armature and the dielectric, or the capacity or self-induction may be too great. (*D'Arsonval.*)

325. **Cause of the lack of response of the muscles and nerves to high frequency currents.**—The old idea was that the currents affected only the surface of the body without penetrating it. *D'Arsonval* exposed this fallacy. It is true that with metallic conductors, the current has a tendency to become localised near the surface as the frequency increases. This is only true, however, of metallic conduction. With electrolytic conduction, on the other hand, the current penetrates the mass of the body more and more as its resistivity increases.

D'Arsonval established the fact of this penetration by passing a high frequency current through a cylinder containing .7% saline solution. The current in the centre and at the periphery did not sensibly differ in intensity. An experiment due to *Maragliano* confirms this. A small electric lamp was placed in the thoracic cavity of a dog, and the poles were joined to two metallic plates, placed one on either side inside the pleural cavity. When the animal was exposed to high frequency currents the lamp became incandescent. (Arch. d'electricite, Médicale, 1901.)

If it were true that the currents did not penetrate the body, it would be impossible to explain the profound action of high frequency currents on nutrition.

At the present day the explanation generally accepted is the following: Motor and sensory nerves respond only to stimuli, whose period is less than 10,000 per second, just as the acoustic nerve responds only to stimuli between 32 and 60,000 per second and the optic nerve to stimuli whose period is between 728 and 497 billions per second.

Weiss' investigation on the physiological action of waves of short duration throws great light on this point, which at first sight appears paradoxical if we admit the accuracy of *du Bois-Reymond's* formula.

326. **Explanation of the phenomenon of non-excitability.**—*Weiss'* experiments shew that an undulation of a given amplitude can only provoke contraction when it is of a certain duration. Consider the curve of excitation of a muscular secousse produced by the closure of a continuous current. The ascending curve due to closure is followed by a flat portion of a duration sufficient for the muscle to reach the level of excitation. If now this flat portion is diminished in length or interrupted, the stimulus immediately falls below the level of excitation. In order to gain the level of excitation with a short or interrupted wave, the intensity of the current must be augmented. Suppose now that the interruption of the flat portion consists of a fall to zero and an inverse wave. The perturbation caused at the moment of inversion will add to the difficulty of regaining the level of stimulation and the intensity must be again increased. By multiplying these inversions a time comes when the first wave, however strong, is powerless to reach the required degree of excitation, and each subsequent wave will be equally powerless.

In Fig. 62, let A B C be a wave of electrical stimulation.

If Q be the quantity of electricity necessary to reach the verge of excitation, and a and b the coefficients of the nerve, (299) then Q = area of A B C (Fig. 62) = a + bt.

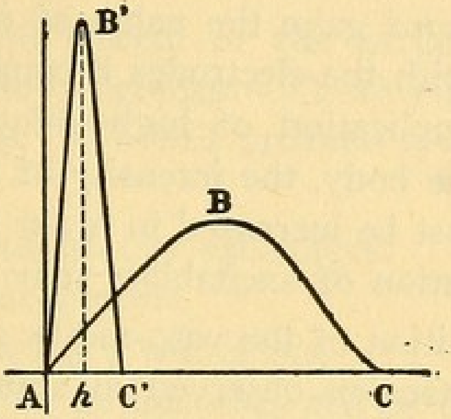


Fig. 62.

If we now diminish t indefinitely, using waves of short duration $\frac{1}{100}$ o $\frac{1}{10,000}$ of a second, the quantity Q required to cause excitation will decrease also, since bt will approximate to zero. The quantity of electricity, a, however, remains unaltered, and to obtain this necessitates an ever increasing height of the wave as the time diminishes. As the sides of the curve AB' and B'C are brought together, the height B'h must increase in order that the area AB' C' may remain equal to a. Hence there must come a time when we can no longer increase the amplitude B' sufficiently to obtain the quantity Q necessary to produce contraction. The same argument applies when we use the modified formula of *Lapicque.*

Hence from a consideration of *Weiss'* formula it is evident that with high frequency currents we cannot reach the required degree of excitation with an isolated wave, or with a succession of waves, since when the time is excessively short each wave weakens the effect of its successor.

327. **Anæsthetic effects of high frequency currents—Inhibitory action—Action on the unstriped muscular fibres**

of the vascular system.—From the very commencement of his work on high frequency currents, *d'Arsonval* noticed their effect on the neuro-muscular system, an effect to which *Brown-Sequard* gave the name of *inhibition.* The tissues in contact with the electrodes become less excitable. Thus after the application of high frequency currents to any region of the body, the intensity of the galvanic or faradic stimulus must be increased in order to produce contraction. This diminution of excitability may go on to analgesia.

The inhibition of the vaso-motor system explains the fall of arterial tension observed in animals submitted to high frequency currents. If a mercurial manometer is introduced into the carotid artery of a dog, a fall of several centimetres of mercury is observed on exposing the animal to high frequency currents. The same phenomenon accounts for the dilatation in the vessels of the ear of a rabbit, and the general sweating observed in patients treated with auto-conduction.

High frequency sparking, on the contrary, produces a spasmodic contraction of the involuntary muscular system, accompanied by anæmia of the tissues and the phenomenon of goose skin. The rise of blood pressure which corresponds to this spasmodic anæmia is specially noticeable when the spine is treated with a shower of sparks. *Montier* has recorded a rise of 4 to 8 centimetres of mercury in the manometer during the exposure of the spine to a shower of sparks passed from above downwards.

The primary vaso-dilatation due to auto-conduction is not persistent, but is followed by vaso-constriction with increased arterial tension which continues for some time after the exposure. When a portion of the body is submitted to effleuvation, the primary congestion is followed after the exposure, by a reaction in the opposite direction with oscillations above and below the normal arterial pressure. This was shewn by *Oudin* in some experiments made with the sphygmo-manometer devised by *Laulanié*.

328. **Physiological effects of the prolonged application of high frequency currents.**—These may be grouped under four headings. We will proceed to study each of these in turn.

a. Effect on the respiratory exchanges.
b. Effect on thermo-genesis.
c. Action on the urinary secretions.
d. Action on cell life, on microbes and on toxins.

329. **Effect on the respiratory exchanges.**—As shewn by *d'Arsonval,* high frequency treatment increases the number and the amplitude of the respiratory movements.

The expired air shews an increase of CO_2. In *d'Arsonval's* experiments on himself under the influence of auto-conduction, the quantity of CO_2 eliminated increased from 17 to 37 litres per hour.

Under the influence of auto-conduction the loss of weight in animals was greater than normal. During an experiment which lasted 16 hours, a guinea-pig lost 30 grammes instead of 6 grammes, and a rabbit lost 48 grammes instead of 23 grammes. After the exposure the animals gained weight, proving that the weight of oxygen absorbed was then in excess of the carbonic acid eliminated. This experiment is in accordance with *Bouchard's* observation, that under the action of high frequency currents, there is an increase of weight although no food or drink has been taken. *Regnauld* and *Reizet* have made similar observations on animals during sleep.

Querton disputes these results. This is probably due to the fact that in his experiments he made use of a solenoid of 72 turns, whereas that of *d'Arsonval* was much shorter.

The enormous amount of self-induction in *Querton's* apparatus modified the electrical conditions considerably. His experiments have also proved how greatly any change in external conditions, such as ventilation, temperature, etc., may modify the results[1].

D'Arsonval points out that *Querton* allowed his animals to remain in a confined atmosphere which became more and more saturated with CO_2. It is not to be wondered at that under these conditions the nutritive exchanges were diminished. The fact that the amount of CO_2 excreted was not diminished proves that the high frequency was able in some measure to compensate the unfavourable conditions of the experiment[2].

Experiments conducted by *Tripet* and *Guillaume* shew that auto-conduction augments the reduction of oxyhæmoglobin in patients with imperfect nutrition, while it diminishes it in patients where the reduction is already exaggerated.

330. **Effect on Thermogenesis.**—*D'Arsonval's* experiments with the anemo-calorimeter shew that the amount of heat given off by the body is nearly doubled under the influence of auto-conduction. These observations have been confirmed by *Bordier* and *Lecomte*. *Bonniot,* using the condensing couch, was led to the same conclusions.

331. **Action on the urinary secretion.**—*D'Arsonval* found from experiments made on patients under the care of *M. Charrin,* that high frequency currents augmented the elimination of extractive matters, particularly urea, and increased the toxicity of the urine. There was at the same time a decrease of the non-oxidised or incompletely oxidised sulphur compounds. (*Réale* and *Renzi*. Experiments on the estimation of oxyproteic acid.)

[1] Annales d'électrobiologie, Jan., 1900.
[2] Annales d'électrobiologie, Sept. and Oct., 1900.

From a series of clinical observations, *Apostoli* and *Berlioz* conclude that under high frequency treatment, the ratio of uric acid to urea tends to approach the normal value, $\frac{1}{40}$, while the ratio of phosphoric acid to uric acid remains unaltered.

The treatment by means of the condensing couch seems to give results which are more rapid than those obtained by auto-conduction. While treating patients suffering from chronic rheumatism, *Morton* observed an augmentation of urea and a diminution of uric acid.

Réale and *Renzi* consider that the favourable result of high frequency treatment in diabetic cases may be explained by the increased excretion of uric and phosphoric acids. This simultaneous increase of excretion of both acids in the same proportion seems to point to some action of the currents on nuclein, which is probably the original source of the sugar in the urine.

Dénoyès, Martre, and *Rouvière* have repeated these experiments. They made three series of observations.

a. Chemical analysis of the urine.

b. Experiments on the toxicity of the urine.

c. Determination of the point of congelation.

From these experiments they obtain the following results:

1. Under the influence of high frequency currents there is an augmentation of the quantity of urine excreted, of urea and of uric acid. The total quantity of nitrogen eliminated is also increased, together with that of the phosphates, sulphates and chlorides. The ratio of nitrogen to urea is also increased.

2. The *uro-toxic coefficient* is raised, and there is a diminution in the number of elaborated toxic molecules necessary to kill an animal of given weight[1]. This last

[1]Bouchard, "Troubles préalable de la nutrition. Traité de Pathologie., Tome, III.

observation is important, since it shews that the increased toxicity of the urine is due, at least in part, to the increased toxicity of each molecule, and not to a mere increase in the number of toxic molecules.

These conclusions have been confirmed by *Dénoyès'* work based on the cryoscopic examination of the urine.

The alteration of the urine due to a high frequency seance is maintained for several days.

332. **Action of high frequency currents on Cell-life, on Microbes and on Toxins.**—High frequency currents have an influence on cell life. They affect the germination of plants and the life of micro-organisms. Observations have been made by *d'Arsonval* and *Charrin* on bacillus pyocyaneus, and the toxin of diphtheria, by *Bonome, Viola* and *Casciani* and *Dubois* on the toxin of streptococcus, and by *d'Arsonval* and *Phisalix* on cobra-venom. In spite of some divergence, these observations concur in shewing that the virulence of toxins is diminished by high frequency currents in the form of auto-conduction.

Their action on living microbes appears more doubtful. Thus bacillus pyocyaneus preserves its colouring and pathogenetic action, although in some instances the bacillus seemed to grow less rapidly. (*D'Arsonval* and *Charrin.*)

Marmier supposes that the above result may be due to a rise of temperature caused by the high frequency current, but recent experiments undertaken by *d'Arsonval* have shewn that this is not the cause.

333. **Local Physiological effects of the effleuves and sparks.**—There is but little to be said of the action of high frequency effleuves or sparks on the healthy skin, if we leave out of consideration the effects on the general system. An energetic vaso-constriction is produced at the spot where a spark or powerful aigrette strikes the skin.

If the exposure is of long duration, a blister may make its appearance, and the inflammation of the skin may be most intense and prolonged. The action of the effleuve on morbid tissue constitutes an important chapter in electrotherapy.

According to *Doumer* and *Oudin,* the effleuve appears to have no action on toxins.

CHAPTER IV.

PHYSIOLOGICAL ACTION OF STATIC ELECTRICITY.

334. **General Considerations.**—We may represent the state of a body, charged to a given electrical potential, as the result of an alteration of the dynamic equilibrium of its molecules. If the body is completely insulated, and the electric charge which has been communicated to it is not dissipated, the alteration is a stable one. A new state of molecular equilibrium has been established, which will persist indefinitely without any expenditure of energy.

This ideal static bath cannot be realised in practice, because it is impossible to insulate a body completely, and in order to maintain it at a given potential, fresh electrical charges must be brought to it to replace those which are dissipated.

In this way an equilibrium may be maintained, since the potential may be kept constant, but it is not an equilibrium of repose but an equilibrium of motion, necessitating the expenditure of energy.

When we place a patient under the influence of an electrostatic machine, we are in reality submitting him to a current of high potential. We get absolutely the same phenomena as when we pass a galvanic current through a conductor. Consider a section of such a conductor. At the moment of "make," it receives a perturbation, and immediately it tends to regain its former condition of equilibrium, by transmitting the perturbation to the adjacent section. This tendency to return to the neutral state is again opposed by a new perturbation, transmitted like the former one. There is thus a series of perturbations continually renewed as fast as they are transmitted.

The physiological effects of such a condition differ greatly from that of the ideal static bath, in which the organism would be raised once for all to a given potential and maintained there in an equilibrium of repose.

In practice the ideal static bath is unobtainable. We have therefore to study the physiological effects produced when an organism is submitted to the various varities of currents of high potential which are produced by an electrostatic machine. These are the electric bath, the electric breeze, sparks, the aigrette, friction and shocks.

335. **Modes of application of the electricity furnished by an electrostatic machine.**—The following are the methods we may employ when using a bipolar electrostatic machine. We may place the patient directly in connection with the two poles of the machine, in which case he will be traversed by an exceedingly feeble current. The energy absorbed by the body will be very small and the effect negligable. The effect may be increased in various ways.

a. We may interrupt the circuit in the course of a conductor. If we separate the two extremities of this interrupted conductor, sparks will pass across the gap, giving rise to variations of potential through the whole circuit at the moment of discharge. The name of *mediate excitatation* has been given by *Tripier* to this form of static discharge. If the poles of the spark gap are furnished with points, and are still further separated, we get a continuous flow of electricity through the air, which is a dielectric of great resistance. We thus obtain an arrangement which *Weill* calls a rheostat, since it introduces a considerable resistance into a circuit, the resistance of which when closed is practically negligable. The gaseous resistance plays the same part as the fine nickel wire introduced into the circuit of a galvanic cell which has been previously short-circuited. The maximum difference of potential is found between the two poles of the rheostat.

b. Instead of introducing an air resistance in the course of the conductor, we may introduce it between the surface of the integument and the electrode attached to one of the poles of the machine.

When such an electrode is placed at a short distance from the skin, a series of sparks is produced between it and the skin. We may sift out these sparks by making them pass through several thicknesses of cloth and we then get the so-called *electrical friction.*

If the electrode is terminated by a point and is removed to a greater distance, we produce the *electric aigrette, electric effleuve,* the *electric souffle* or the *electric douche.*

In this case the disruptive discharge takes place on contact with the skin, and it is there that the principal fall of potential occurs. The various forms above described are termed *direct franklinisation.*

The electric bath is only a form of direct franklinisation, in which we may imagine the electrode separated from the patient's body, placed at a distance, and finally suppressed, being earthed or not as the case may be. The electricity is then discharged into the surrounding air from every asperity on the patient's body.

The conditions may be varied by earthing either the patient or the active electrode. According to the old terminology, the patient was said to undergo *electric exhaustion* when the operator was earthed and drew sparks from the patient. On the other hand the patient was said to undergo *electric irroration* when the patient was earthed and received sparks from the machine.

Mediate excitation consists in the production of sudden variations of potential in the circuit, at the moment when the spark passes across the gap in the circuit. It is of interest to the physiologist in consequence of its motor effects.

The production of *Morton's* currents (177) is another method by which rapid variations of potential are produced in the circuit of a static machine.

We shall now proceed to examine the physiological properties of each of these different methods in turn.

336. **Electrostatic Bath.**—The patient is insulated and placed in connection with one pole of the machine, the other pole being usually earthed. The electricity escapes from all points of the integument, giving a slight tickling sensation, as if the skin were rubbed with gauze. The body is thus traversed by a constant electric current of high tension. There is some controversy about the physiological effects of the electrostatic bath, but they appear to be as follows:

a. Increase of frequency of the pulse, which may be maintained for a week after treatment by static electricity has ceased. (*Truchot.*)

b. Increase of arterial tension. All observers recognise this effect, although it does not seem to be in accordance with the increased frequency of the pulse.

c. Slight rise of the general temperature. (*Vigouroux.*) According to *Damian* the increase is more noticeable when the positive pole is used. It may persist for some time after a course of several seances. There is also an increase of muscular force immediately after the use of the static bath. (*Truchot.*)

d. According to *d'Arsonval* there is an augmentation of the respiratory combustion. This is due to the production of ozone, which is more readily fixed by the red blood cells than atmospheric oxygen. (*Bordier.*)

e. The secretion of urea is greatly modified, the ratio of urea to the total nitrogen being increased. (*Truchot.*) This indicates that the oxidation of nitrogenous matter is very active, since urea is the product of complete oxidation of nitrogenous matter. The opposite effect is produced if the seances are too frequently repeated. According to *Truchot's* theory, the organism when burning too fast, burns badly, and leaves products of combustion which are incompletely oxidised.

The physiological effects of the *negative bath* on the urinary secretion have been specially studied by *Matre* and *Florence,* who followed the work of *d'Yvon* on this subject. They found a diminution of the phosphates and uric acid, and a decrease of the ratio of the total carbon in the urine to the carbon present in the albuminoids, corresponding to a diminution in the average weight of the molecule. The static bath therefore acts in the same way as the currents of high frequency, but not so powerfully.

c. Other general effects are produced, such as acceleration of the digestive functions and a tendency to sleep.

337. **Electrostatic Souffle.—Electrostatic Douche.—Effleuvation.**—The electric souffle is produced by a current of electrified gaseous molecules, impinging on the skin. It produces a lowering of the surface temperature and a cooling sensation. This is due to increased cutaneous evaporation and also to the contact of the cooler gaseous particles with the skin. *Bordier* has shewn that the negative souffle produces a greater reduction of the temperature than the positive souffle, and that this reduction is prolonged for some time after the termination of the sitting.

The electrostatic density is greater with the negative than with the positive souffle. An experiment of *Bordier's* proves this conclusively. He exposed starch iodine test paper, which turns brown under the action of ozone, to the positive and negative souffle and found that the area of discolouration produced by the negative souffle is of deeper colour, but of less extent. The same author measured the intensity of the air current by means of an anemometer, and found that the negative breeze was stronger than that issuing from the positive pole.

The angle of the discharging point is also of great importance. *Bordier* found that the area influenced by the breeze increased with the bluntness of the point. The optimum effect was produced with an angle of 90° or more. (*Bordier,* Précis d'électrothérapie.)

The static breeze has a sedative action, calming painful sensations. It also appears to act as a stimulant of the vitality of the tissues, probably by its action on the trophic nerves. In this way we may explain its beneficial effects on the voice, in the case of public singers. (518.)

338. **Electrostatic Sparks.—Electric friction.**—Electrostatic sparking of the skin by means of an exciter has various effects.

a. Effects on the nerves of general sensation, or on the local sensory nerves.

b. Effects on vaso-motor nerves.

c. Motor effects.

d. Effects on the general system.

339. (a) **Sensitive or sensory effects of the static spark.**—If the spark is small and thin, the sensation is that of a small pin-prick, while if the spark is stronger there is a sensation of shock. In sensory nerves, such as the optic nerve, the spark produces the same effect as other nerve stimulants.

340. (b) **Vaso-motor effects.**—When a region is subjected to a shower of sparks, the first result is vaso-constric-

tion, with pallor of the skin. To this succeeds vaso-motor paralysis with relaxation of the smaller vessels, local rise of temperature and redness.

These effects become more noticeable with the positive than with the negative pole. This was clearly demonstrated by *Bordier's* experiments, in which all sources of error due to direct heating by the spark were carefully eliminated.

The effects of the direct spark vary with the patient, with the intensity of the spark, and with the pathological condition. In subjects affected with goitre they are most marked, these patients often exhibiting the phenomenon known as *dermographism*[1].

341. (c) **Motor effects of the direct spark.**—The sensation of shock which accompanies the spark is due to muscular contraction. If instead of passing between the exciter and the skin, the spark be allowed to pass in another portion of the circuit, the prickling sensation is suppressed, and the shock only is felt. In this way we are better able to study motor effects. *Bordier's* experiments, made with *Marey's* myograph, shew that the contraction is quicker and more pronounced with the negative pole. This corresponds with the action of the negative pole on closure with the galvanic current.

From experiments on muscular contraction made with mediate sparks of different lengths, *Bordier* has shewn that "the degree of muscular contraction is directly proportional to the square of the spark length."

When the muscle is stimulated by means of the direct spark, using spheres of different sizes as exciter, it is found that the degree of muscular contraction varies with the size of the sphere. *Bordier* has determined the relation between

[1] Bordier. Archives d'Electricité Médicale, 1898, p. 506.

the degree of contraction and the diameter of the exciter for a given length of spark.

He has also demonstrated the influence of the electric density on the contraction of the muscle, employing an exciter with balls of different sizes. The smaller the ball, the greater is the electric density, since the surface of contact between the ball and the skin is smaller for a sphere of less diameter. His results agree with what we should expect from theoretical considerations; the greater the density, the stronger is the contraction. With direct stimulation we get the greatest result with the smallest electrode, the maximum effect being produced by a pointed electrode in contact with the skin. The contraction would be greater still if we could charge the patient himself, since the electric density would be at a maximum, the section of a spark being still smaller than that of a pointed electrode.

342. (d) **General effect.—Electric friction.**—The static spark has a more profound effect than might be expected. We have already seen in our study of the motor effects, that the deeper tissues are influenced by variations of potential. We shall meet with even more manifest effects of the variable electrical state when we come to study the motor phenomena of Hertzian franklinisation.

Electric friction, by means of a rain of small sparks also produces a sedative effect on the deeper tissues. (*Vigouroux.*)

When prolonged and localised on one spot, the spark douche may cause the formation of a blister.

343. **Morton's Currents.—Hertzian Franklinisation.**—We may obtain a sort of direct franklinisation of the skin by means of Morton's currents applied with an electrode held at a short distance from the skin. The action is then comparable with that of the high frequency sparks, or elec-

trostatic sparks. The usual way of applying Morton's currents is to place the active electrode directly on the integument, the patient being earthed. (177.)

With each spark in the spark gap, the patient is submitted to a sudden variation of potential, followed by isochronous oscillations which rapidly die down. (123.) The motor effects of Morton's currents are characterised by their depth, their energy and their freedom from pain. The currents act most energetically on unstriped muscular fibre, as well as on voluntary muscle. With discharges repeated fifty times per second, a painless tetanisation of the muscle may be obtained.

CHAPTER V.

PHYSIOLOGICAL ACTION OF THE VARIOUS RADIATIONS.

344. **General Considerations.**—The study of the diffent radiations or undulations transmitted by the ether should include the Hertzian waves, radiant heat, the infra-red rays, light, ultra-violet rays, and the various new radiations which under the name of X-rays, secondary rays, cathode rays, radio-active radiations, N-rays, etc., either find their place in the gamut of wave lengths, or are caused by the emission of ultimate particles of matter.

At the present time this synthetic study is not possible, and in any case it would not come within the scope of this work.

The Hertzian undulations constitute the lower notes of the scale of transverse vibrations of the ether. These have been already studied in the paragraphs devoted to high frequency treatment and we need not consider them further.

The electro-cautery will come under the heading of heat radiation resulting from the transformation of electric energy.

In studying the physiological effects of Light we shall restrict ourselves to a consideration of the *Finsen* treatment. Finally, the physiological action of the new radiations may be summed up in a single chapter, which will include a study of radio-dermatitis.

The recent discoveries of *Bécquerél, Curie, Blondlot, Charpentier, Meyer, Bichat* and others have opened up to us new and vast intellectual horizons, since vital phenomena appear to be associated with the production of a new order of radiations. These observations are, however, too recent as yet to find their place in a chapter on general physiology. We shall confine ourselves to consideration of the following subjects.

1. Galvano-cautery and the action of radiant heat from an electric source.

2. The action of light rays derived from an electric source.

3. The action on the normal organism of the X-rays, and the rays emitted by radio-active substances.

345. **Action of Radiant Heat.**—A certain mean temperature is indispensable for every organism. Physiology explains the means by which this constant temperature is maintained in spite of external variations. Nevertheless, the variations of external temperature produce certain physiological effects, and may consequently be employed for therapeutic purposes. There are three methods of applying heat.

1. *Moist Heat,* by means of warm baths, poultices, fomentations, vapour baths, etc. We will not allude to these further than to warn patients of the danger of using the vapour bath above 45°C. in consequence of the diminished evaporation from the surface of the integument, and also from the respiratory tract, if the head is included in the bath. The symptoms are vertigo, syncope, congestion and hæmorrhage.

2. *Dry Heat,* by means of bran, hot sand, the electric thermophore, the hot dry air bath, etc. Although a hot air bath may be used at a higher temperature than a steam bath, it is better not to raise it above 80°C. The *electric thermophore* consists of a light incombustible tissue in which are woven wires of high resistance carefully insulated, which may be heated by the passage of a current. The

thermophore may be applied directly to the skin, or with the interposition of a compress, in order to produce a moist heat or poultice.

If not well ventilated, the hot air bath soon becomes transformed into a vapour bath, and the danger of a high temperature increases with the degree of moisture. With good ventilation, a temperature of nearly 140°C. may be borne. (*Tallerman.*)

3. The third category, which more particularly interests us here, includes all the applications of radiant heat from sources which are also luminous.

Here it is no longer the contact of the circumambient air at a high temperature which stimulates the skin, but radiations from a distant source which fall upon the skin without producing any great rise in the temperature of the air through which they pass. A thermometer placed in a beam of radiant heat may rise to 240°C., while the organism which receives the rays is in no way incommoded. The body may be without danger completely immersed in a radiant heat bath which will raise the thermometer to 205° C. provided that the air is constantly renewed, so that the bath does not become a vapor bath. *Tonta* of Milan has designed an arrangement whereby the ventilation is ensured, and the hygometric condition of the air indicated continuously[1].

As regards the action of these electric heat baths, they do not differ from those of heat in general. The surface circulation is increased, and the lymphatic vessels are dilated. (*Kowolski.*) At the same time there is diminution of the arterial pressure, and augmentation of the pulse frequency.

The sedative action of moist heat has been well known for ages. There is a tendency in these days to employ methods

[1] Congress of Berne. 1902.

of treatment whose novelty consists only in the complexity and luxury of the apparatus. It is well that both the patient and the practitioner should be on their guard against this tendency.

346. **Galvano-cautery.**—In the effect on the tissue there is no fundamental difference between the old-fashioned metal cautery, the thermo-cautery and the galvano-cautery. The two latter are, however, in universal use on account of their convenience, and the absence of heat radiation from a large mass of metal necessary in using the older form.

The galvanic cautery, and particularly the galvanic knife, enables us to sever tissues without hæmorrhage.

The hæmostatic effect is due in part to the obliteration of the smaller vessels by the action of heat, and in part to the coagulation of the blood.

In order to secure this hæmostatic action the temperature should not be too high. We should always use the same cautery, as practice, better than any mode of measurement, enables us to regulate the required degree of heat. The intensity of current required to keep the cautery at a dull red heat varies according to circumstances. For example, a cautery which will become white hot in air with a current of 8 amperes, may require 20 amperes to enable it to cut rapidly through muscular tissue, while in other cases it may only require 12 amperes. An amperemeter is of great use, especially if one is working in a position where the noose is not readily visible. The amperemeter will warn us if we are in danger of fusing the wire.

347. **Action of Electric Light.**—We shall only treat here of the physiological effects of light which specially interest the medical electrician. A large volume might be written on the action of light on the evolution of living organisms. A luminous ray, from whatever source, has the

same properties. The only factor which differentiates the rays of light from one another is their wave length.

The luminous gamut, that is the scale of rays which are able to impress the retina, commences with a wave length of 698 μ and goes up to 392 μ.

The following table gives the luminous sensations corresponding to a given wave length:

Violet	392 μ to 428 μ
Indigo	434 μ to 449 μ
Blue	457 μ to 500 μ
Green	500 μ to 544 μ
Yellow	562 μ to 583 μ
Orange	600 μ to 660 μ
Red	663 μ to 698 μ

The ultra-violet rays with a shorter wave length than 392 μ, and the infra-red rays with a longer wave length than 698 μ are both imperceptible to the retina.

Although invisible, these rays form a large part of the external conditions which have determined the evolution of living organisms. This is especially the case with the infra-red rays, among which are the caloric rays. The atmosphere being much more opaque to the ultra-violet rays, the organism has not been subjected to their influence during the long course of evolution. This fact must be remembered in studying the action of monochromatic light on organisms which have been developed under the influence of solar light. We have at our disposal two methods of experimentation. We can submit the organism to what is called *positive phototherapy, i.e.,* a more intense light of a definite wave length. Or we may deprive the organism, for a longer or shorter period, of a portion of the rays of the solar spectrum. This *negative phototherapy* is the method adopted by experimenters who have desired to study the action of green, red or blue light on the evolution of animals or plants.

In the case of a living organism under a screen which is opaque to light of a certain wave length, we must remember that it is deprived of only one light note of the whole gamut of transverse ethereal vibrations. It is difficult to eliminate the caloric rays since most coloured screens are diathermic.

Some chemical substances, a solution of alum for example, are transparent to the waves of light but not to those of heat. Others, such as a solution of iodine in bisulphide of carbon, are diathermic, but opaque to light. When we expose an organism to monochromatic light we merely eliminate that part of the scale vibrations which is immediately above or below the given tint, *i.e.*, the rest of the *visible* spectrum. Such being the case, we are the less surprised at the contradictory conclusions to which different experimenters have arrived. For instance, the suppression of the luminous rays of wave length between 340 μ and 700 μ will have a different effect according as the organism is subjected to a greater or less irradiation from invisible rays of shorter wave length.

A second cause of error is that the light screens for monochromatic light allow other rays to filter through, which differ according to the nature of the screen. There is also considerable difficulty in comparing the intensity of monochromatic and ordinary light.

We shall proceed to give some results of negative photo experiments which are of interest in their bearing on phototherapy.

We shall proceed to the study of some positive photo experiments. These consist in the exposure of the organism to monochromatic or polychromatic light of medium intensity, or to the more intense radiations of the *Finsen* light.

348. **Negative phototherapy.**—In spite of numerous contradictions, certain conclusions seem fairly well established.

The blue and violet rays of the spectrum are necessary for the development of eggs and larvæ. Rays of short wave length stimulate their development more than ordinary light. On the other hand, green or red light retards development. These are the results of experiments by *Béclard* on the eggs of musca carnaria in 1858, and of *Schnetzler* on the eggs of frogs in 1874. As regards their stimulating action on development, *Yung* arranges the rays in the following order; Violet, Blue, Yellow, White, Red, Green, which differs but little from the order of *Béclard.*

According to most observers, the absence of all light retards evolution, and diminishes the activity of nutritive change. Animals inhale less CO_2 in the dark. This has been observed in experiments on dogs, pigeons and chickens.

The largest amount of carbonic acid is exhaled under the influence of yellow light. (*Selmi* and *Piacentini.*) In 1875 *Pott* observed that yellow and green light stimulate the elimination of CO_2. *Fubini* confirms these results in the case of frogs, the effect being the same, though in a less degree, when the animals are deprived of their sight. Similar results were obtained by experiments on hybernating animals, such as dormice and bats, shewing that the increase of tissue exchange is not due merely to wakefulness or muscular activity.

Recently *Mme. Rogovine* has carried out some experiments in *M. Richer's* laboratory on the production of the lactic ferment. These shew that blue, violet and ultraviolet rays stimulate the production of the ferment, whereas green rays retard it.

In general, we may say that the actinic rays accelerate the growth of primitive organisms, while green and red rays retard it. The suppression of these actinic rays may sometimes be of service in treatment. The intense application of monochromatic light of short wave length may also be used in phototherapy. The explanation of its use must be sought in these negative photo experiments.

349. **Action of positive phototherapy on the tissues.**—A cell, an organ or tissue, whose evolution has taken place under the influence of solar irradiation, can be influenced, not only by deprivation, but also by exaggeration of certain rays of the spectrum which fall upon it. An organism whose evolution has occurred under the influence of only a portion of the solar spectrum, may be incapable of adapting itself to a life in a more luminous entourage. Positive photo-experiments prove that light has a deleterious effect on the growth of such organisms. *Downes* and *Blunt* have shewn that the active rays especially have a destructive action on bacteria and their spores. *D'Arsonval* and *Charrin* have made similar observations on bacillus pyocyaneus, and *Arloing* on bacillus anthracis.

Gebhard has shewn that the integuments are permeable to the luminous rays. This he did by taking an impression on a photographic plate through the thickness of the hand, the interdigital spaces and edges being stopped with plaster. This enables us to understand the therapeutic action of light on microbic growth, an idea which has borne fruit in the treatment of lupus by the *Finsen* light. (482.)

First we may study the physiological action of luminous rays of great intensity. Even in feeble doses, light has a deleterious action in certain diseases such as variola and measles. With the intense irradiation now used in treatment, it must exercise a still greater effect.

After a seance of phototherapy by *Finsen's* method, the healthy skin becomes red and swollen, the inflammation attaining its maximum 10 to 12 hours and sometimes 24 hours after exposure. This delayed reaction is characteristic of the active rays; the caloric rays produce an instantaneous reaction. The delay is even more marked in the case of the X-rays, with which radio-dermatitis sets in 5, 10 or 15 days after exposure. With the *Finsen* treatment, the inflammatory symptoms subside from 4 to 8 days after exposure, and are followed by desquamation and pigmentation.

The action of the rays depends on their wave length. In ordinary sunburn, it is not the caloric rays, but the shorter chemical rays which produce the effect. The production of the ice-burn of the glaciers is a striking example of this.

Long before the introduction of phototherapy, *Bouchard* had studied the action of the different rays of the spectrum on the skin. The experiment was made by exposing his own arm to the focus of a lens placed in the various portions of the spectrum. The duration of each exposure was 30 seconds.

Red rays produced no effect.

Yellow rays produced a slight burning.

Green rays set up a slight erythema.

Blue rays produced a distinct blister.

As a result of these lesions and more particularly under the action of a "coup de soleil" (sun-burn), the skin becomes vascular and pigmented.

The increase in vascularity is not a mere dilatation, like that produced by heat; it is a durable phenomenon which may persist for months. Moreover, the integument becomes pigmented,—and pigmentation may be regarded as a mode of defense of the organism against the chemical rays, since the pigment absorbs the shorter radiations and thus protects the subjacent tissues. Under the article Ephelides, par. 491, the reader will find some further remarks on the reaction of the skin to solar irradiation, and on the subject of pigmentation and increased cutaneous vascularity.

350. **Action of X-rays and the radiations of Radio-active bodies.**—Without entering into the question of the nature of the X-rays and the various radio-active radiations, and ignoring the action of the electric field which always accompanies their production, we find that X-rays have a very definite action on the normal organism.

The most noticeable is the action on the skin. We can only treat this matter very briefly here, referring the reader for further information to the article by *Oudin* in *Prof. Bouchard's* Traité de Radiologie médicale.

a. Prolonged exposure to a powerful source of X-rays produce a definite alteration of the skin, which is known as *active radiodermatitis.* This is particularly the case if the focus-tube be a soft one giving out rays of feeble penetration. This may be termed the "coup de soleil" of the X-rays, and may be compared with the "coup de soleil" of the electric arc lamp produced by the chemical light rays. What characterises it more especially is the slowness of the appearance and evolution of the lesion. Burns produced by heat are instantaneous, chemical rays produce lesions which are progressive, but the X-rays set up lesions which are tardy in their appearance and in their evolution. Acute radiodermatitis commences with an erythema which appears from 24 to 36 hours after exposure. After remaining some days without any painful sensation, the erythema becomes a brighter red or violet colour, and first begins to become painful in from 10 to 25 days. Vesiculæ filled with a serous fluid make their appearance, and these are followed by bullæ and phlyctenulæ, which break and leave an ulcer at their base. A special pigmentation appears, which is more intense than that caused by the chemical rays. At the same time the hairs usually fall off in the irradiated area, while in the surrounding region, which has been more slightly irradiated, the capillary papillæ are by no means withered, but seem on the contrary to be stimulated, and the hairs grow more vigorously. This stage of radiodermatitis, which is a very painful one, terminates in the formation of a large superficial suppurating ulcer. Reparation may follow at this stage, or the wound may begin to slough, with the formation of yellow islands of dead tissue at the bottom of the wound. At this period the pain is so severe as to have an injurious effect on the general health, and the patient may become cachectic. The sloughs separate very slowly, and a new one may appear. Cicatrisation is delayed and is accompanied by the formation of cicatricial tissue like that which follows a severe burn. The later stages of radiodermatitis somewhat resembles the ulceration caused by the action of the strong acids.

b. *Chronic radiodermatitis* is produced by frequent exposure to a more feeble or a more distant irradiation. The skin is reddened or of a violet hue, the dermis becomes thickened and less supple, the epidermis hypertrophied and coarse, and deep cracks, which defy all treatment, may make their appearance. Occasionally there is ankylosis of the joints.

c. Alterations of the general health may accompany too long or too frequent exposure to the X-rays,—palpitations, cardialgia, vomiting, oppression, and trembling. The more penetrating rays from a hard tube have an action on the deeper organs and more especially on the nervous centres. In guinea-pigs, paraplegia has been produced by these means. From the experiments of *Lépine* and *Boulud,* it was found that guinea-pigs, exposed for long periods of an hour or more to the X-rays, lost weight, and this was accompanied by a diminution of glycogen in the liver. This increased destruction of glycogen was confirmed by experiments *in vitro.* They exposed one half of the liver to irradiation, keeping the other half for comparison. A considerable diminution was observed in the irradiated portion. This may account for the action of the X-rays on tumours rich in glycogen. (*Brault.*) The X-rays also increase glycolysis in defibrinated blood. Under their influence the reducing action of the pancreas is greatly increased. (*Lépine* and *Boulud.*)

The general symptoms due to the X-rays are also produced by the radiations from radio-active bodies, but in a lesser degree.

It would be premature at the present time to attempt any explanation of the action of the X-rays on the organism, although the cause of the physiological phenomena are to be sought in the domain of biological physics. In this connection we may recall an observation of *Bordier's,* who found that osmosis was retarded when the osmotic membrane was exposed to the X-rays. An explanation may be found in the property which the X-rays possess of discharging a charged electrified body. This has a far-reaching effect on many electric phenomena which are akin to osmosis.

CHAPTER VI.

PHYSIOLOGICAL ACTION OF OZONE.

351. **General Considerations.**—Ozone has a far-reaching action on the organism. When present in the air in a quantity greater than .8 milligrammes per litre, it produces serious symptoms and even death from œdema of the lungs. In a proportion not exceeding .1 milligrammes per litre, ozone becomes a powerful therapeutic agent.

The question of dose is therefore of the greatest importance. Unfortunately the estimation of ozone is a procedure which can only be carried out in the laboratory. It depends on the property which ozone possesses of decomposing potassium iodide. The liberated iodine may be estimated by means of hyposulphite of soda in the presence of starch. Another method is to use arsenic acid, which is reduced to arsenious acid by the liberated iodine. The determination of the quantity of arsenious acid before and after the passage of ozone through the solution will give the quantity of iodine liberated.

It is most important to determine whether the ozone is accompanied by nitrous products. *Bordier's* method is to shake up the ozonised air with a solution of meta-phenylene diamine, which takes a brown colour with nitrous products. The air may also be shaken up with a solution of potash, subsequently examining the solution for nitrates and nitrites.

We shall proceed to the study of the action of ozone on the blood, on microbes, and on the higher animals.

352. **Action of Ozone on the Blood.**—In the pulmonary alveoli, the hæmoglobin of the blood takes up oxygen from

the air and is transformed into oxy-hæmoglobin. This oxy-hæmoglobin carries the oxygen to the tissues and is there reduced again to hæmoglobin. According to *Labbé's* observations, ozone augments the proportion of oxy-hæmoglobin in the blood, when the quantity is below the normal.

In patients treated with ozone inhalations, the number of the red blood globules increases with the increase of hæmoglobin, while the number of white cells decreases.

Some authorities have maintained that this oxy-hæmoglobin was changed by ozone into methæmoglobin, a more stable product, and consequently not so well adapted for respiration. *Bordier,* operating *in vitro* on the blood of a dog, proved that this was not the case. The blood was shaken up with 132 litres of air containing 83 milligrammes of ozone. The bands of absorption due to oxy-hæmoglobin were well marked, while those due to met-hæmoglobin were absent.

Ozone moreover augments the rapidity of reduction of oxy-hæmoglobin in the blood, *i.e.,* in ozonised animals the oxy-hæmoglobin disappears more quickly. The experiments were made by means of a direct vision spectroscope. The blood was observed through the thumb-nail, the circulation of the thumb having been previously impeded by a ligature. *Labbé* and *Lagrange* have noticed an increase in the frequency of the pulse, and a rise of arterial pressure, following the inhalation of ozone.

As might have been expected, the proportion of urea in the urine is augmented. (*Peyrou.*)

The effects of ozone on the organic interchanges explain the increase of weight and appetite exhibited by patients treated with ozone. The experiments made *in vitro* also shew that we have in ozone a powerful means of modifying organic combustion and nutrition. We may now proceed to consider the local and general effects of the gas on patients submitted to its action.

353. **Action of Ozone on Animals.**—*Bordier's* experiments have shewn that with a dose of .8 milligrammes per litre, ozone may produce most serious symptoms on animals, on birds and even on man. In experiments on guinea pigs, after ten minutes' exposure to a current of ozonized air of this strength, the animal begins to exhibit signs of restlessness, accompanied by cries of distress. After twenty minutes the respirations are increased from 116 to 160 per minute; the animals rubs its nose with its paws as if to remove some obstacle to respiration, and at the end of 30 minutes death ensues. Under similar conditions a bird succumbed in 65 minutes with the same symptoms.

If the inhalation is stopped when the symptoms become alarming, and the animal is subjected to the same experiment on the following day, the animal survives for a few days and then dies. A guinea pig weighing 235 grammes, died on the third day after inhalations of 12 minutes and 6 minutes on two succeeding days.

The amount of ozone absorbed by the animal may be estimated by measuring the quantity which makes its exit from the bell jar in which the guinea pig is confined, compared with the quantity before the animal is put in. An animal weighing 308 grammes was killed by a total dose of 14 milligrammes of ozone, inhaled for ten minutes. The animal died after an hour and a half.

The post-mortem appearances are in all cases the same. The lungs are swollen, of a pale rose colour, the bronchi are filled with serous froth, and the blood of the larger arteries is black in colour. Death is due to an acute œdema of the lung, followed by asphyxia.

If the ozone is diminished to .5 milligrammes per litre, or if the duration of inhalation is diminished, no deleterious result is produced. On the contrary, there is an augmentation of weight. *Bordier's* experiments give .5 milligrammes as the maximum dose, while *Labbé* considers that .1 milligrammes should not be exceeded.

It is evident that we cannot be too careful when using so potent a remedy. It is of importance to ascertain the maximum output of any apparatus used for the inhalation of ozone.

A large quantity of ozone is produced by the high frequency effleuve. If the room is well ventilated the percentage of ozone will not be raised to any dangerous extent, and the patient may benefit by its presence. The practitioner who passes long periods in an ill-ventilated apartment may, however, be exposed to serious bronchitic irritation. In *Bordier's* case this became most acute.

The room for high frequency applications should therefore be well-ventilated, and the operator should be careful to leave the apartment during long seances. For this purpose the electrodes should be mounted on insulating stands so that the presence of the operator is not required during the whole seance.

354. **Action of Ozone on Microbes.—Antiseptic action.** —Great hopes were founded on the bactericidal action of ozone, but these hopes were doomed to disappointment. Cultures of bacteria are deleteriously influenced when exposed to air which is ozonised to over .05 per cent., but even with the maximum therapeutic dose their vitality is not affected. According to *Labbé's* experiments, a current of air charged with 10 milligrammes per litre is not sufficient to arrest putrefaction after it has already commenced. Ozone of this concentration is hardly sufficient to arrest development when shaken up with a bacterial culture in

bouillon. On the other hand, air containing 2 milligrammes of ozone per litre is sufficient to sterilize water which has been contaminated. We may thus give up the idea of any bactericidal action in the treatment with ozone. The therapeutic dose, *i.e.*, the non-poisonous dose, is far too small to influence the proliferation of bacilli. Ozone-therapy should not be employed to combat the microbic growth directly, but to influence the soil in which it may develop.

CHAPTER VII.

THE PHYSIOLOGICAL PROPERTIES OF MAGNETS.—MECHANICAL APPLICATION OF ELECTRIC ENERGY.

355. **On the Physiological effect of a Magnetic Field.**—When a body is immersed in a magnetic field, the conditions of its molecular equilibrium are altered. This phenomenon was discovered by *Faraday,* who demonstrated the rotation of the plane of polarisation. *D'Arsonval* tried to shew this molecular alteration by chemical means. He found that alcoholic fermentation is retarded by a magnetic field. The early stages of embryonic development are also affected by a magnetic field. (*D'Arsonval, Dubois, Michaelis.*)

These facts may explain the action of magnets on certain hysterical manifestations, a therapeutic result which is generally attributed to the effects of suggestion. Suggestion, it is true, may play a large part in these cases, but it may coincide with and even conceal a true physical therapeutic action.

356 **Masso-therapy— Vibro-therapy — Sismo-therapy —Mechanotherapy.** — Electricity is often employed to produce mechanical massage, and the passive gymnastics of muscles and articulations.

Mechanical or vibratory massage, or sismotherapy, as it is called by *Jayle* and *Lecroix,* is of considerable use in many affections. Vibratory massage stimulates the circulation locally and facilitates the reabsorption of exudations and extravasations. It also produces analgesic effects, and causes a reflex dilatation of the vessels, which persists for some time after the conclusion of a seance. Moreover, by reflex action, it causes an augmentation of the glandular secretion and has apparently some action on the general health. We have all noticed the physiological effects of a journey by train, which is, after all, but a form of trepidotherapy.

THIRD PART.

MEDICAL TREATMENT.

357. **Classification.**—The application of electricity in its different forms to purposes of diagnosis and treatment has of late years become so extensive that it has become impossible any longer to dissociate electro-diagnosis and radio-diagnosis from the portion of the work relating to electro-therapeutics.

Every day the medical electrician is called upon to diagnose new diseases. It is therefore convenient to treat electrical diagnosis and electrical treatment under the same heading, *viz.*, that of the disease or group of diseases involved.

Moreover a chapter on electro-diagnosis or radio-diagnosis would be useless without some reference to therapeutics.

In the section devoted to the nervous system will be found a separate chapter devoted to the study of abnormal reactions of the sensitive and neuro-muscular systems. Following this, all questions of electro-diagnosis or radio-diagnosis will be treated under the chapter which deals with each separate disease.

CHAPTER I.

THE NEURO-MUSCULAR AND NEURO-SENSITIVE SYSTEMS.

I. General Considerations.

358. **Affections of the neuro-muscular system of interest to the medical electrician.**—If we consider the constitution of the neuro-muscular system, and the modern conception of the neurone, we may group the diseases of this system under the following headings:

a. Affections of the muscle itself or of the nervous mechanism which supplies it, unaccompanied by organic lesion of the nerves or nerve centres. To this division belong the different forms of myopathy.

b. Affections of the peripheral nerves passing from the nerve centres to the muscles or sense organs, unaccompanied by lesion of the nerve centres. To this division belong the various forms of neuritis and polyneuritis, neuralgia, and peripheral paralysis.

c. Lesions of the nerve centres.

This includes two divisions. 1. Lesions of the cerebral or cerebellar tracts, more particularly the white substance of the cord, as in locomotor ataxy and the various forms of leuko-myelitis.

2. Lesions of the grey substance of the neurone itself. Under this heading we may group poliomyelitis, from lesion of the cells of the anterior grey cornua, bulbar paralysis from lesion of the corresponding nuclei in the bulb, and ophthalmoplegia from lesion of the nuclei of the pons.

The conducting fibres, as well as the grey matter of the neurones, may be involved by lesions due to sclerosis, acute inflammation, traumatism or hæmorrhage.

d. Affections of the nerve centres unaccompanied by any appreciable lesion. To this division belonging the various forms of neurosis and psychosis.

Electro-diagnosis is called for in all cases where there is an alteration of muscular contractility, whether this is a consequence of the primary lesion, or is due to neuritis, or to injury in the nerve centres.

Electro-therapeutic treatment is useful in a great variety of cases sometimes as the principal treatment, sometimes as an adjunct. In the electric treatment of diseases of the central nervous system the results are often attributed to suggestion. It is true that suggestion may contribute to its success as it does in many other modes of treatment. It will be the duty of the physician to determine whether he is justified in adopting a mode of treatment which finds no support in experimental physiology or therapeutics. This is a question of ethics, and we only allude to it here in answer to those who in ignorance of the progress of biological science are too prone to condemn all electrical treatment.

359. **Divisions.**—We shall begin with a study of electro-diagnosis by means of the neuro-muscular reactions. This chapter will include all neuro-muscular affections, except those which are of central origin. Here also we may place the description of the motor points, a knowledge of which is necessary both for diagnosis and treatment. We shall afterwards proceed to the study of each individual disease in the following order:

Affections of muscles.

Affections of nerves.

Affections of the nerve centres.

Neuroses and nervous affections of which the organic cause is unknown.

II. Electro-Diagnosis and Technique—Abnormal Reactions—Motor Points.

360. **Electrical testing for abnormal muscular reaction.**—In electro-diagnosis, whatever be the apparatus employed, we should always be able to switch on the faradic or galvanic current without detaching the handles we are using.

The indifferent electrode is formed by a rectangular metal plate covered with felt or chamois leather. A better way is to use a bare metal plate placed on a layer of absorbent cotton wool enveloped in gauze. A clean pad may then be used for each patient. The indifferent electrode should be 100 to 200 square centimetres in area.

The *exploring electrode* consists of a pad 2 or 3 centimetres in diameter and should be furnished with an interruptor in the handle.

Procedure for testing muscles and nerves by the galvanic current.

a. We begin by comparing the resistance to the faradic current on the right and left sides respectively. A milliamperemeter cannot be used with a faradic current and any difference of reaction on the two sides may be merely due to a difference of resistance. In order to determine this we may make use of *Bergonié's* method already described in par. 263.

b. The electrical source which drives the coil should vary as little as possible during the observation. Hence the current from a battery is not to be recommended. It is better to use an accumulator or the supply from the public electric mains. The strength of the current may be regulated by a rheostat placed in the secondary circuit. When a sledge coil is used the current is regulated by sliding one coil over the other.

Procedure for testing muscles and nerves by the galvanic current.

a. We do not require to make a preliminary measurement of the resistance, as the current employed whilst comparing the reactions on the right and left sides respectively is measured by means of a milliamperemeter. During the examination, however, some idea of the comparative resistance on the two sides may be obtained by observing the position of the contact point of the potential reducer for equal currents. If there is any great difference a further investigation of the relative resistances will be necessary.

b. The milliamperemeter should be very sensitive, and be graduated from 0 to 25 milliamperes in tenths of a milliampere.

c. The current may be graduated by a rheostat, or better still, by a potential reducer (par. 93), but not by a collector since this increases the voltage too suddenly.

d. The table or wall-tablet should carry a current reverser.

361. **Mode of procedure for testing the reaction of nerves and muscles.**—The patient should be placed in a horizontal position, or in a chair with the back well supported. He should be told to relax his muscles and to rest in a condition of complete repose.

The *indifferent electrode,* previously well moistened with warm water, should be placed on the spine—either at the neck, if the upper part of the body is to be tested—or in the lumbar region. The electrode should be applied to the skin firmly and uniformly. This may be done by the weight of the body or by means of an elastic bandage. The axis of the electrode should be kept in the median line during the exploration of symmetrical points. The electrode should be covered by a piece of felt or a serviette, in order to protect the clothes.

The operator should place himself near the patient within reach of the terminals, reverser, etc. A table that can be easily wheeled up to the patient is very convenient.

The exploring electrode, previously moistened with warm water, is applied to the motor points of the muscles and nerves which are to be tested.

362. **Manipulation for the exploration of nerves and muscles.**—In order to test the muscles and nerves properly, the exploration should be carried out in a systematic manner.

1. We commence with the faradic current, so that the tissues may not be polarised at the beginning of the investigation. By this means we obtain at once a general idea of the condition of the nerve or muscle, for if the faradic contractility is not altered, the galvanic contractility is probably normal. We may also compare the resistance of the right and left sides by means of the telephonic explorer.

2. *The exploring electrode* should be joined to the negative pole of the secondary current. There is no great object in comparing the actions of the anode and cathode. We begin with the rheostat in its position of maximum resistance.

3. The strength of the current is adjusted by gradually decreasing the resistance in the secondary circuit until the limit of excitation is reached.

The resistance of the rheostat in ohms at the moment of contraction is then read off.

When a sledge coil is used, the strength of the current is adjusted by sliding the secondary coil over the primary, and reading off the displacement of the coil in millimetres.

The motor point is found by trial and by moving the exploring electrode about until the exact position is located. In cases where only one side is affected, the healthy side should be tested first.

4. In some cases it is difficult to test a single muscle by this means, in consequence of the contractions of neighbouring muscles. We may then have recourse to *Duchenne's* method, which consists in applying an electrode to either end of the muscle whose contractility we desire to test.

5. We next proceed to test the muscle by means of the galvanic current.

Firstly we determine whether with increasing intensity the muscular contractions follow in the normal physiological order.

KCC, ACC, AOC, KOC.

The examination is begun with the reverser in its usual position, making the exploring electrode negative. We gradually increase the strength of the current, closing and opening the key in the handle so as to give currents of about two seconds duration. This is necessary in order to avoid polarisation of the tissues. From time to time we may reverse the current to see if ACC will not appear before KCC.

At the first contraction of the muscle, the strength of the current is read off.

For instance, in testing the facial nerve we record as follows:

KCC	2	milliamperes
ACC	3.5	"
AOC	4.7	"
KOC	5.5	"

By using the reverser each time that we alter the intensity of the current, we obviate the necessity of making 4 series of experiments and bringing back the current to zero after each.

6. *Longitudinal reaction* of the muscle. With an electrode 2 or 3 centimetres in diameter, the maximum current which can be employed without producing excessive pain or burning is 15 milliamperes. If a muscle does not respond to this current, we must have recourse to the so-called longtitudinal reaction. We place the active electrode not on the motor point, but on the lower tendon of the muscle, and proceed as before. The contraction of a muscle which follows stimulation of its motor point is indirect, the stimulus passing along the nerve filaments. When, however, a muscle no longer responds to excitation of its motor point, we may still produce direct contraction by exciting the tendon.

The determination of the longitudinal reaction is the complement of the galvanic test, just as *Duchenne's* bipolar method is the complement of the faradic test.

363. **Motor Points.**—At the end of this work will be found charts of the motor points according to the researches of *Eichhorst* and *de Castex*. In each region we give all the motor points, to whatever nerve trunk they may belong. Each muscular group supplied by the same nerve is indicated by a different colour or sign. We thus see at a glance all the motor points in a given region—those we desire to stimulate and those we wish to avoid. At the same time we can see clearly all the motor points of a given nerve trunk which we are desirous of testing. Whenever a nerve has a superficial course which is accessible for stimulation, it is drawn with a dotted line.

364. **Nerves of sensation.**—The reader will also find

figures of the upper and lower limb showing the cutaneous territories innervated by the sensitive nerves. The figures are copied from *Eichhorst* and *Henle's* plates.

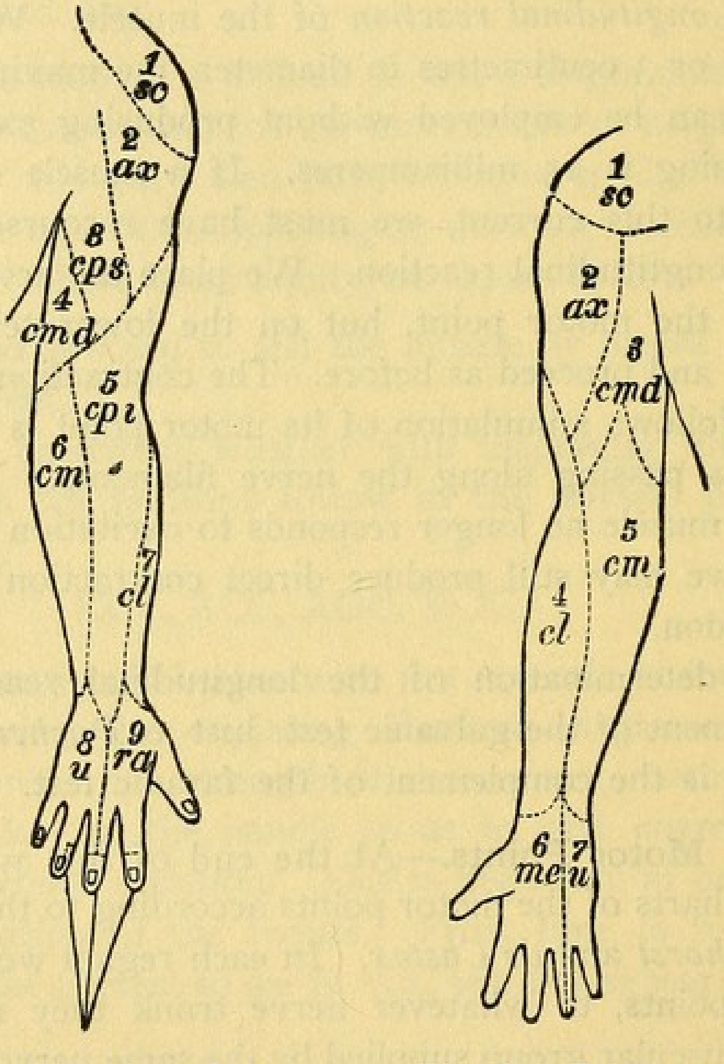
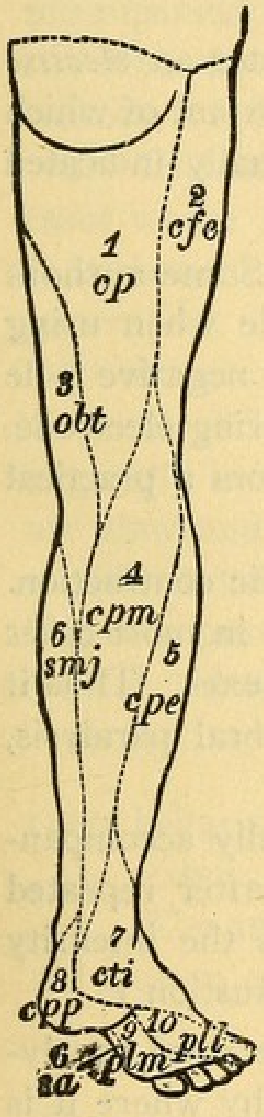


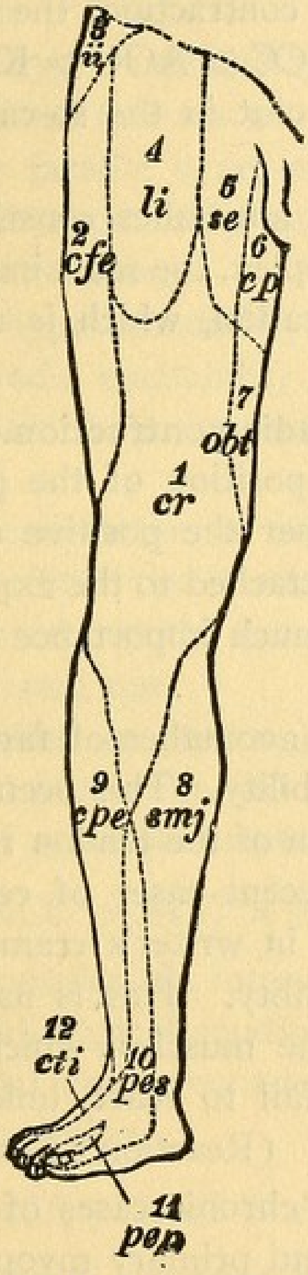
Fig. 63.—Dorsal surface. Fig. 64.—Palmar surface.

Cutaneous nerves of the arm after Eichhorst. sc, cutaneous branches of the cervical plexus.—ax, circumflex nerve.—cps, branches of the musculo-spiral nerve.—cmd, lesser internal cutaneous nerve.—cpi, external cutaneous branches of the musculo-spiral nerve.—cm, internal cutaneous nerve.—cl, musculo-cutaneous nerve.—u, ulnar nerve.—ra, radial nerve.—me, median nerve.

365. **Abnormal reaction.**—We have hitherto studied

the points to be selected and the technique to be followed in the electrical testing of a nerve or muscle. We may now proceed to discuss the theory of electrical testing.





1, Small sciatic.—2, External cutaneous.—3, Obturator.—4, External saphenous.—5, sural branch of the external popliteal.—6, internal saphenous.—7, Musculo-cutaneous.—8, Calcaneal branches of posterior tibial.—9, Internal plantar.—10, External plantar.

1, Anterior crural.—2, External cutaneous.—3, Lateral cutaneous branch of last dorsal.—4, Genito-crural.—5, Ilio-inguinal.—6, Small sciatic.—7, Obturator.—8, Internal saphenous.—9, External popliteal, sural branches.—10, Musculo-cutaneous.—11, Anterior tibial.—12, External saphenous.

Fig. 65. Fig. 66.
Distribution of the cutaneous nerves of the leg after Henle.

1. In what way a muscle contracts when it does not respond to electrical stimulus in a normal manner.

2. The pathological significance of anomalous contraction and how these anomalies are grouped in each disease.

We shall first consider anomalies of faradic contractility, consisting of slowness of contraction, the inversion of the normal formula KCC > ACC > AOC > KOC, and the displacement of the motor point in the so-called longitudinal reaction. (372.)

The groupings of these anomalies constitutes an *electric syndrome* or symptom-complex, the most important of which is the reaction of degeneration, which is usually indicated by the letters DR.

366. **Anomalies of faradic contraction.**—Some authors attach importance to the position of the pole when using the faradic current, whether the positive or negative pole of the induced current is attached to the exploring electrode. This is not, however, of much importance from a practical point of view.

There are two principal anomalies of faradic contraction.

1. Faradic hyperexcitability. This occurs in most cases where there is exaggeration of the tendon reflexes. Thus it is met with in tetanus, recent cases of cerebral paralysis, hemichorea, athetosis and in writer's cramp.

2. Faradic hypoexcitability. This is usually accompanied by rapid fatigue of the muscles, which after repeated faradic stimulation soon fail to react, unless the intensity of the current is increased. (Reaction of exhaustion.)

This anomaly occurs in chronic cases of cerebral paralysis, long standing tabes, and primary myopathy where it is associated with galvanic hypoexcitability. It is found also in diseases which present the symptom-complex DR, in which the faradic and galvanic reactions do not correspond, the former being exaggerated while the latter may be absent.

367. **Quantitative anomalies of galvanic contractility.**

—**Slowness of contraction.**—The quantitative anomalies of galvanic contractility are of much less importance than the form of the contraction, and the order in which the contractions appear.

1. Galvanic hyper-excitability is met with in all cases where the tendinous reflexes are exaggerated. It is usually accompanied by faradic hyper-excitability, but it may persist after faradic excitability has been abolished, as in the reaction of degeneration.

2. Galvanic hypo-excitability. This is met with in most cases where faradic excitability is diminished or abolished. It is characteristic of the last stage of nerve and muscle degeneration.

Slowness of contraction is an important sign in electro-diagnosis. The "lost time" which is usually inappreciable is greatly increased and the curves of ascension and descent are slow and drawn out.

368. **Anomalies in the order of the contractions.—Total or partial inversion—Rich's reaction.**—The physiological order of muscular contraction is

$$KCC > ACC > AOC > KOC,$$

there being a considerable interval between ACC and AOC.

In certain pathological conditions this order is altered.

a. The anodal closure contraction may precede the cathodal closure contraction.

$$ACC > KCC > AOC > KOC.$$

This is called partial inversion of the physiological formula.

b. Total inversion has the formula

$$ACC > KCC > KOC > AOC.$$

c. In some cases there is merely an approach of ACC to AOC, both contractions occurring with the same intensity of current, or the order may even be reversed. This, which is called *Rich's* reaction, has the formula

$$KCC > ACC \lesseqgtr AOC > KOC$$

The above are briefly the anomalies of electro-diagnosis which have given rise to so much discussion.

The explanation of quantitative alterations of faradic and galvanic excitability are comparatively easy. The phenomena of inversion, on the contrary, are somewhat difficult to observe, and their interpretation is a problem of the greatest difficulty—so much so that some authors have contested their value and even denied their existence.

Recent investigations, however, among them those of *Cluzet,* have demonstrated the reality and the importance of these phenomena. Partial or total inversion of the physiological formula is part of the symptom-complex known as the reaction of degeneration. It varies with the degree and the stage of evolution of the lesion, and must therefore be carefully studied by the medical electrician.

369. **Inversion of the physiological formula—Interpretation.**—In their normal condition, unstriped muscles, instead of presenting the ordinary sequence KC, AC, AO, KO as the current is increased, begin to contract with closure of the anodal current AC. They thus exhibit an inversion of the normal physiological formula. This inversion, however, is more apparent than real. *Biedermann* has shewn that it depends on the formation of a virtual cathode in the region around the anode. When a small cathode is used to stimulate the circular fibres of the intestines, a slight elevation occurs immediately beneath it, whilst the zone around the cathode remains flat and shows no sign of contraction. At the anode, on the contrary, the polar zone remains inert, whilst the peripolar tissue forms a circular swelling due

to contraction. This is so marked that the small central depression is frequently overlooked.

The labours of *Wiener, May* and *Cluzet* seem to shew that in the case of striated muscles also, the inversion is more apparent than real, whether the stimulation is applied to the motor point or along the course of the motor nerve. The pathological inversion is due to the fact that there is an area of decreased excitability under the exploring electrode when compared with the normal excitability of the surrounding zone. The peripolar zone plays the part of an anode in relation to the polar area under the cathode. On the other hand, when the polar area is an anode, the peripolar region constitutes a cathode.

We shall now proceed to consider separately the question of inversion affecting the nerve and inversion affecting the muscle.

370. **Explanation of inversion affecting the nerves.**— In practice, inversion affecting the nerves is but rarely observed, since in the progress of any disease its duration is very brief. (*Cluzet.*)

It is, however, very easy to produce it experimentally. The sciatic nerve of a frog is divided, and the indifferent electrode is placed at the lower extremity of the limb, while the active electrode is placed just below the point of section. Inversion may be observed soon after the section of the nerve. The following is *Cluzet's* explanation of the phenomenon: "Immediately after section, the excitability of the part of the nerve which has been injured is increased, but it speedily becomes less than that of the part nearer to the muscle, which has not been injured. An ascending current soon ceases to produce contraction. This may be due to deficient reaction of an hyper-excitable region to the stimulus, or it may be due to an arrest of the stimuulation due to electrotonus. The descending current on the other hand produces contraction, not so much by stimulation at the point of entry near the cut end of the nerve, as by excitation at the points of exit which are hyper-excitable.

"The reason that a feeble current no longer produces contraction, is because the lower portion of the nerve is more irritable than the upper part. If during KC the active electrode should stimulate the cut end of the nerve in spite of its hypo-excitability, the stimulus will be arrested by an electrotonus of the lower portion of the nerve.

"If, on the contrary, a contraction follows AC, it is because the stimulus is given, not to the hypo-excitable cut end of the nerve, but lower down to the hyper-excitable portion, which is in fact a virtual cathode.

"The inversion of the law of contraction is thus seen to be dependent in part on modifications of excitability due to electrotonic action. All the anomalous phenomena may be explained by differences of excitability in different portions of the nerve. It may be remarked that in mediate excitation with the nerve *in situ*, inversion may not occur after section of the nerve, whereas it appears at once when the electrode is applied to the nerve itself.

"The difference of excitability between the injured and the uninjured portion of the nerve is not sufficient to cause inversion when the excitation is mediate. With mediate excitation the current is diminished by its diffusion through the tissues.

"Inversion is but rarely noticed in practice, either because the difference of excitability is very evanescent, or because the position given to the electrodes is not suitable, or because the differences of excitability are compensated by variations in the density of the current."

371. **Explanation of inversion in the case of muscles.**

—The observations of *Wiener* tend to shew that the phenomena of inversion observed in a degenerating muscle may be explained in the same way as those of the nerve. His experiments were made on muscles artificially affected in consequence of the *Wallerian* degeneration of their nerve supply. By employing a very small unpolarisable electrode applied to the muscle, he shewed that the optimum point of excitation was not as it should be normally, at the point of entry of the nerve supply, but at either extremity of the muscle. Thus when the active cathode is applied to the motor point it occupies a region of lessened excitability when compared with the surrounding area. The question of inversion then resolves itself into this: is the stimulus at the pole produced by the active cathode in a hypo-excitable area, where the lines of flux are concentrated, greater or less than the excitation produced in the peripolar zone by a virtual cathode, in a more excitable area, where the lines of flux are less dense. In one case there will be no inversion because the polar phenomena will be in the ascendance, and KC contraction from the active cathode will occur. In the second case there will be inversion, since the peripolar phenomena will predominate, and contraction due to a virtual peripolar cathode will result in making the active electrode an anode.

May's observations shew that a degenerating muscle reacts in this respect exactly like the unstriped muscles in *Biedermann's* experiments. (369.)

The recent researches of *Mlle. Joteyko* explain how the process of degeneration may cause a striated muscle to resemble an unstriated one in this respect. There are two distinct contractile substances in each muscular fibre, the dark discs and the non-differentiated sarcoplasm, which contracts more slowly. Degenerating muscle shews a marked diminution of the fibrillary substance, and a considerable increase of the sarcoplasm. In the course of degeneration the muscle therefore acquires the morphological characters of unstriped muscle. This will explain the abolition of faradic contractility, the slowness of galvanic contraction, and the phenomenon of inversion.

372. **Displacement of the motor point.—Longitudinal reaction.**—As degeneration progresses, the optimum point of excitation is displaced towards the excentric extremity of the muscle.

This phenomenon is related to that of inversion. As the excitability at the motor point decreases, the stimulation *en masse* of the whole muscle overshadows the excitation at the motor point. The best means of acting on the whole mass of a muscle is to cause the lines of flux to pass through the entire length of the muscle. Longitudinal reaction therefore is a sign of advanced degeneration.

373. **The manner in which these symptoms are grouped in disease.**—Hitherto we have studied a number of abnormal reactions in diseased organs, faradic hyper- and hypo-excitability, galvanic hyper- and hypo-excitability, inversion of the normal formula, and longitudinal reaction.

We have moreover endeavoured to form some notion of the meaning of each of these anomalous reactions.

It remains for us to see in what way they are grouped in disease.

Some of the modes of grouping are simple enough.

Both faradic and galvanic excitability are usually increased in those diseases where the tendon reflexes are exaggerated, as in tetanus and hysterical paralysis. This connection is, however, not universal since there may be increased excitability in diseases such as tabes, where the reflexes are totally abolished. Moreover we find decreased faradic and galvanic excitability in essential myopathy and long-standing cerebral paralysis.

In *Thomson's* disease the anomalies of reaction are grouped in a more complicated manner in the so-called myotonic reaction of *Erb.* The myotonic syndrome is characterised by normal excitability of the nerve, with galvanic and faradic hyper-excitability of the muscle, accompanied by partial inversion, ACC $>$ or $=$ KCC. The muscular contractions are sluggish, tonic and prolonged, and persist for some time after excitation.

But of all the groups the most important in electro-diagnosis is the so-called "reaction of degeneration," or rather the "syndrome of degeneration," which is usually expressed by the abbreviation DR.

374. **Reaction of degeneration.—Syndrome of degeneration, DR.**—The symptom-complex of degeneration, DR, is composed of a group of anomalous reactions which are associated with well known morbid conditions. These anomalous reactions moreover vary with the stages of evolution of the morbid process.

The expression syndrome of degeneration is preferable to that of reaction of degeneration, since DR denotes an assemblage of abnormal reactions. Since the abbreviation DR is well understood, it may be retained, remembering that it is not a single abnormal reaction, but a reaction-complex, or rather the mode in which the organism reacts to different forms of electrical stimulation. It is called in Germany EaR (*Entartung's reaction*).

The following is the sequence of the phenomenon which characterise DR in the successive phases of degeneration, for example the *Wallerian* degeneration occurring in a nerve and the muscles it supplies, after section of the nerve trunk.

The following phenomena follow section of the nerve: For the nerves.—The excitability for both galvanic and faradic currents increases for the first three days. Subsequently it diminishes gradually until the normal is reached in five days, and continues to decrease until the tenth day, when it entirely disappears.

For the muscles.—The faradic excitability diminishes regularly until it entirely disappears at the end of the second week.

The galvanic excitability diminishes during the first week, then increases till it exceeds the normal in the course of the second week, and persists in an exaggerated state after all other reactions have been abolished. At this stage the muscular contractions become sluggish, and we get mechanical excitability. At the end of the second week phenomena of inversion begin to appear. ACC occurs before KCC, and shortly afterwards KOC occurs before AOC, when the inversion is complete.

This stage may last for several weeks. In the nerve there is total abolition of faradic excitability, accompanied by galvanic hyper-excitability and complete inversion of the normal formula.

Lastly the galvanic excitability diminishes. First we are unable to obtain AOC, and then KOC and KCC successively disappear, ACC alone remaining. At the same time the longitudinal reaction can be easily obtained with a weaker current than that which will provoke ACC at the motor point.

In the latest stage ACC ceases and finally the longitudinal reaction disappears.

Fig 67, page 318a, indicates the course of OR in its different stages.

It shows at a glance at any given period the symptoms

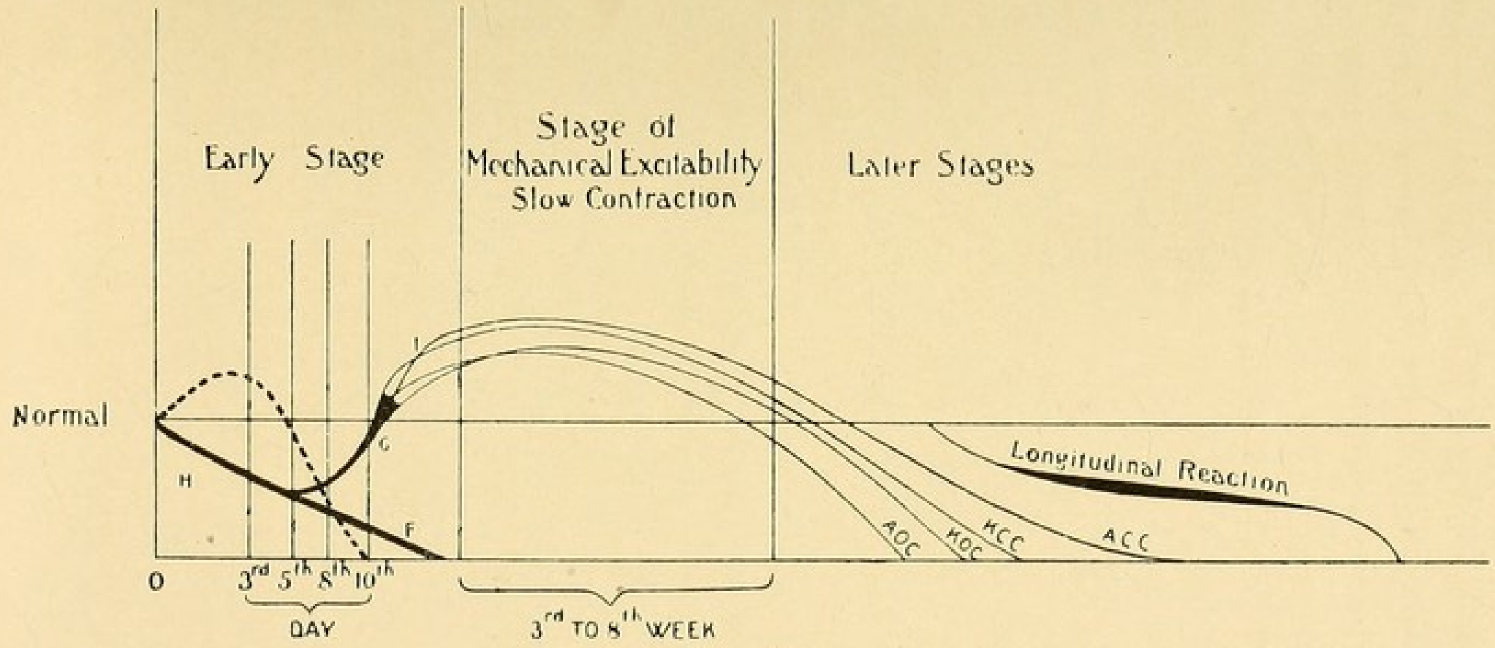


Fig. 67.

Diagram showing the stages of DR.

The dotted line represents the curve of *Nerve*-**excitability** both for Faradic and Galvanic currents.

The continuous lines represent the curves of *Muscle*-excitability. "F" for the Faradic current, "G" for the Galvanic current, "H" for the Galvanic and Faradic muscle-excitability, "I" point of inversion of **KC**, "J" point of inversion of **OC**.

composing the syndrome. Thus at the 3d day there is for the nerve hyper-excitability to both currents, and the reverse for the muscle. This is the first phase of DR.

At the 8th day there is hypo-excitability for both nerve and muscle, more especially to the faradic current. This is the second phase of DR.

At the 10th or 12th day the excitability of the nerve is abolished. For the muscle, the faradic excitability is almost abolished, whereas the galvanic excitability is increased, and there is commencing inversion of the normal formula.

This is the third phase of DR.

Finally we reach the stage of complete DR. The muscle alone reacts to a stimulus, but it reacts in an abnormal manner, the contraction is sluggish and the inversion is complete.

In the final stage we have longitudinal reaction, and gradual decrease and loss of excitability at the motor points.

375. **Pathological meaning of DR.**—DR is met with in diseases such as polyomyelitis anterior, bulbar paralysis, and ophthalmoplegia, where the anterior cornua or the nuclei in the pons and medulla are affected. It also occurs in neuritis and polyneuritis, where the nerve itself is primarily affected. Later on we shall be able to study the particular variety of the syndrome under each disease. Its value as a prognostic sign is very variable in different cases.

DR is not found in essential myopathy, or in cerebral diseases where the anterior cornua or the bulbar nuclei are unaffected.

III. Electrical Diagnosis and Treatment.

A. Diseases of Muscles.

Primary myopathy—Atrophy caused by surgical or articular traumatism—myalgia—lumbago—muscular rheumatism.

376. **Primary myopathy.**—Primary myopathies, *i.e.*,

muscular affections which are not due to any apparent lesion of the nervous system, are of two principal types.

1. Pseudo-hypertrophic paralysis (*Duchenne's* disease) occurs in early infancy, commencing with the lower limbs. It is characterised by an apparent hypertrophy of the muscles, but the contractile element of the muscular fibre is in reality atrophied. It is the hyperplasia of the interstitial connective tissue that gives to the child an appearance of strength in striking contrast with its feeble powers of progression.

2. Progressive atrophic myopathy (*Landouzy-Dejerine*) is a disease which occurs in the second childhood of old age. It begins in the face, and is often confined to that region. Later on it may invade the muscles of the shoulders, the arms and the legs.

Sometimes the atrophy begins in the lower limbs. (*Leyden-Moebius.*) The type described by *Charcot-Marie* is probably due to a lesion of the central nervous system.

Electro-diagnosis.—In all cases of primary myopathy there is an absence of DR. (374.) An apparent exception is the *Charcot-Marie* type, but this is, as we have said, probably due to a central lesion.

In all cases there is diminution of faradic excitability, (*Duchenne's* reaction) and of galvanic excitability. In advanced cases there may be a complete absence of all excitability.

At the commencement of the examination the hypo-excitability may not be very marked, but the muscles speedily shew the reaction of fatigue. (366.)

Electro-therapeutic treatment.—The aim of the physician is to combat the atrophy of the muscle by exercise. This is best done by rhythmic galvano-faradisation as described in par. 313.

The classic treatment for all cases of muscular atrophy is massage, but in this disease it is of doubtful utility. It is the contraction of the muscular fibrillæ that stimulates the nutrition of muscle, and massage is powerless to cause this contraction.

Rhythmic galvano-faradisation. This consists of a continuous galvanic current with a coil and metronome placed in series in the circuit. Instead of a metronome *Bergonié's* rhythmic interruptor may be used. This enables us to vary the current gradually so as to imitate the physiological contraction of the muscle.

Procedure.—The indifferent electrode should be applied to the back, either at the nape of the neck or in the lumbar region. The active electrode, a pad about 4 cm. in diameter, should be connected to the negative pole of the battery. This should be applied to each motor point for about two minutes, the current being adjusted by trial until an appreciable reaction is obtained.

The treatment should be repeated every day or every other day.

A large induction coil giving a strong current at a low potential should be chosen and the interruptions should not be too rapid.

Alternative electric treatment.—If no contraction can be obtained with the galvano-faradic current, the variable period of opening and closure of a continuous current may be utilised.

The current is rendered intermittent by means of a metronome or some other form of interruption. A very excellent method advised by *Bordier* is to alter the direction by means of a current reverser mounted on a motor making 40 revolutions per second, interrupting the current so obtained by the ordinary metronome device.

If neither of these instruments is available, the faradic current may be applied rhythmically, keeping on the current just long enough to produce sustained contraction without causing fatigue. This may be repeated again and again by the ordinary metronome device.

Some authorities recommend the continuous current, using an arm-bath or foot-bath for the cathode, and a large dorsal electrode for the anode. From 15 to 20 milliamperes may be given with a duration of 10 minutes. For the face, 5 to 8 milliamperes is sufficient. (*Castex.*) Others recommend the electric bath with sinusoidal current. Seances should be given three times a week, the duration being 10 to 20 minutes.

We can only hope to delay the atrophy of the muscles by the use of any of these methods.

377. **Muscular atrophy of traumatic origin.**—Muscular atrophy often follows contusions, wounds, or fractures. In some cases injury to the nerve may contribute to the muscular atrophy.

Injury to the articulations may also cause atrophy of certain muscles. For instance atrophy of the deltoid frequently follows injury to the shoulder, and we may meet with atrophy of the triceps in injury to the elbow, of the quadriceps in injury to the knee, and of the tibialis anticus in injury to the ankle. *Vulpian* and other authors attribute the atrophy to a reflex action on the trophic centres of the cord.

Electro-diagnosis.—In these cases we get hypo-excitability to both the faradic and galvanic currents. DR is not found unless there is an injury to the nerve. If the cause is removed and the atrophy is in its early stage, a fortnight's treatment should suffice where only a slight degree of faradic hypo-excitability exists. On the other hand, where there is marked hypo-excitability many months of treatment may be required.

When the atrophy is due to an injury of the joint, a radioscopic examination should be made.

Electro-therapeutics.—These cases should be treated by faradisation, or better still, by rhythmic galvano-faradisation of the affected muscles. Cases due to articular injury should in addition be treated by the galvanic current.

Procedure.—Faradisation or galvano-faradisation may be carried out in the manner described for primitive myopathy (376.) The duration should be longer, 2 to 5 minutes for each muscle.—Galvanisation: A large anode should be placed on the neck or the lumbar region and a large cathode, 50 to 150 square centimetres, should be placed at the lower end of the affected muscles. A current of 8 to 12 milliamperes should be applied for 5 to 10 minutes every day or every alternate day.

The muscle should also be exercised by mechanical means, taking care not to injure the articulation.

The result is generally satisfactory after treatment varying from a fortnight to three months.

378. **Paralysis of the peroneus longus—Flat foot—Hollow foot.**—Paralysis of the peroneus longus merits especial mention, since it is the cause of painful flat foot (*Duchenne de Boulogne.*)

When flat foot is due to this cause, the peronei may be treated by rhythmic faradisation or by rhythmic galvano-faradisation. (376.)

This may be followed by galvanisation, using a large anode on the lumbar region, and a large cathode or a foot-bath to the foot. A seance of 6 minutes should be given every other day, using a current of 8 to 12 milliamperes. The limb should be kept at rest.

The same treatment may be adopted for the hollow claw-like foot, where the muscles of the calf and the flexors of the toe are affected.

379. **Myalgia—Lumbago— Torticollis — Pleurodynia —Muscular Rheumatism.**—The myalgias are pains due to muscular rheumatism. Lumbago is a myalgia localised in the lumbar region and torticollis is a myalgia of the cervical region, involving the trapezius and sterno-mastoid muscles.

Electro-diagnosis. This will be called for only in the atrophic forms, as in the case of scapular atrophy, where it may enable us to estimate the severity of the accompanying lesions due to myositis or neuritis.

Electro-therapeutics. All myalgias of whatever kind, especially those in an early stage, should be treated by galvanisation.

In the local treatment of this affection, the transport of medicinal ions into the tissues by means of the galvanic current is coming more and more into use. Faradisation, or better still, galvano-faradisation, may be used to relieve pain, and to combat the atrophy which follows. These cases may also be treated by the sinusoidal current, by static electricity, or by high frequency. The following are the directions for treatment in each case.

Lumbago. 1. A continuous current is to be applied by means of a large anode 100 sq. cm. on the painful region, and a large indifferent cathode 400 to 500 sq. cm. on the abdomen. The large anode should be employed as active electrode since it diminishes the excitability of the nerve.

Intensity, 60 to 100 milliamperes; duration of seance, 20 to 30 minutes; repeated every day or every second day.

When salicylates are indicated, an active cathode 100 sq. cm., should be soaked in a 1 per cent solution of sodium salicylate. If iodine is preferred, the cathode may be soaked in a 1 per cent solution of iodide of potassium.

2. In an acute case if we can treat the patient from the commencement, we may direct the effleuve from the static machine on the painful region for a period of 10 to 15 minutes, giving a seance every day. The static effleuves may be replaced by those from a high frequency apparatus.

3. If the foregoing remedies fail, we may have recourse to the sinusoidal current by means of an electric bath at a temperature of 97° F. One pole of the apparatus should be joined up to a number of electrodes hung round the sides of the bath, which should be made of some insulating material. The other pole should be applied to the lumbar region. The patient should be sensible of a slight tetanisation of all his muscles.

4. In cases of atrophy of the muscles following acute lumbago, rhythmic faradisation, or rhythmic galvano-faradisation may be employed, as for muscular atrophy. (377)

Torticollis.—The same mode of treatment should be adopted. The active anode should be placed on the trapezius or the sterno-mastoid as the case may be. In consequence of the shape of the region affected, the electrode will be a small one and a current of 15 to 20 milliamperes will suffice. Labile galvanisation by means of a positive roller passed over the painful region gives excellent results. A current of 15 to 20 milliamperes may be used. As with lumbago, we may use the faradic current or the galvano-faradic current. The discharge from a high frequency apparatus may also be employed by means of a condensing electrode, which is less painful than a pencil or brush.

B. Affections of the Nerves.

Neuritis—Polyneuritis—Paralysis of peripheral origin—Neuralgia.

380. **Polyneuritis.**—Neuritis is usually due to a de-

structive alteration of the axis cylinders or of the myeline sheaths of cellulifugal or cellulipetal nerves. The lesions are usually localised in the smaller branches, and are caused either by cold or some toxic or infectious agent. The principal varieties are saturnine polyneuritis, alcoholic polyneuritis and diphtheric polyneuritis.

Saturnine polyneuritis has many points of resemblance to polyomyelitis and manifests itself by rapid and progressive paralysis, followed by muscular atrophy.

Alcoholic polyneuritis, which shews itself by incoordination of movement and ocular troubles, has some points of resemblance to tabes. It is important therefore to be certain of the diagnosis.

Electro-diagnosis.—All varieties of neuritis are characterised by DR more or less complete. In saturnine polyneuritis it comes on early and is very complete, whereas in alcoholic polyneuritis it is incomplete and in diphtheric polyneuritis it is absent. This last form has special characters which place it in a category apart.

Saturnine polyneuritis.—Lead palsy, which is chiefly motor and but slightly sensitive, is accompanied by early muscular atrophy and early and complete DR. The DR may be recognised by testing certain muscular groups according to the part which is paralysed. In paralysis of the upper-arm, it is the extensors of the fingers that are chiefly affected. The supinator longus is not affected, contrary to what takes place in paralysis of the fore-arm. The anconeus is also unaffected in lead palsy. In the brachial type, the deltoid, the biceps, the brachialis anticus and the supinator longus are affected. In the leg the extensors of the great toe, the peronei, and the tibialis anticus are paralysed.

Alcoholic polyneuritis.—Alcoholic polyneuritis is of a mixed type. The sensitive nerves are attacked even before the motor nerves. DR comes on later and is less complete than in lead palsy. It occurs chiefly in the extensor muscles, extensor communis digitorum, extensor proprius pollicis, peronei, tibialis anticus, and the muscles of the foot. When it attacks the upper limb there is partial DR of the extensors.

Diphtheric polyneuritis.—This variety chiefly attacks the velum palati and the pharynx, and more rarely the diaphragm. DR does not occur, but merely some diminished excitability of the muscles involved.

The nature of these post-diphtheritic complications is not well established. In some cases the muscles are chiefly involved, in others the nerves, in others the cells of the anterior cornua, while in still others there may be no appreciable lesion whatever.

Electric exploration is not only useful for diagnosis, but it has also a special value as a means of prognosis. In general we may say that the prognosis is unfavourable when there is complete DR accompanied by longitudinal reaction, whereas partial DR, if the malady is at its height, is of better augury. On the other hand in neuritis *a frigore,* complete DR is not of such grave import.

The Choice of the active electrode.—Before entering on the subject of electro-therapeutics, it may be well to lay down the general rules which guide us in determining whether the active electrode shall be an anode or a cathode.

The negative pole has a resolvent action on chronic inflammations and more particularly on neuritis. It arrests the cicatricial process, and formation of sclerous tissue, an important point in the electro-therapeutic treatment of affections of the brain and spinal cord. The negative pole, moreover, augments the excitability of the nerve (cathelectrotonus) and is thus useful in paralysis.

The positive pole, on the contrary, diminishes the excitability of the nerve. Its action is sedative and depressant. (*Leduc.*)

In the diseases we are about to consider there are two opposing symptoms, *viz.,* pain and paralysis. The cathode should be the active electrode in the treatment of paralysis, the anode should be used for the relief of pain.

Electro-therapeutics.—General treatment of all polyneuriteis.—Electrical treatment should not be commenced until the cause has ceased to act. The best means of treatment is that by means of the continuous current, a large indifferent electrode being applied to the roots of the affected nerve, and a large active electrode on the peripheral region. The rule for the sign of the active electrode is given above, *i.e.,* the anode for pain, the cathode for paralysis. Atrophy should be treated by faradisation or, better still, by rhythmic galvano-faradisation.

If there is DR with inversion of the normal formula, we may use the galvanic current with rhythmic interruption. A metronome may be used giving one beat per second. The positive pole should be applied to the motor points.

Sinusoidal voltaisation has given excellent results in the hands of some experimenters. (*Regnier, Bordier.*)

Saturnine polyneuritis. 1. The affected nerves should be galvanised. When the fore-arm is affected, a cathode of 30 sq. cm. should be applied to the back of the hand. When the upper arm is attacked, a cathode of 100 sq. cm. should be applied to the front and lower part of the arm. When the leg is attacked a cathode of 100 sq. cm. should be applied to the dorsum of the foot, the ankle and the front and outside of the leg. The cathode is chosen as the active electrode because in saturnine polyneuritis, the disease affects the motor rather than the sensitive nerves. The indifferent electrodes should have a surface of at least 200 sq. cm., and should be applied to the nape of the neck or the loins, according to the situation of the paralysed muscle. A seance of 10 to 15 minutes should be given daily at first, and afterwards every other day. With a cathode of 20 sq. cm. the intensity should be 10 milliamperes. With larger cathodes, we may give 15, 20, or even 30 milliamperes.

2. The atrophied muscles may be treated by means of galvano-faradisation, the active electrode being applied to the motor point of each muscle. In accordance with the general law, the active electrode should be connected to the negative pole. If there is no apparatus available to interrupt the current periodically, this may be done by hand, in order not to fatigue the muscles by sustained contractions of too great duration. The treatment should be repeated every day or every other day.

If the muscle does not react to the galvano-faradic current, we may employ a galvanic current, interrupted by a metronome beating seconds. The active electrode should be an anode, as there is inversion of the normal formula, and ACC appears before KCC. We may increase the current to the limit of tolerance, and if this is not successful, we may transfer the active electrode to the lower extermity of the muscle so as to get longitudinal reaction. In this case the active electrode should be a cathode. In many cases one may employ an electrode large enough to cover the motor points of several muscles, and thus obtain the simultaneous contraction of a group of muscles.

3. Static electricity may be used in these cases, by means of the static spark or *Bergonié's* excitateur, or high frequency sparking may be employed. The treatment is usually protracted, lasting several months.

Alcoholic polyneuritis. 1. Galvanisation. The anode should be used where there is much pain, and the cathode if the symptoms are chiefly paralytic. An active electrode of 60 to 100 sq. cm. should be applied to the back of the foot and ankle, and the front and outer part of the leg. The indifferent anode should have a surface of at least 200 sq. cm. and should be placed over the loins. When the extensors of the arm are affected, the treatment is the same as for saturnine neuritis in the same situation.

The duration and number of the seances is the same as for saturnine neuritis.

2. Galvano-faradisation may be employed in the same manner as for saturine neuritis.

3. Static electricity or high frequency may also be used. The treatment is protracted, lasting at least six or eight weeks, and often longer.

Diphtheritic polyneuritis.—The best treatment is faradisation. (*Duchenne, Erb.*) Galvanism is more difficult to apply and not so efficacious. The paralysis of the velum palati is greatly improved by general faradisation, not directed especially to the paralysed part.

Larat prefers the treatment by means of sinusoidal currents.

The following is the technique of the treatment by faradisation. One of the electrodes with a surface of 100 sq. cm. is applied to the neck. The other electrode consisting of an arm-bath or foot-bath is connected to the negative pole of the coil. The duration of the seance is 15 minutes. and the intensity should be limited by the sensation of pain. The treatment may be repeated every day or every other day. In ordinary cases a cure will result in about a month. In order to avoid paralysis of the diaphragm we may faradise the phrenic nerve. The active electrode should be placed just above the clavicle at the outer border of the sterno-mastoid (*Rockwell*). For electric treatment of the velum palati see par. 386.

381. **Neuritis of single nerve trunks.**—Neuritis of a single nerve trunk is usually traumatic, and caused by a prick, cut, contusion, or fracture. It may be caused by a tumour or by exposure to cold, or by some general affection, such as is sometimes followed by polyneuritis.

According to the severity of the lesion and the nature of the nerve attacked, the neuritis may be accompanied by motor paralysis, or by alterations of sensation such as hyperæsthesia or anæsthesia.

Electro-diagnosis. The same as for polyneuritis, but in this case the gravity of the prognosis does not correspond with the degree of DR. We must take into consideration the cause of the neuritis.

Electro-therapeutics. An isolated neuritis should be treated in the same way as a polyneuritis. The nerve should be treated by galvanisation, and the muscle by faradisation, or by rhythmic galvano-faradisation, with variable interruptions. Fatigue of the muscle should be carefully avoided.

We may take the treatment of sciatica as an example.

Isolated neuritis of the sciatic nerve. 1. *Galvanisation of the sciatic nerve.* A large indifferent cathode of at least 200 sq. cm. is applied to the lumbar region. The anode consists of a foot-bath or a large electrode of cotton wool and gauze bandaged round the ankle and lower part of the leg. —Duration 10 to 15 minutes.—Intensity 10 to 30 milliamperes.—Seances every day or every second day.

2. *Faradisation or galvano-faradisation of the affected muscles.* The active cathode is applied to each motor point and each muscle is made to contract rhythmically by means of the rhythmic interruptor, or by periodic interruptions

made by hand. (380) Seances every day, or every other day.

If the muscles do not react to the faradic current or the galvano-faradic current, a galvanic current interrupted by means of a metronome should be employed. If there is inversion of the formula the active electrode should be the anode. A group of muscles may be treated simultaneously.

Other methods. *Denoye* and *Bordier* recommend the direct application of high frequency currents, using a metallic plate of lead or tin on the loins and another just below the calf. The electrodes are connected to the *d'Arsonval* self-induction helix.—Seances of 10 minutes' duration repeated every other day.

In all cases of neuritis electrical treatment should be immediately stopped on the occurence of phenomena of contracture.

382. **Herpes zoster.**—Obstinate cases of herpes zoster may be treated by galvanisation. A large anode should be placed on the spine over the roots of the affected nerves, and one or more negative electrodes on the skin of the affected region, taking care to avoid the points of eruption. —Intensity, 5 to 15 milliamperes.—Duration, 10 minutes, every day or every other day.

383. **Paralysis due to peripheric causes.**—There are some paralyses of peripheric origin, which are not part of a neuritic process. We shall give the most important of these, and discuss the central lesions and general diseases giving rise to similar symptoms.

384. **Facial paralysis.**—When we are called to treat a case of facial paralysis there are several questions to be considered in making a diagnosis. Firstly, we must be careful not to mistake for paralysis a contracture of the opposite side, which makes the healthy side look weak and flabby by contrast.

Secondly, we must ask ourselves what is the cause of the paralysis. There are four principal varieties.

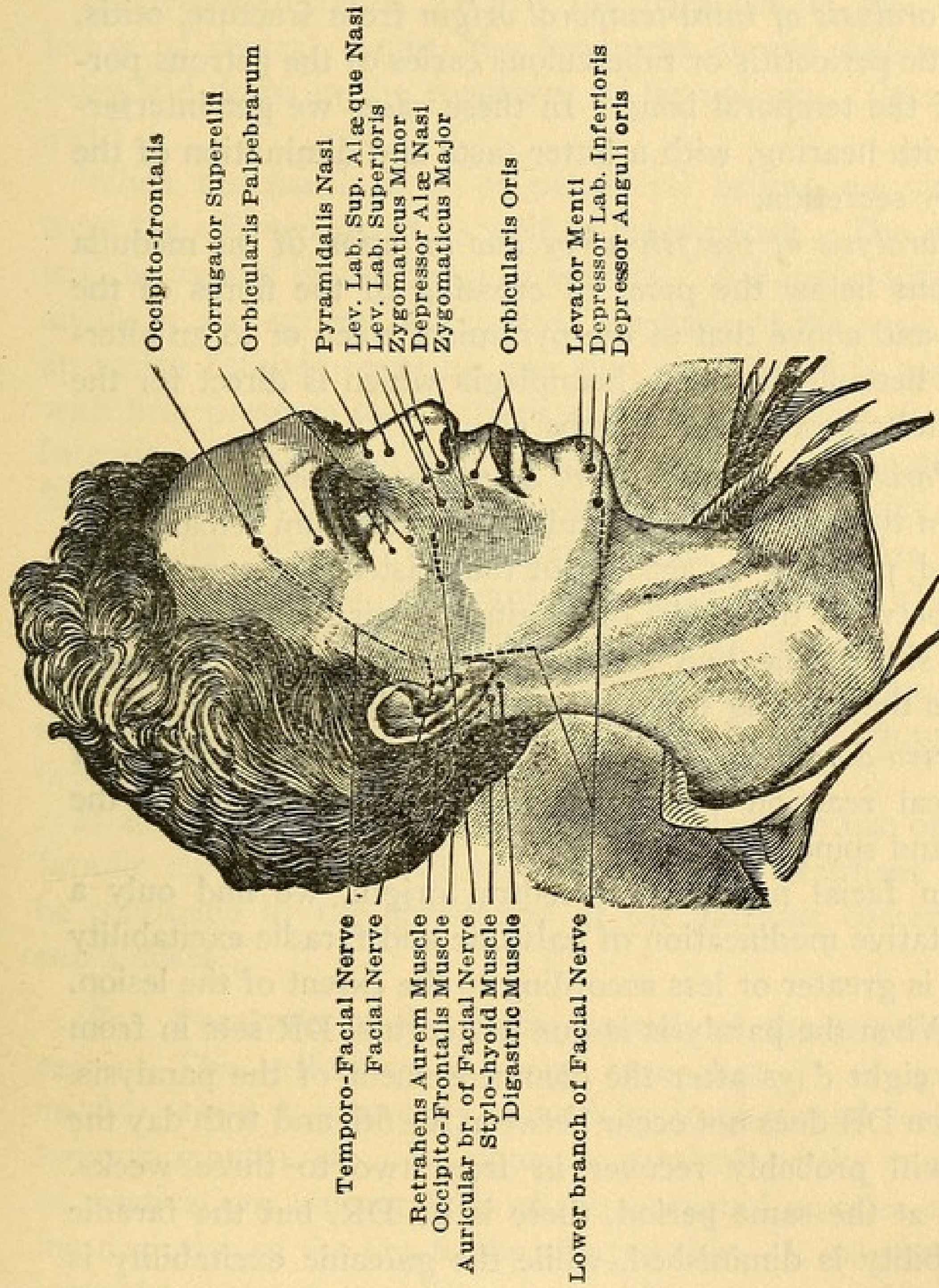


Fig. 68.—Motor Points of the Muscles of the Face supplied by the Facial Nerve (Eichhorst).

a. *Paralysis of peripheric origin.* These include paralysis a frigore in rheumatic cases from exposure to cold, traumatic paralysis resulting from compression by means of the forceps in labour, paralysis due to a syphilitic tumour of the parotid, or to neuritis as described in par. 381.

b. *Paralysis of intra-temporal origin* from fracture, otitis, syphilitic periostitis or tuberculous caries of the petrous portion of the temporal bone. In these cases we get interference with hearing, with a bitter taste and diminution of the salivary secretion.

c. *Paralysis of the 7th nerve due to lesion* of the medulla and pons below the point of crossing of the fibres of the facial, and above that of the pyramidal tract, or to an alternating hemiplegia, *i.e.,* a hemiplegia which is direct for the face, and crossed for the limbs.

d. *Paralysis of the 7th nerve due to hæmorrhage or softening.* In these cases the orbicularis palpebrarum remains unaffected, probably on account of the existence of commisural fibres between the nuclei of origin of their motor nerves on either side. The two latter classes will not be discussed here as they belong more properly to a later chapter.

Electro-diagnosis. We may here recall the anomalies of electrical reaction which are produced by lesions of the brain and spinal cord.

1. In facial paralysis of central origin, we find only a quantitative modification of galvanic and faradic excitability which is greater or less according to the extent of the lesion.

2. When the paralysis is due to neuritis, DR sets in from six to eight days after the commencement of the paralysis.

When DR does not occur between the 6th and 10th day the case will probably recover in from two to three weeks. When at the same period, there is no DR, but the faradic excitability is diminished, while the galvanic excitability is increased, the case will probably recover in from six to twelve weeks. Finally, when DR occurs, we may expect the paralysis to disappear after three to eight months, or not at all, according to the degree of DR, whether partial or complete.

Electro-therapeutics. When the paralysis is due to a lesion of central origin, the treatment should follow the rules laid down in the treatment of hemiplegia. (411 and 412.)

When the paralysis is of peripheral origin, we should treat the affected nerve as well as the muscles. The nerve is to be treated by the galvanic current. A large indifferent anode of 200 sq. cm. is placed on the back of the neck, and an active cathode covering one side of the face is applied with firm pressure to the trunk of the facial below the ear. Intensity: 10 to 15 milliamperes.—Duration: 10 minutes.—Seances at first every day, afterwards every other day.

After ten days, we may begin to treat the muscles with galvano-faradisation, by means of a small electrode of 3 or 4 sq. cm. applied to each motor point. We should be careful not to fatigue the muscles, and should therefore give only short seances and make use of the rhythmic interruptor in order to interrupt the current periodically.

If any signs of contracture should appear, the use of the faradic current should be stopped, and the treatment may be continued by the application of the galvanic current in small doses.

385. **Paralysis of the motor branch of the trigeminal nerve.**—This affection is very rare, but is of grave augury, since it is usually caused by intra-cranial lesions, tumour, gumma, etc. Its signs are paralysis of the muscles of mastication, and paralysis of the pterygoid muscles causing deviation of the jaw to the affected side. It may be followed by contracture. When caused by intra-cranial lesion, *Eichhorst* recommends bilateral galvanisation of the cranium, and faradisation of the masseter and temporal which

are the only muscles easily accessible. The nerve itself may be galvanised, using an active cathode as in the treatment of facial paralysis.

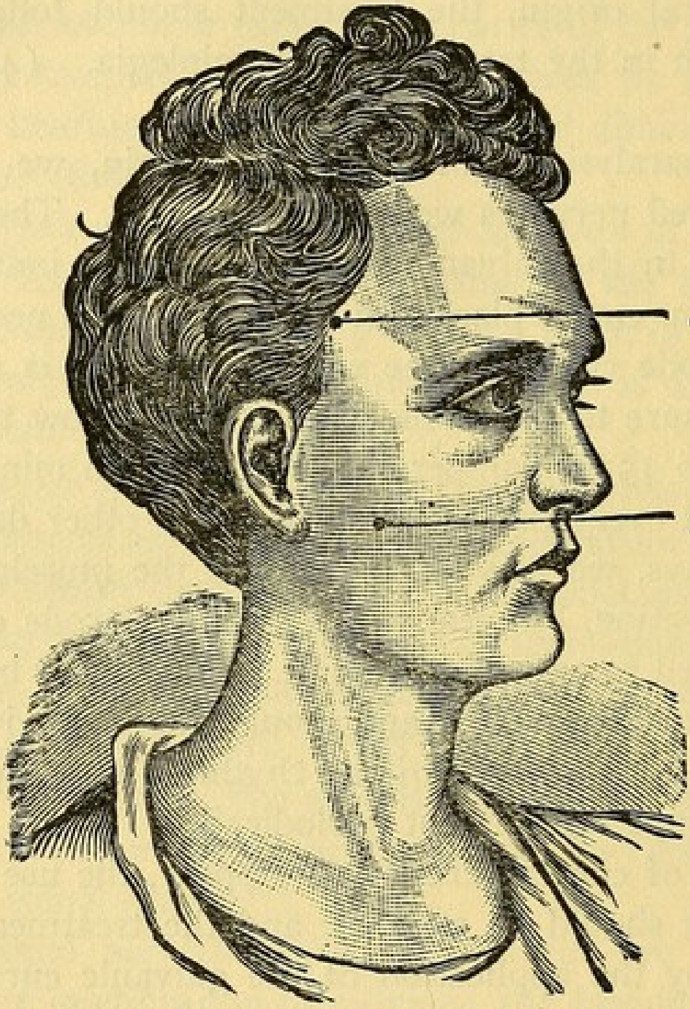


Fig. 69.—Motor Points of the Temporal and Masseter Muscles.

386. **Paralysis of the spinal accessory nerve.**—The spinal accessory nerve has two branches, the external branch supplying the sterno-mastoid and trapezius, and an internal branch going to the velum palati.

Paralysis of the external branch is accompanied by loss of power in the sterno-mastoid and trapezius muscles. It is usually caused by exposure to cold, traumatism, tumours or abscesses of the neck, and affections of the cervical column. The treatment consists in galvanisation of the nerve. An anode is applied to the back of the neck and a cathode to the antero-lateral surface of the affected side. This should be followed by faradisation of the paralysed muscles.

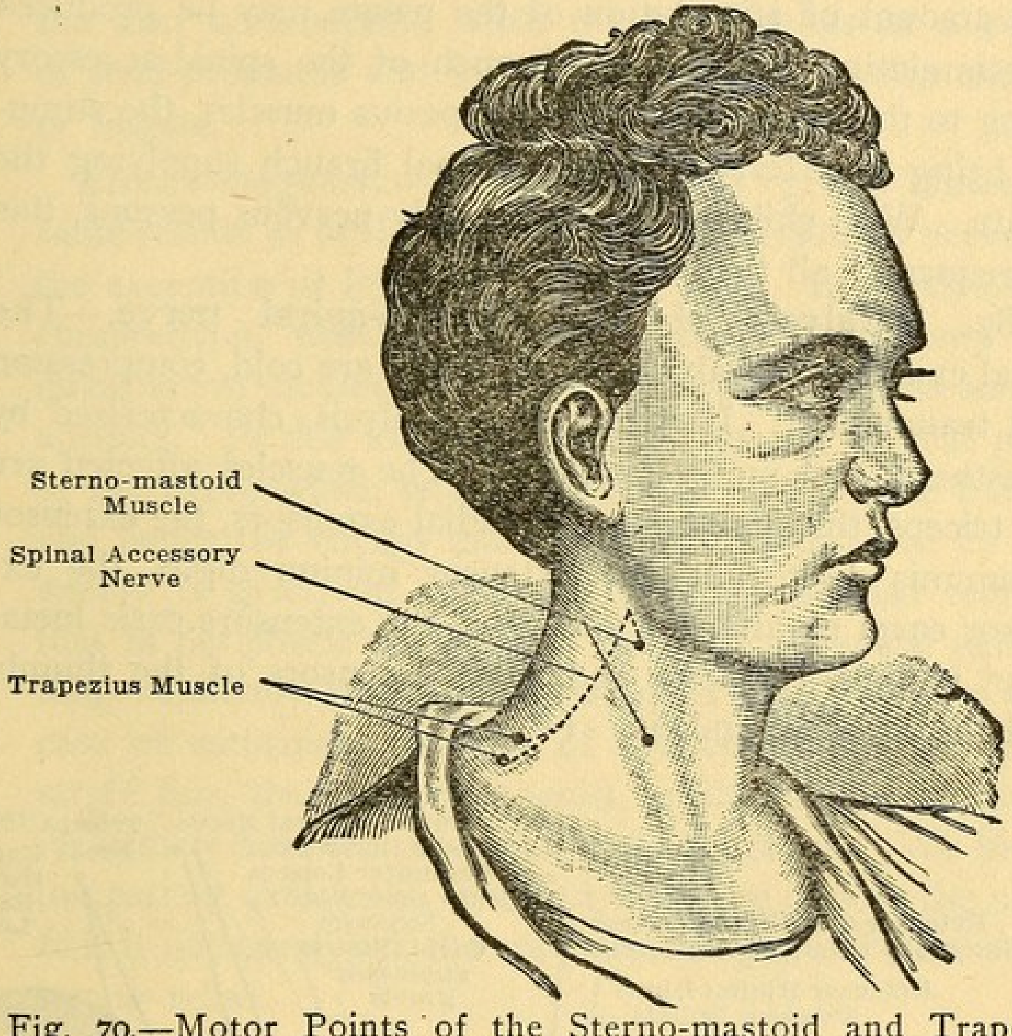


Fig. 70.—Motor Points of the Sterno-mastoid and Trapezius Muscles.

In cases where there is a lesion of the central nervous system, *Eichhorst* recommends galvanisation of the cranium.

The treatment of paralysis of the internal branch of the spinal accessory nerve necessitates a special technique.

The palate may be treated directly by means of the curved electrode designed by *Bordier.* The extremity should be well padded with moistened cotton wool covered with gauze. The indifferent electrode being placed on the neck, we begin by giving the galvanic current for a few minutes with the negative pole on the palate, after which we give one or two minutes' faradisation or galvano-faradisation, interrupting the application as often as necessary. A certain amount of stimulation of the palate may be produced by stimulating the external branch of the spinal-accessory going to the sterno-mastoid or trapezius muscles, the stimulus being transferred to the internal branch supplying the palate. With children or exceedingly nervous persons, this is frequently all that can be done.

387. **Paralysis of the musculo-spiral nerve.**—The usual causes of paralysis of this nerve are cold, compression and traumatism. It is a mixed paralysis, characterised by anæsthesia and motor paralysis. The muscles affected are the triceps, the supinators, the radial extensors, the extensor communis digitorum, the extensor minimi digiti, the extensor carpi ulnaris, the anconeus, the extensors ossis metacarpi pollicis, the long and short extensors of the thumb, and the extensor indicis. (Fig. 71.)

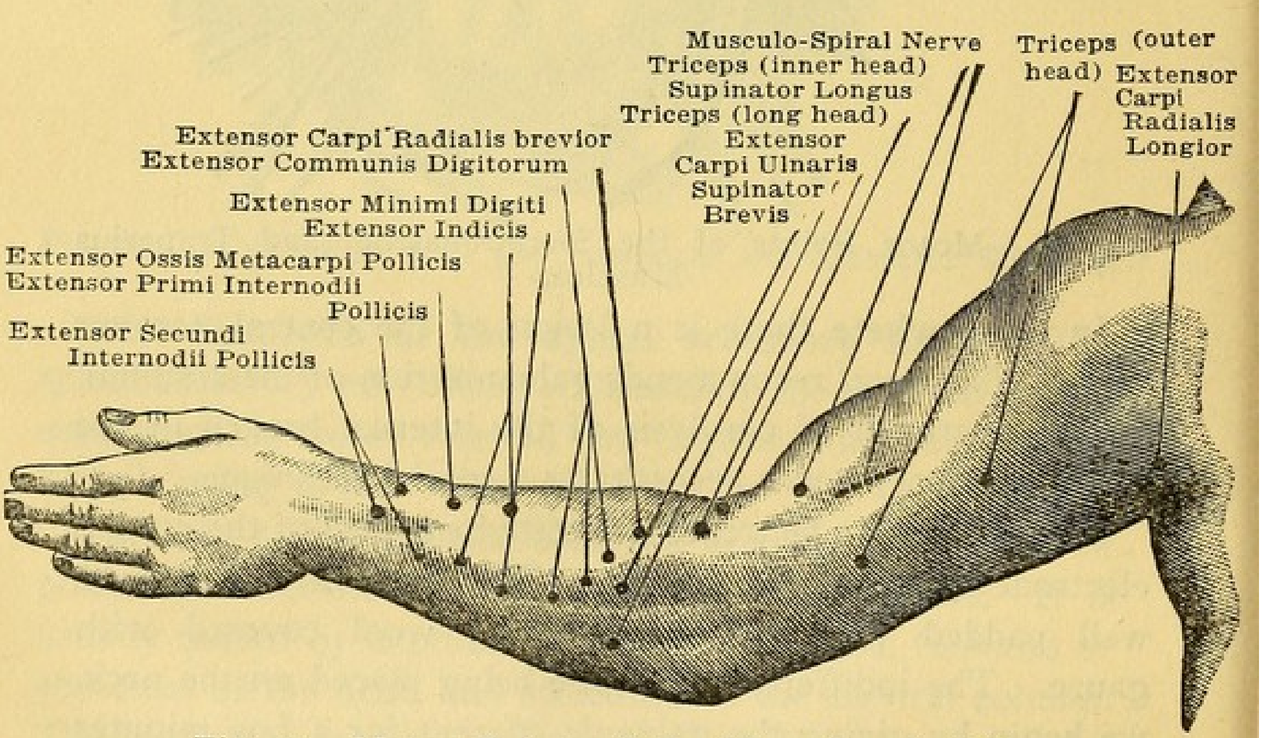


Fig. 71.—Motor Points of the Musculo-spiral Nerve.

The sensory territories corresponding to the branches of the musculo-spiral nerve are represented in Figs. 63 and 64. Paralysis of this nerve may be easily recognised by raising the arm horizontally, when the hand drops in a position of semi-pronation and the patient is unable to flex the wrist or fingers.

Electro-diagnosis.—Electro-diagnosis gives almost the same results as in the case of paralysis of the 7th nerve, with the exception of DR, which is very rare. In paralysis from compression, usually produced during sleep, only slight quantitative modifications occur, and the paralysis soon disappears. In this form, the pressure occurs on that portion of the nerve which winds round the shaft of the humerus, and hence the triceps muscle is unaffected, since its motor supply is given off high up. We should also remember that in peripheric paralysis of the musculo-spiral nerve the long supinator is paralysed, whereas this is not so in the case of saturnine paralysis of the extensors. To demonstrate this, the fore-arm should be placed in a position intermediate between pronation and supination. We then tell the patient to flex the fore-arm while we oppose the motion. If it is not paralysed, the supinator longus will start out into strong relief.

Electro-therapeutics. We begin with galvanisation of the nerve, with an indifferent anode of at least 200 sq. cm. at the back of the neck, using an arm-bath as cathode, or a flexible electrode of 100 sq. cm. bandaged to the back and outside of the fore-arm and wrist.—Intensity: 20 to 40 milliamperes.—Duration: 10 minutes.—Seances every day or every second day.

The muscles should be treated with the galvano-faradic current, interrupted by the rhythmic interruptor. The active electrode is applied to the motor points of the affected muscles, and the treatment should be continued for only a few minutes.

388. **Paralysis of the median nerve.**—This affection, which is very rare, usually results from luxation, from traumatism or from compression due to the formation of callus after a fracture. The symptoms differ according to the position of the injury to the nerve.

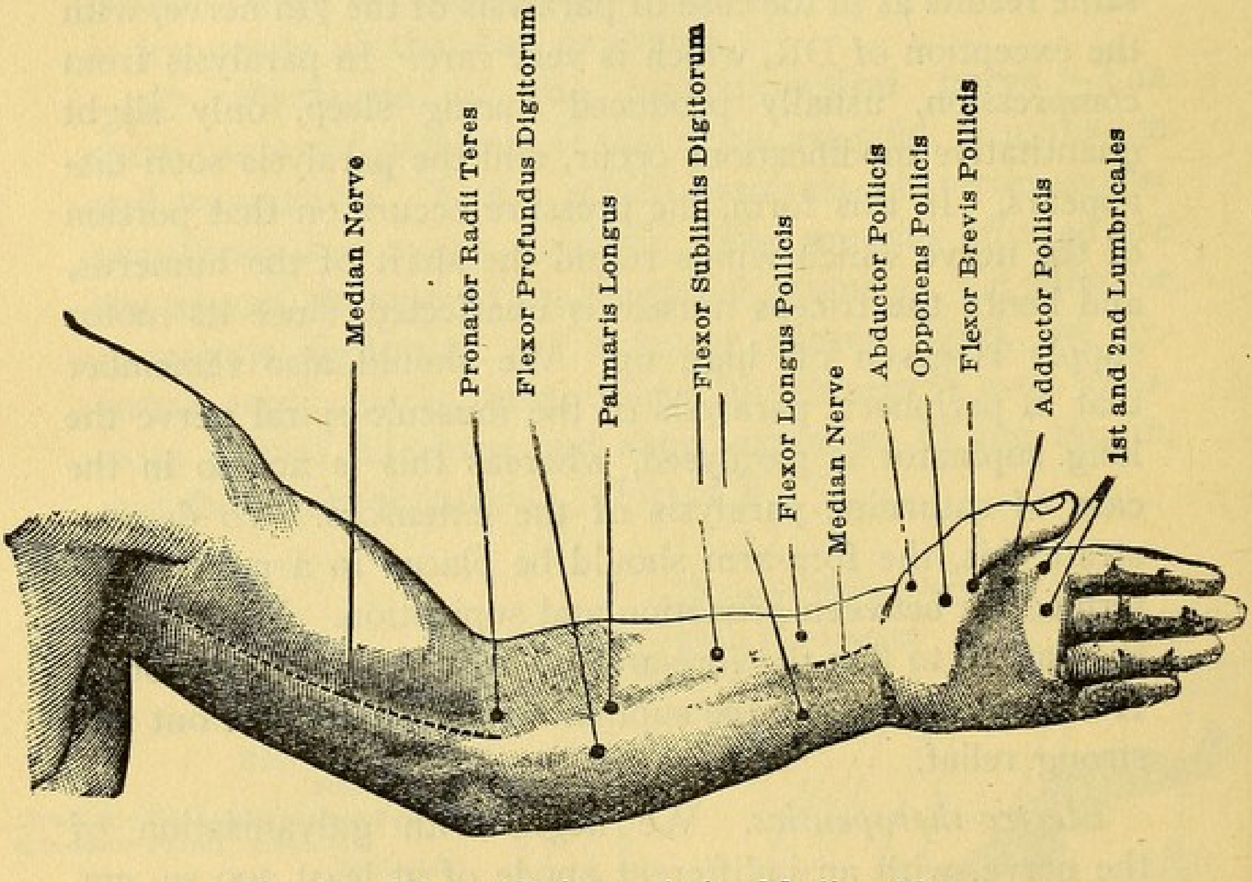


Fig. 72.—Motor Points of the Median Nerve.

Fig. 72 shews the motor points of the affected muscles. The treatment is the same as that given above for musculo-spiral paralysis. It consists of galvanisation of the nerve, and galvano-faradisation of the muscles. (387)

389. **Paralysis of the ulnar nerve.**—The same may be said of paralysis of the ulnar nerve, which is usually of traumatic origin. It affects the muscles of the hypothenar eminence, the interossei and the 3d and 4th lumbricales. In

severe forms, with advanced trophic alterations, the hand takes the form of a bird's claw. Fig. 73 and 74 shew the motor points of the affected muscles.

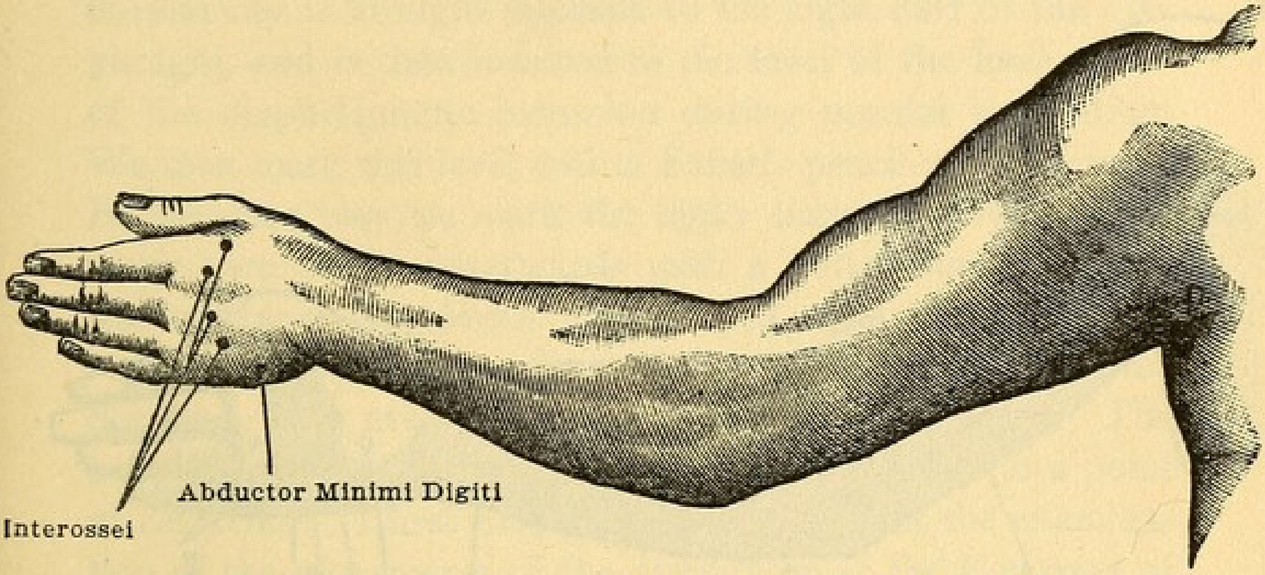


Fig. 73.—Motor Points of the Ulnar Nerve (Dorsal Surface).

390. **Paralysis of the nerves of the upper arm.**—There are numerous instances where paralysis may affect the territories of two or more nerves at the same time. We shall only allude to two of these. One is caused by contusion, luxation or fracture of the shoulder, and is characterised by atrophy of the deltoid. The other is paralysis of *Erb's* plexus, limited to paralysis of the deltoid, the biceps, the brachialis anticus and the supinator longus. In these affections, which differ greatly according to the severity of the original lesion and the degree of neuritis and muscular atrophy, we must combine the galvanic with the faradic current, as in paralysis of the musculo-spiral nerve. The motor points of the muscles supplied by the ulnar nerve are given in Plates V and VI. For further information on muscular atrophy we may refer the reader to par. 377.

391. **Paralysis of the diaphragm.**—Paralysis of the diaphragm may be partial or total. It is met with in the course of pleurisy and peritonitis, or it may be a result of neuritis

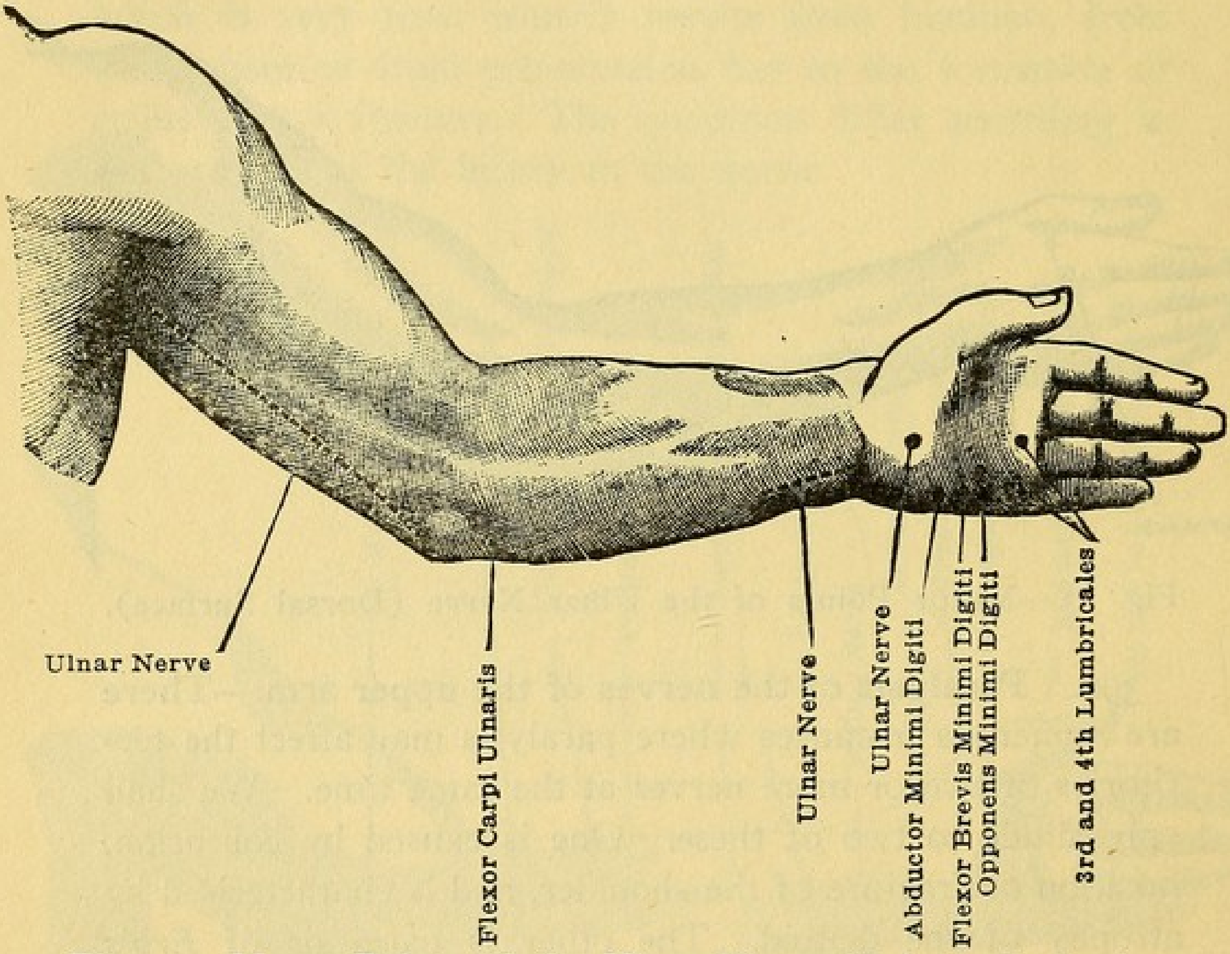


Fig. 74.—Motor Points of the Ulnar Nerve (Palmar Surface).

of the phrenic nerve of saturnine or diphtheritic origin. The dyspnœa usually comes on in paroxysms when the respiration is increased by the least exertion.

Radio-diagnosis.—The radioscopic examination of patients suspected of paralysis of the diaphragm is of the greatest utility, both for diagnosis and for following the progress of the disease. When paralysis is complete, the diaphragm no longer sinks at each inspiration, but is drawn slightly upwards in consequence of the diminished pressure in the chest. Thus we may say that diaphragmatic movement becomes less and less with the progress of the malady. and is reversed when the paralysis is complete.

The examination of the diaphragmatic incursion is made in the following manner. The patient is placed in front of the tube carrier as if for ortho-diagraphy of the heart. The normal ray is brought opposite to the right half of the diaphragm, and is then lowered to the level of the lower limit of the diaphragmatic incursion during normal respiration. We then mark this level with a Faber's pencil on the screen. In the same way we mark the upper limit of the diaphragmatic incursion. Afterwards with a dotted line we mark the corresponding levels with forced respiration. A corresponding observation is made on the left side and the pencilled lines are then taken off on transfer paper. The median point of the upper sternal notch is marked as a point of reference. I first exhibited this method for the examination of the movements of the diaphragm at the Congress of Paris in 1900, before the introduction of orthodiagraphy. It should be of great service to clinical medicine, not only in cases of true paralysis of the diaphragm, but also in a number of cases where its function is altered by reflex action, neurosis, or other causes. The instruments designed since 1901 in Germany for the orthodiagraphic measurement of the area of the heart are not so suitable for this purpose, as they do not afford so extensive a view of the thoracic contents.

Electro-therapeutics.—The phrenic nerve should be treated by means of the continuous current. A large anode may be placed on the neck and a small cathode on the trunk of the phrenic nerve between the two insertions of the sterno-mastoid. Or we may place a small anode on the phrenic and a large cathode on the epigastrium and hypochondrium. A current of 5 to 10 milliamperes should be employed. The seance may be terminated by excitation by means of the faradic current. The contraction of the diaphragm is accompanied by a loud sound indicating the penetration of air into the respiratory tract.

392. **Paralysis of the anterior crural nerve.**—In this case, the psoas and iliacus, the sartorius and the extensors of the thigh are affected, and frequently undergo secondary degeneration.

The electro-diagnosis and the treatment are the same as for paralysis of the musculo-spiral nerve. The anterior crural nerve is only accessible just below *Poupart's* ligament. The motor points are given in Plates VII and VIII.

393. **Paralysis of the sciatic nerve.**—This affection is fairly common, as the result of traumatism, compression, neuritis or exposure to cold. The following are the symptoms of the different varieties dependent on the part of the nerve affected.

When the nerve is injured near its origin, the upper collateral branches will be affected, causing paralysis of the obturator internus, the gemelli, the quadratus femoris, the semitendinosus and semi-membranosus muscles. The adduction of the thigh and the flexion of the leg are interfered with.

When the paralysis affects the peroneal nerves, the following muscles are affected, the tibialis anticus, the extensor communis digitorum, the extensor longus pollicis, the peronei, the extensor brevis digitorum and the extensor proprius pollicis. The extension and adduction of the ankle is interfered with, and the foot is placed in the position of varus equinus, with dropping of the toes and the external border of the foot.

If the paralysis only affects the popliteus internus, the following muscles are paralysed, the gastrocnemius, soleus and plantaris, the popliteus, the tibialis posticus and the deep flexors of the toes. The foot is placed in the position of talipes valgus, with its point and external border raised.

The electro-diagnosis may be made in the way previously described for paralysis of the facial and musculo-spiral nerves.

Treatment will consist in the use of the continuous current with an indifferent anode over the loins and a foot-bath or active electrode attached to the negative pole. This may be followed by the rhythmic galvano-faradisation applied to the motor point of each muscle.

394. **Other forms of paralysis.**—The above are the forms of paralysis most frequently met with. There are other forms affecting special nerves or organs, such as paralysis of the recurrent nerve, of the sphincters and of the bladder. We shall allude to these under the heading appropriated to each particular organ. Thus the diseases of the larynx, of the throat and of the nose will be treated in separate paragraphs. The paralysis of the velum palati is described under that on the spinal accessory nerve. For paralysis of the recurrent nerve we must refer the reader to par. 516, and for that of the bladder to par. 473.

395. **Neuralgia.**—Neuralgia may be a concomitant of neuritis, or it may appear without any sign of neuritis, in which case its pathology is exceedingly obscure. It may follow traumatism or exposure to cold, or it may depend on general causes such as rheumatism, gout, diabetes, syphilis, infectious diseases such as paludism, toxic diseases or neuroses. In many cases the etiology is unknown, and it may then be considered a part of the arthritic diathesis, of which it may be the only manifestation.

Proper electro-diagnosis is impossible in this affection. When, however, neuralgia is accompanied by muscular atrophy, both are probably due to neuritis. In this case electro-diagnosis may enable us to recognise the organic cause of the affection.

Electro-therapeutics. The electrical treatment will vary according as the neuralgia is due to a general or to a local cause. If to a general cause, this must be treated by the usual therapeutic measures. In neuralgias entirely dependent on local causes, we may employ galvanism followed by faradisation or electric counter-irritation. In neuralgias dependent on general causes, the electric treatment includes general faradisation, static electricity, the electric bath and high frequency currents.

1. *Continuous current.*—In most cases, the treatment par excellence for neuralgia is that by the galvanic current. Electrodes of large area should be employed, thus enabling us to give currents of considerable intensity. The usual dose is one-tenth to one milliampere per square centimetre of surface.

Some patients, however, can hardly bear one-twentieth of a milliampere per square centimetre. *Bergonié, Bordier, Guilloz, Vernay* of Vienna and others employ strong currents having an intensity of 1 milliampere per sq. cm. *Guilloz* gives as much as 3 milliamperes per sq. cm. even for the face. The intensity of the current is limited only by the risk of injury to the patient's skin and to his powers of endurance of pain.

Here, above all, we must look to the state of the electrodes. Each patient should have a fresh electrode. This should be covered with wool and gauze and adapted to the region which is affected. The electrode should be a thick one, so that the density of the current may be the same over the whole surface. This will not be the case when the electrode is unequally oxidised and covered with thin felt unequally applied.

Leuilleux employs electrodes made of asbestos.

The choice of the metal for the electrode is important.

Tin speedily tarnishes with the use of the intense currents necessary for neuralgia. The best results are obtained with aluminium or platinised copper. (*Bordier.*) The active electrode is usually connected to the positive pole. The positive pole diminishes the excitability of both sensitive and motor nerves, although the effect soon passes off. (*Eulenberg, Erb, de Watteville, Waller, Leduc.*) Other experimenters have obtained equally good results by using the negative pole as the active electrode. The choice of the pole in all cases may not be of great importance, but it is better to adhere to the general rule and employ the positive pole as the active cathode when there is great excitability.

The seances should be fairly long. The old method by short seances of feeble intensity is being gradually abandoned. A seance may be given every day or every two days, the duration varying from 30 to 85 minutes according to circumstances. Occasionally as much as two seances a day may be required. (*Vernay.*) The galvanic current gives excellent results in cases of essential neuralgia and neuralgia of rheumatoid origin. When the affection is the result of general causes, the treatment is much less efficacious.

In addition to the continuous current for neuralgia, we have the treatment by the electrical introduction of chemical ions into the tissues, a method which is yet in its infancy, but which promises a vast field for practice in the future. (*Leduc.*)

2. *Electrical application producing counter-irritation or revulsion.—Faradisation.*—In the treatment of neuralgia when pressure on the affected nerve eases the pain, *Rockwell* recommends the use of the faradic current, the galvanic current being preferable when pressure increases the pain.

By *Duchenne's* method, faradisation may be applied by means of a metallic brush attached to the negative pole of the induction coil, the positive electrode being placed on an indifferent region.

The skin should be quite dry. For this purpose *Duchenne* rubs it over with some absorbent powder such as starch or lycopodium. If preferred vaseline may be used instead of starch.

Duchenne found by experience the importance of this precaution, the reason for which may be explained in the following manner.

When an electric circuit is composed of segments of different material, with different resistances, the greatest fall of potential occurs between the points which are separated by the greatest resistance. In the case in question, the circuit is composed on one side of the positive rheophore, the moistened indifferent electrode, and the body, while on the other side it consists of the negative rheophore and the metallic brush. The whole of this resistance is negligable in comparison with the enormous resistance offered by the dry integument, where it is in contact only with the small points of the metallic brush. Since the electric energy in any part of the circuit depends on the fall of potential, the greater part of the electric energy will be concentrated on the points of contact with the skin. Here the density of the current will be a maximum, the ends of the metallic brush concentrating the electric energy on excessively small areas of the skin. The revulsive action of the faradic brush compares favorably with other methods, of counter-irritation by blisters, cauterisation, etc. The effect is often most marked, the patient being relieved after a few minutes' application.

The procedure known as the "electric hand" may also be usefully employed. The faradic current passing through the body of the operator may be transmitted to the patient by means of his hand passed gently over the painful region. Although far inferior to the foregoing, with nervous patients this method may prove of use.

Morton currents—Statical electricity—High frequency.—Morton reports good results from the use of the currents which go by his name. *Weill* recommends the use of Morton currents. In his method the positive armature of the Leyden jar is earthed, while the negative armature is connected to the electrode,—a rheostat being placed between the armature and the exciting electrode. (335.)

The exciting electrode is passed over the skin along the course of the nerve, at a distance of one or two centimetres. *Bishop* of Washington recommends this procedure even in cases of neuritis.

Static electricity may also be used as an energetic means of revulsion.

The high frequency currents act in the same way. They may be applied by means of the condensing electrode, or with a metallic brush, or with a charcoal electrode passed over the skin. This method has given most excellent results in my own practice. The relief of pain is rapid, although the improvement does not appear to be so durable as with the galvanic current.

When using static electric sparks or high frequency effleuves, the skin should be dried in the same manner as for treatment by faradic revulsion.

396. **Facial neuralgia — Trigeminal neuralgia.**—The *painful points of Valleix.* The trigeminal nerve on its exit from the gasserian ganglion, breaks up into three branches, the ophthalmic, the superior maxillary, and the inferior maxillary. In facial neuralgia there are a number of especially painful spots. These correspond to the points of exit of the nerves from the skull. They are also found at the

points of emergence from a muscle before the nerve enters the skin, and in certain areas where the nerves spread out in the integument.

1. In neuralgia of the *ophthalmic* nerve a *palpebral* painful spot may be found at the outer part of the upper eyelid where the lachrymal branch of the ophthalmic nerve emerges. There is a *supra-orbital* point where the frontal branch of the ophthalmic nerve issues from the supra-orbital foramen. There is a *nasal* point where the external branch of the nasal nerve emerges at the internal angle of the eye. Lastly there is a *naso-lobular* point where the internal branch of the nasal nerve expands over the lobe of the nose.

2. In neuralgias of the *superior maxillary* nerve, we get the *sub-orbital* point, at the sub-orbital foramen, the *malar* point where the temporo-malar branch spreads out over the cheek, and the *dental* points.

3. In neuralgia of the *inferior maxillary,* there is the *auriculo-temporal* point, where the nerve of that name, having passed round the neck of the condyle of the jaw, divides to supply the external ear and temple. We have also the spot over the *mental foramen* where the dental nerve emerges, the *dental* points and the *lingual* points.

These painful spots are shewn in Plate II.

Two forms of facial neuralgia may be distinguished. The slighter form only affects some fibres of the ophthalmic nerve. A much more serious variety is the true "tic doloreux" or epileptiform neuralgia of *Trousseau,* which is often accompanied by spasm. This, which is a most severe and obstinate affection, frequently affects both the superior and inferior maxillary nerves.

Electro-therapeutics.—The most successful treatment of facial neuralgia is that by the continuous current. The other methods alluded to in the paragraph on general neuralgia are of inferior value. When the neuralgia is due to general causes, such as paludism, syphilis, diabetes or hysteria, the general condition should be carefully attended to.

Technique. A large indifferent cathode of 300 to 500 sq. cm. is placed on the neck. The active cathode should cover the entire side of the face, leaving apertures for the eye and mouth. (Fig. 75.)

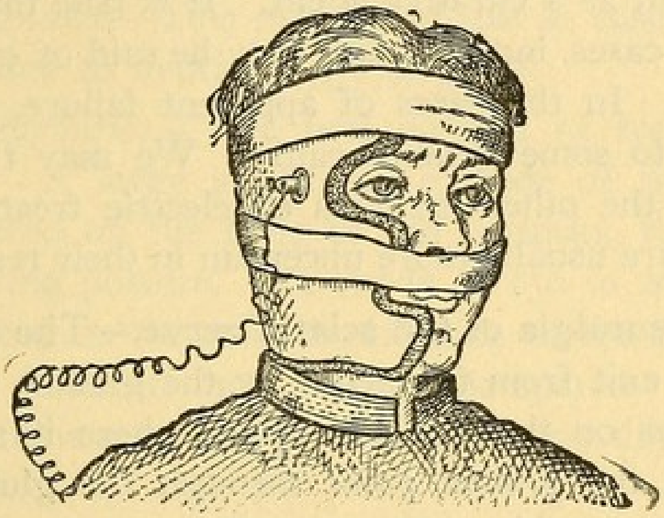


Fig. 75.

Guilloz applies an active electrode 3 cm. in diameter to each painful spot. This is in accordance with the older methods with this difference, that much stronger currents are employed. We must remember that the nerve tissue itself, in virtue of its great conductivity, concentrates the lines of flux between the electrodes, even when the latter are of considerable area. This condensation is increased by the bones of the cranium, in which, as *Bordier* says, the foramina constitute paths of least resistance. Thus the lines of flux are concentrated like a pencil of rays around the nerves themselves.

The electrode should be most carefully applied in close contact with the skin. The intensity may be from 50 to 80 milliamperes and the duration of the seance 45 minutes to an hour, with seances every day, or every other day. The treatment should be continued with somewhat less intensity after all painful symptoms have disappeared.

Results.—The use of currents of high intensity and long duration have placed electricity in the first rank as a means of treatment for facial neuralgia, even in the severe forms of tic doloureux. It acts not only as a means for the relief of pain, but as a curative agent. It is true that it may fail in certain cases, but the same may be said of every mode of treatment. In the cases of apparent failure, this is probably due to some general cause. We may then have recourse to the other methods of electric treatment, which, however, are usually more uncertain in their results. (365.)

397. **Neuralgia of the sciatic nerve.**—The sciatic nerve makes its exit from the pelvis by the greater sciatic notch. It then lies on the ischiatic spine, where it may be compressed at the *gluteal point* through the gluteal muscles. It next passes mid-way between the posterior border of the great trochanter and the ischium, where we find the *trochanteric point.* In the popliteal space is a third point, the *popliteal point,* where the trunk divides into the internal and external popliteal. There is also a *plantar point* lower down.

When, as is often the case, neuralgia of the sciatic nerve is due to neuritis, it may result in muscular atrophy. It may then cause so-called *crossed scoliosis,* in which the body is inclined to the opposite side. *Homologous scoliosis,* in which the body is inclined to the affected side, is much more rarely met with. The distinction is of importance, since crossed scoliosis is simply due to instinctive contraction of the muscles on the healthy side, in order to bring the weight of the body over to that side; whereas, if there is homologous scoliosis there is contracture of the muscles on the affected side.

Like facial neuralgia, sciatica may be due to ordinary causes, such as exposure to cold, and this form is speedily curable. On the other hand, it may be due to lesions of the kidney or spine, or to general causes, such as gout, syphilis, diabetes, gonorrhœa or tuberculosis. Electrical treatment alone is manifestly useless in a case of sciatica caused by syphilis or the compression of a tumour.

Electro-diagnosis.—This may be of use in cases of atrophic sciatica due to neuritis. (380, 381.)

Electro-therapeutics.—The best method of treatment is galvanisation. A large indifferent cathode of 200 to 500 sq. cm. is placed on the loins or the buttocks, the patient being in a sitting posture. An anode of 150 to 200 sq. cm. should be placed on the calf, or the back of the foot, or in a foot bath. Intensity 40 to 80 milliamperes. Duration of seance 30 minutes to 1 hour, repeated every day or every second day.

We may keep in reserve the methods of revulsion enumerated in par. 395. For faradic treatment the foot may be placed on the indifferent electrode, and a metallic brush passed over the course of the nerve. This procedure may advantageously replace the ordinary treatment of the application of cold by means of ethyl chloride.

Atrophy of the muscles may be treated by the galvano-faradic current as described in par. 377. Contracture, if it occurs, is best combated by the galvanic current.

398. **Cervico - occipital neuralgia — Cervico - brachial neuralgia—Intercostal neuralgia.**—The galvanic current should be employed at first, reserving revulsive treatment for a later stage.

In neuralgia of the cervico-occipital, cervico-brachial or intercostal regions, the active anode of 50 to 100 sq. cm. should be placed on the painful area, while the indifferent cathode of 200 to 500 sq. cm. should be placed on the neck or lumbar region. Intensity 40 to 80 milliamperes. Seances 30 minutes to 1 hour every day, or every other day. A rapid result generally follows.

399. **Neuralgia of the ovaries and testicles.**—Neuralgia of the ovary is frequently met with in neurotic females. It is characterised by paroxysmal crises during which the patient bends herself forward and presses her hands on the hypochondrium. The pain irradiates towards the kidneys. The cases are usually of a chronic nature.

This neuralgia of ovarian origin is usually rapidly cured by the application of the continuous current. Active anode of 60 to 100 sq. cm. on the ovarian region. Large indifferent cathode of 200 to 500 sq. cm. on the loins. Intensity, 40 to 80 milliamperes. Duration, 1 hour. Seances every day, or every second day.

Neuralgia of the testicle may be treated in the same manner, the cathode being placed on the loins while an anode, well covered with cotton wool, is applied to the scrotum. Intensity, 20 to 30 milliamperes. Duration not to exceed 30 minutes. Seances every day, or every other day.

400. **Paresthesic meralgia.**—This is an affection of the anterior-crural nerve. The patient complains of numbness and formication of the front and outside of the thigh. The skin is hot, insensible and of a violet colour. In some cases there are symptoms of neuritis.

Galvanisation may be employed, with an anode of 100 to 200 sq. cm. placed on the painful area, and a cathode of 200 to 500 sq. cm. on the loins.

Intensity, 20 to 60 milliamperes. Duration, 15 to 75 minutes. Seances every second day.

Bordier, who has treated three cases of paresthesic meralgia, advises the use of high frequency currents, by means of a stimulating electrode consisting of a few sheets of metallic foil, connected to the resonator so as to produce sparking. Two or three seances may be given each week.

401. **Migraine.**—This is usually a manifestation of the arthritic diathesis, or it may be a concomitant of dyspepsia or dysmenorrhœa. According to *Bouchard*, migraine is a "painful affection of the head, either unilateral or bilateral, affecting the upper branches of the trigeminal or occipital nerves, sometimes involving the ciliary nerves, and the optic and auditory nerves, and occasionally the vagus; the whole being accompanied by encephalopathy and spasm or paralysis of the cervical sympathetic." We place this affection among the neuralgias, because it has some symptoms in common with them, and the indications for treatment are similar. Moreover some idiopathic neuralgias are rheumatismal or arthritic in their origin. There is, however, one great difference between migraine and neuralgia. The continuous current which is curative for the latter is in most cases useless for migraine.

Electro-diagnosis.—In this affection some observers have noticed an increase of the electrical resistance of the head, or an inequality of the resistance on the right and left sides. Even if this observation were well established it would not appear to be of any great importance.

Electro-therapeutics.—1. Static electricity is the best treatment for idiopathic migraine. The patient is insulated by means of a platform with glass legs. He is then connected to the positive pole of a powerful machine, the negative pole being earthed. A static discharge from a pointed electrode may be directed on the more painful spots, and *Truchot's* electrode may be placed over the head. The pointed electrode and *Truchot's* electrode should both be earthed. Duration, 20 to 30 minutes every day, or every second day.

2. Galvanism of the sympathetic may also be used. The active negative electrode is applied to the superior cervical ganglion of the sympathetic, at the anterior border of the sternomastoid, the indifferent anode being applied to the neck. *Müller* recommends this method when migraine is accompanied by pallor and dilatation of the pupil. He gives a seance of 3 minutes' duration every day, with an intensity of 2 milliamperes. Where there is redness of the face and contracted pupils, he gives an application of only 30 to 40 seconds with an intensity of 1 milliampere. These numbers are given solely on *Müller's* authority.

Larat has seen good results follow faradisation of the stomach, in cases of dyspeptic migraine.

C.—Diseases of the Spinal Cord.

Chronic myelitis—Sclerosis—Acute myelitis.

402. **Affections of the spinal cord.**—In diseases of the spinal cord affecting the peripheral motor system, electro-therapy is particularly indicated, since it affects paralysed muscles as well as those which are only functionally affected.

Among diseases which come more particularly under the notice of the medical electrician is tabes, a chronic lesion of the cerebro-spinal system which we can hardly hope to cure, but which we may ameliorate.

Friedreich's disease is also a cerebro-spinal lesion, in which some of the symptoms may be relieved by electric treatment.

We may also be called on to treat some of the diseases resulting from a chronic lesion of the cells of the anterior cornua of the cord, resulting in muscular atrophy. Among these is the well-known type of progressive muscular atrophy of *Aran-Duchenne.*

The muscular atrophy and the anæsthesia which accompany syringomyelitis may also be treated with electricity.

Little's disease is also amenable to electricity aided by rational gymnastics.

Among acute medullary affections amenable to electric treatment are the various forms of poliomyelitis, affecting the trophic centres of the muscles in the anterior cornua. The two most common forms are the acute poliomyelitis of infancy, and the acute anterior poliomyelitis of the adult.

In addition to these affections, there are several other forms of sclerosis with varying clinical symptoms, in some of which electricity may be found useful.

403. **Tabes dorsalis—Progressive locomotor ataxy.**— There is of late too great a tendency to regard tabes as a disease against which electrotherapy, in common with all other treatment, is necessarily powerless. Tabes is not invariably fatal. Although we may be unable to act on the sclerosed tissue, there is a stage when the disease has as yet only attacked the capillaries. Even after the disease has invaded the posterior columns of the cord the axis cylinders of the nerves may still remain intact. (*Bouchard.*) In this stage, according to *Onimus,* electricity may be of great service. Even when the disease has progressed still further towards its fatal termination, there are successive processes of degeneration, secondary invasions, and consecutive attacks of neuritis, in which electric treatment may be of service. Tabes, therefore, must not be considered as one of those diseases in which electro-therapeutic treatment offers but a temporary amelioration. It may be useful at any stage, but more particularly in the earlier ones.

We must refer our readers to the special treatises on pathology for a further study of this disease, the protæan forms of which must be thoroughly understood before we can apply a rational treatment with hope of success. We shall allude here only to those points which are of special interest for electro-therapeutic treatment.

In the early stage of tabes, the disease attacks the medullary prolongations of the posterior roots of the spinal nerves. These, together with the commissural fibres of the posterior horns, form the columns of *Burdach*. Besides this variety of sclerosis, which is confined more particularly to the lumbar region, we find lesions of the commissural fibres which form the columns of *Goll*. Higher up, in the floor of the 4th ventricle, continuous with the sclerosis of the column of *Burdach*, we find lesions of the sensitive nuclei of various mixed nerves, the ascending root of the 5th, the nuclei of the restiform body, etc. The abolition of the reflexes and the shooting pains in the lower limbs, which are so marked a feature in the earlier stages of tabes, are due to these primary medullary lesions. In this stage, the continuous current gives very good results, since the pain is due to a process of irritation of the posterior roots, akin to that of neuritis. Moreover, certain symptoms of the first period of tabes are due to a veritable neuritis. Among these are the visceral pains, the transient paralysis of the 3d, 4th and 6th ocular nerves, the laryngeal symptoms, and the spasm of the glottis due to neuritis of the laryngeal and pneumogastric nerves. The atrophy of the optic nerve, which often ends in blindness, is also a neuritis. Some of the early symptoms of tabes are also due to invasion of the spinal roots of the sympathetic. This explains the good results obtained by galvanisation of the sympathetic. (*Onimus.*)

In the early period, the anterior cornua of the cord and the neuro-motor system are not affected, and the muscles preserve their original force. The muscles indeed are in a state of hyperactivity, which *Onimus* designates "contracturie." This may be seen in the way a tabetic patient executes a movement. He employs far more energy than necessary, but without measure or coordination. It would therefore be a grave mistake to attempt to strengthen the muscles by exercise, under the false impression that the muscles are weak because the patient cannot remain upright. Later on, when the anterior horns are affected and there is true muscular atrophy during the period of cachexia, we might perhaps try faradic stimulation, but it will be seldom of any advantage.

Electro-diagnosis and radio-diagnosis.—Electro-diagnosis is of but little use in tabes. Symptoms of DR appear only after the cells of the anterior cornua are attacked, and the neuromotor system is secondarily affected.

Radio-diagnosis may give useful information concerning the state of the osseous and articular systems. In some cases we find rarefaction and disappearance of the osseous tissue of the ends of the bones, together with osteophytes invading the articular regions. The destruction of osseous tissue may involve the diaphysis. Radioscopic examination will often demonstrate these anomalies of the articulations due to osseous neoformation.

Electro-therapeutics.—Opinions as to the value of electric treatment differ. On the one side we find most favourable statistics like those of *Lewandowski,* and authors like *Onimus,* who are convinced of the utility of the treatment, while on the other hand many authorities are completely sceptical as to the value of electricity in any form.

What we have said as to the treatment in different stages of the disease will explain these divergences of opinion.

Electricity is of service only in certain lesions and symptoms of the early stage, or to alleviate neuritis and other secondary lesions in their inception. On account of our ignorance of the exact pathological anatomy of the disease, it is difficult to define accurately the cases in which electrotherapeutic treatment is indicated.

The method of application in a case of tabes is galvanisation of the spinal cord. Originally *Onimus* practised galvanisation of the limbs, with one electrode on the lumbar region, but he abandoned this mode of treatment to localise the current on the spinal cord.

He attaches great importance to the direction of the current, although most authors use the ascending or descending current indifferently. (*Tessier* of Lyon.)

The following is, in my opinion, the best means of treating tabes. At the commencement, when there are shooting pains in the legs, galvanism should be employed. A large indifferent anode of 300 or 400 sq. cm. should be applied to the neck, while a large cathode of 150 sq. cm. should be placed under the thigh or calf of each leg. The cathodes on both legs should be electrically connected, and the current should be of 10 to 40 milliamperes applied for 10 minutes.

After this the spinal cord may be galvanised for 5 to 10 minutes by placing the cathode on the sacrum. The seance may be terminated by galvanisation of the cervical sympathetics, the active cathode of 10 sq. cm. being applied to the border of the sterno-mastoid. The current should not exceed 10 milliamperes, and should be applied for 5 minutes. According as the disease is a tabes superior or inferior, the upper or lower part of the spine should be treated for a longer or shorter time. In opposition to the opinion of *Onimus,* I use galvanisation of the lower limbs. Two cases which I had treated by spinal galvanisation without success were greatly relieved when the cathodes were removed to the thighs.

When we have to treat attacks of visceral or præcordial pain, a large cathode may be placed over the solar plexus, with an indifferent anode on the neck.

The best mode of applying the current may be determined experimentally since the course of treatment for tabes is usually of considerable duration.

When muscular atrophy has set in, the affected muscles may be treated by galvano-faradisation. I usually place the indifferent anode on the proximal end of the limb, rather than on the neck or lumbar region.

404. **Friedreich's disease.**—Both in its symptoms and its pathological anatomy this disease has many points of resemblance with tabes. There is incoordination of the muscles of progression, and sclerosis of the columns of *Goll* and *Burdach*. It differs from tabes, however, in the fact that the cerebellar tracts are affected, while the heavy irregular gait is not that of tabes. Pain is very rarely present, and muscular atrophy is usually absent. The principal symptoms are trembling and choreiform movements, with disturbance of the speech and of the ocular muscles.

Treatment consists in the application of the continuous current as for locomotor ataxy. (403.)

405. **Progressive muscular atrophy—Disease of Aran-Duchenne.**—This disease, which is due to lesions of the anterior cornua, is a typical muscular atrophy of medullary origin.

When the cells of the anterior cornua are affected we may expect to see muscular atrophy of the corresponding territory. Thus in diffuse myelitis, or circumscribed sclerosis, atrophy appears as soon as the anterior cornua are affected. *Aran-Duchenne's* disease is a well-defined morbid entity, which may serve as the clinical type of all muscular atrophies of medullary origin.

It commences by atrophy of the abductor brevis pollicis, and invades successively the hand, the arm and the trunk. Finally, in five to ten years, it attacks the muscles of respiration and deglutition.

There is another well-defined type of atrophy, commencing with the muscles of the shoulder, which is also due to lesions of the anterior cornua. This is the scapulo-humeral type described by *Vulpian.* When the lesion of the anterior cornua progresses upwards and attacks the nuclei of the pons and medulla, we get bulbar paralysis and external ophthalmoplegia, but the muscles of the face are not affected. When we meet with a case of progressive atrophy of the facial muscles, it is probably due to a primary myopathy, the progressive atrophic myopathy of *Landouzy-Dejerine.* Electro-diagnosis will set all doubts at rest on this matter.

Electro-diagnosis.—As we have seen, the reaction of degeneration is characteristic of affections in which the myopathy is due to lesion of the nerve substance, as in neuritis, acute myelitis, and sclerosis. It is not met with in primitive myopathy, or in myopathy of cerebral origin, unless the spinal cord is involved.

In cases of doubt as to the nature of a myopathy, one should always test for DR of the affected muscles. This should be done whether the case presents the symptoms of the progressive muscular atrophy of *Aran-Duchenne,* or the scapulo-humeral type of *Vulpian,* or any other form in which the anterior cornua are affected. In these cases the DR is always an early symptom preceding the visible atrophy. It is moreover always accompanied by slowness of the muscular response. In myopathy of medullary origin, the electrical resistance is increased, contrary to what is observed in primary myopathy.

Electro-threapeutics.—Although there is no great prospect of cure, electricity is a valuable aid both for the treatment of the nervous lesion and as a means of preventing muscular atrophy by means of muscular gymnastics.

As in tabes, the spinal cord should be galvanised by means of an ascending current. A large electrode should be placed on the neck and another on the lumbar region. Intensity, 10 to 40 milliamperes. Duration, 10 minutes. Seances every other day. It is important also to galvanise the nerves of the affected limb, placing a large cathode on the hand, and another on the spine in the upper dorsal region—10 to 40 milliamperes. Duration, 10 minutes.

The muscular atrophy should not be neglected, but as in tabes, the cord should not be irritated by the variable state of the faradic current. The muscles should be exercised by placing a large indifferent anode on the arm or forearm, and exciting the muscles by galvano-faradisation at their motor point, or at the insertion of the distal tendon, the point of longitudinal reaction. If the muscle does not respond, we may increase the stimulus by using a metallic brush, interrupting the current by means of a metronome.

406. **Syringomyelitis.**—This affection is usually due to a glioma of the posterior part of the cord, resulting in a cavity, or to a myelitis, or to some malformation of the cord. Syringomyelitis is very variable in its clinical aspect. It is characterised by areas of anæsthesia, more especially anæsthesia to heat and to pain, while the sensations of touch are unimpaired. It is also accompanied by motor troubles, analogous to those of progressive muscular atrophy.

Electro-diagnosis and radio-diagnosis.—Electro-diagnosis is only of service in testing muscles which are beginning to be atrophied. We may test for DR, although it is difficult to diagnose syringomyelitis if the characteristic affections of sensibility are not recognised.

The X-rays will help us to determine the state of the articular and osseous system. In certain cases there is progressive destruction of the ends of the bones, with disappearance of the articulation, in the shoulder or elbow for instance.

Electro-therapeutics.—The treatment is the same as for progressive muscular atrophy. *Bordier* recommends galvanisation of the spine, with a current of 60 to 100 milliamperes.

407. **Little's disease.**—*Little's* disease is most often due to an arrest of development of the pyramidal tracts. In its clinical aspect it is a spasmodic pseudo-paralysis without muscular atrophy. On testing the muscles the reactions are found intact, while occasionally there is tetanic exaggeration of their contractility. The electric treatment consists of a rational muscular gymnastics under the faradic stimulation of the muscles.

408. **Acute diffuse myelitis—acute myelitis—acute poliomyelitis of infancy—acute anterior poliomyelitis of the adult.**—Acute myelitis may be diffuse or limited to a certain region of the cord.

We need not linger over the consideration of diffuse acute myelitis, since it does not come under the notice of the medical electrician except as regards the paralysis or muscular atrophy which follows it.

In the second category there are two types which more particularly interest us, the acute poliomyelitis of infancy, or spinal infantile paralysis, and acute poliomyelitis in the adult. Both of these diseases are characterised by acute lesion of the anterior cornua.

Infantile spinal paralysis is very common, and the practitioner is often called on to advise as to electrical treatment. We shall, therefore, take this disease as the type of this group.

It is a disease of early infancy, occurring in children from one to three years of age. It commences with a febrile period, often of very short duration, which is sometimes accompanied by contracture. At the first onset of the paralysis, all the affected muscles are attacked at the same time. Some of them gradually recover, till at the end of 4 to 6 months the disease is localized only in certain muscles, such as the extensor communis digitorum, the peronei, the anterior tibial, the triceps or the deltoid.

In consequence of the paralysis the muscles become atrophied, and subsequently the osseous system may participate in the deformity, which in its more accentuated form is met with in the "cul-de-jatte."

The adult form of acute poliomyelitis, although not so definite in its symptoms, has the same clinical history.

Electro-diagnosis.—In poliomyelitis the question of electro-diagnosis is of importance, since a careful testing of the muscles is necessary in order to determine the prognosis. An interval of a fortnight should elapse after the acute attack, before proceeding to the exploration of the muscles, for the results are very uncertain at an earlier date.

In testing a paralysed muscle, we may only find a diminution of its faradic excitability, without inversion of the galvanic formula, KCC and ACC being merely brought nearer together. In this case we may affirm that the muscle will regain its power within a period of 3 to 5 weeks.

It may be that we discover complete abolition of the faradic excitability, with slowness of response and partial inversion of the formula, ACC $>$ KCC. In this case, the prognosis is more serious, but we may still hope for good results from electrical treatment. A cure may be expected in from 3 to 6 months.

If, on the other hand, the muscle shews complete DR, or only longitudinal reaction, the atrophy is fatal.

In acute spinal paralysis, there is considerable increase of the electrical resistance, but this is quickly altered by the passage of the current. This fact must be taken into consideration in conjunction with the fall in temperature of the paralysed limb. As *Leduc* has proved in his experiments, the fall in resistance is not wholly accounted for either by the fall in temperature, or by the state of hyperæmia of the integument. It is due to an increase of the ionic transmission of the current in an integument which has become gradually more hyperæmic and warmer.

In infantile paralysis, radio-diagnosis may also assist us in an examination of the bones, which undergo trophic changes, becoming smaller, and having their articular extremities more rounded.

Electro-therapeutics.—Electrical treatment is most useful in spinal paralysis. Of this we have repeatedly assured ourselves during the course of an epidemic of infantile paralysis. The children who had been electrically treated furnished a contingent of cases, either cured or improved, in a proportion far larger than those who had been left untreated.

In all cases of acute myelitis, it should be the rule not to commence treatment till after the febrile period has passed. It is useless, however, to wait for weeks before commencing galvanic treatment.

As soon as symptoms of paralysis are noticed, galvanisation by means of the continuous current should be begun at once. A large cathode of 100 to 200 sq. cm. is placed over the portion of the cord affected, and an anode of 40 to 100 sq. cm. on the group of muscles affected. Intensity, 10 to 25 milliamperes.—Duration, 10 minutes.—Seances every day or every other day.—*Larat* uses a descending current of 8 to 12 milliamperes.

Two or three weeks after the termination of the febrile period, the stimulation of the paralysed muscles may be begun. When the muscle reacts to the faradic current, the rhythmic galvano-faradic current may be chosen. If that is not available a continuous current may be used, with a metronome to produce interruptions. The active electrode should be placed on the motor point of the muscle. In cases where the motor point is displaced (in the longitudinal reaction of *Remak-Doumer*) the active electrode should be applied to the junction of the muscle with its distal tendon. For this part of the treatment, which consists solely in exciting the muscular fibre, I usually place the indifferent electrode at the junction of the limb with the trunk, rather than on the spine. The seances should be short, especially at the commencement of treatment. All fatigue of the muscle should be studiously avoided, each group being exercised for from 3 to 5 minutes only.

In a short time, we see a very appreciable improvement in the function of the muscle. The temperature rises and becomes nearly normal. The duration of treatment is very variable and may in severe cases last for several years. The frequency of the seances may be gradually reduced, and during the second year, we may give only two seances per week, with intervals of repose.

The same rules hold good with regard to anterior poliomyelitis of the adult.

D. Diseases of the Medulla Oblongata, the Pons and Cerebellum.

409. **Diseases of the medulla and pons.**—There is not

much to be said on this group of diseases. The lesions of the medulla oblongata and pons are often merely prolongations upwards of myelitis or sclerosis of the cord. The lesions most frequently met with are bulbar paralysis and nuclear ophthalmoplegia. Both of these are due to chronic lesions of the nuclei, which are the homologues of the anterior cornua of the cord.

It is possible that in some cases electricity may be of service, although up to the present time there are no statistics available on the subject. All that we can say is that the chronic affections of the medulla oblongata and pons are similar to those of progressive muscular atrophy, in which electrical treatment plays a most important rôle.

We are not able to say anything concerning the electrical treatment of cerebellar disease.

E. Diseases of the Encephalon.

410. **Electrical treatment of disease of the encephalon.** —Among the various diseases of the brain, congestion, hæmorrhage, softening, inflammation and tumours, hæmorrhage alone has been treated by electrical methods.

In cerebral disease, electricity addresses itself to symptoms and not directly to the lesion. Since the symptoms of the various lesions are chiefly due to softening and hæmorrhage, we shall deal only with these.

411. **Cerebral hæmorrhage** — Hemiplegia. — Cerebral hæmorrhage is almost always caused by the rupture of a miliary aneurism. These are usually due to hereditary causes, alcoholism, gout, diabetes, Bright's disease, or syphilis. Atheroma plays quite a subordinate part. A miliary aneurism arises in one of the smaller vessels from a periarteritis with muscular atrophy, whereas atheromatous lesions commence with endarteritis. The clinical symptoms vary greatly, according to the site of the cerebral hæmor-

rhage. *Apoplexy* is due to inundation of the ventricles, or in certain cases may be the result of a reflex blow or impression.

Muscular contracture sometimes occurs as an immediate result. This early contracture, differing in its nature from the secondary contracture due to sclerosis, is not amenable to treatment, and disappears of its own accord.

More frequent than apoplexy or early muscular contracture is *hemiplegia,* the one-sided paralysis which is the invariable concomitant of cerebral hæmorrhage. The hemiplegia is invariably on the side opposite to the cerebral lesion. When the left side is paralysed, we know that the right cerebral hemisphere is affected, and *vice versa.* If there is an alternate hemiplegia, with the face paralysed on one side and the limbs on the opposite side, we may be certain that the lesion is either in the pons or the medulla oblongata. These indications are of importance to the medical electrician, since he must treat the seat of the lesion as well as the paralysis. We may also note that in hæmorrhagic hemiplegia of the face, the orbicularis palpebrarum is paralysed, whereas it is unaffected in peripheral paralysis of the facial nerve.

It is rare to find hemi-anæsthesia in cases of cerebral hæmorrhage, and when it occurs it needs no intervention.

The early symptoms of cerebral hæmorrhage then, are apoplexy, early muscular contracture and hemiplegia. The secondary symptom of greatest importance to the medical electrician is the later muscular contracture. It is often adduced as a reproach to the electrical treatment of hemiplegia that it is apt to be followed by incurable contracture. It may be useful to recall the genesis of these contractures, as we need to be always on our guard as to the possibility of their appearance. In the early stages, the walls of the hæmorrhagic focus are formed by normal

24

cerebral tissue, which is more or less torn and pressed aside. Later on, this tissue becomes sclerosed. If this sclerosis invades the pyramidal tract in any part of its course, a descending sclerosis is produced, with resulting muscular contracture. The medical electrician should therefore always warn the friends of the patient of the possibility of this contracture. By carefully watching the reflexes he may have warning of its approach some time before its occurrence. If, two or three weeks after a stroke, we find exaggerated reflexes, we may be sure that contracture is imminent. The flexors of the arms are the first to be attacked. When there is contracture of the face, the healthy side appears flabby in comparison. The features are drawn towards the affected side, and we may easily mistake the condition for a paralysis of the opposite side. The muscles affected with contracture are frequently the seat of trembling or choræic movements, which are only produced in the course of voluntary movements.

The sclerosis may not stop at the pyramidal tract. The cells of the anterior cornua of the cord may be attacked. In this case there will be wasting of the muscles like that in progressive muscular atrophy. The atrophy may affect the various groups of muscles in a very irregular manner, and is often difficult to detect, on account of the paralysis of the limb and the accumulation of adipose tissue.

Electro-diagnosis.—The question of electro-diagnosis has no great practical importance. In the early stage, there is increased excitability to the galvanic and faradic currents, more especially to the latter. This hyperexcitability persists for some time and is most marked in the second and third week. It has not the same importance for prognosis as the exaggeration of the reflexes. The latter symptom is a sign of sclerosis of the pyramidal tract and is almost invariably followed by muscular contracture.

In the advanced stages, there is hypoexcitability both to the galvanic and faradic current, even when there is no muscular atrophy.

Electro-therapeutic treatment. a. The treatment should not be commenced for a month after the stroke. *Duchenne* usually waited six months.

b. If at this period there are any signs of contracture, we should be careful to avoid the use of the faradic current or stimulation by the variable state of the galvanic current.

c. If, on the other hand, the paralysed muscles are perfectly lax and feel flabby, with no symptoms of contracture, electrical treatment should be carried on in two directions, by direct galvanisation of the brain, and by local stimulation of the muscles.

1. *Galvanisation of the brain.*—It was long believed that the lines of electrical flux did not penetrate the skull.

The contrary was proved by the experiments of *Erb,* of *Buckhardt* and *v. Ziemssen.* The terminal of an electroscope was applied to the cerebral surface, through an aperture in the skull made by a trephine. It was found that the current penetrated the skull when the head was galvanised. *Leduc,* who has made frequent experiments on this subject, remarks that the resistance of cranial bones impregnated with organic fluids is much less than might be supposed. The penetration of the galvanic current is also proved by the sensations of vertigo, which occur in galvanisation of the head. During bilateral galvanisation, when the current is closed, the animal inclines or even falls over towards the anode. In some experiments by *Zimmern* and *Batelli* epilepsy has been produced by cerebral electrisation. *Schnyder* has shewn that fatigue may be relieved by a current of 5 milliamperes in either direction between the neck and forehead.

Even if this be granted, it is doubtful whether the absorption of the blood clot can be facilitated by the electric current, at all events, without using an intensity which will do more harm than good. (*Dignat.*) Cerebral galvanisation must not on that account be regarded as useless. Under its action the vitality of the nerve cells may be increased in consequence of the increase of the nutritive exchanges following ionisation of the tissues. This will greatly aid the process of repair. In addition to the theoretic indications for galvanic treatment, we have the evidence of experience. Although statistics on the subject are not available, yet most observers are agreed that cerebral galvanisation is of benefit in the after-treatment of a paralytic stroke.

Procedure.—We should always bear in mind that the anode is calming and depressing, whereas the cathode is stimulating and has a resolvent action on inflammatory processes.

An indifferent cathode of 100 to 200 sq. cm. is placed on the back of the neck, and an anode of 50 to 100 cm. on the side of the head corresponding to the injured hemisphere. Intensity 5 to 10 milliamperes.—Duration 5 to 10 minutes.—Seances every other day.—The circuit should be opened and closed very slowly and gradually.

2. *Electrisation of the affected muscles.*—The peripheral treatment of the hemiplegic limbs has two principal objects.

a. To remove stiffness of the joints caused by immobility by means of a passive gymnastic treatment.

b. To treat the muscular atrophy and the obstructed circulation of the limbs, which results in œdema and blueness. There are two distinct conditions, each of which requires different treatment. If there are no symptoms of contracture, we may stimulate the muscles by the faradic or the galvano-faradic current, at the same time that we endeavor to improve the circulation and the reabsorption of the œdema by galvanisation. If, however, there is any indication of contracture, we must limit the electrical treatment to the galvanic current alone. We will take each of these conditions in turn.

For galvanisation we may use a large electrode of 200 to 300 sq. cm. on the nape of the neck or lumbar region, employing for the other electrode a foot-bath or arm-bath, or a plate of 50 to 150 sq. cm. applied to the extremities of the limbs. Although the direction of the current is immaterial, it is usual to connect the indifferent electrode to the positive pole.—Intensity, 10 to 20 milliamperes.—Duration 5 to 8 minutes for each limb.

When, some three to five weeks after a paralytic stroke, it is decided to try electrical treatment, we should begin by galvanisation of the limbs. If there is any fear of contracture we should go no further. If, on the contrary, the paralysed muscles are perfectly soft and flabby, we may proceed to treat them by faradisation.

In a case of hemiplegia, faradisation, or, better still, rhythmic galvano-faradisation of the muscles, may be carried out in the usual manner. The indifferent electrode, connected to the positive pole of the battery, is placed on the nape of the neck or the lumbar region, while a cathode 3 or 4 cm. in diameter is applied to the motor points. Each limb should be stimulated for a period of only 2 to 4 minutes. Another method is by the employment of the faradic roller, which may be moved slowly over the limb for 2 or 3 minutes.

If the muscles do not contract under the faradic current, we may employ the galvanic current interrupted by means of a metronome.

If any signs of contracture should make their appearance during the course of treatment, all faradic stimulation must be immediately suspended.

Improvement should be visible in the course of a month or six weeks, but the result of electrical treatment is often unsatisfactory.

412. **Cerebral softening—Hemiplegia due to softening.**—Cerebral softening following thrombosis, embolism, or atheroma, is due to the death of a portion of the brain substance following interference with the circulation. Like hæmorrhage, it is followed by secondary descending sclerosis. In cases of embolism and sometimes in thrombosis, the softening may shew itself suddenly by symptoms of apoplexy and hemiplegia analogous to those of hæmorrhage. Or the softening may come on more slowly and progressively, as in cases of atheroma and syphilitic endarteritis. Aphasia is a frequent manifestation of this variety.

Electro-diagnosis and Electro-therapeutics.—Electro-diagnosis can only give us information of the state of the affected muscles. Any local treatment of the brain is useless, and we can only act on the muscles in the way pointed out in the treatment of hæmorrhagic hemiplegia.

NEUROSES.

Chorea—Writer's Cramp—Myoclonus—Hysteria—Neurasthenia —Parkinson's disease—Somnambulism—Exopthalmic goitre.

413. **Chorea or St. Vitus' dance.**—The clinical aspects of this disease are very varied. In addition to the typical form usually seen in young girls, there are cases following rheumatism, in which endocarditis is frequent and of which the prognosis is serious. Other cases due to simple hysteria are accompanied by anæsthesia or hyperæsthesia. In some instances the muscles, instead of being continually agitated by involuntary contractions, are in a condition of complete relaxation, a sort of lax paralysis. Finally, there are choreas

of a very formidable character which occur at the period of adolescence, and are accompanied by serious psychical perturbation.

Before undertaking the electric treatment of a case of chorea, or attempting to estimate its duration, it is well to give a careful consideration as to the variety of the disease with which we have to deal. When it is of hysteric origin, the case may improve with great rapidity, or on the other hand, it may respond to treatment very slowly. We should be careful not to confound with chorea the hemichorea, which is symptomatic of a central lesion, or the rhythmic chorea of hysteria, or even the chorea of electrical origin.

Electro-diagnosis.—The reactions of chorea are normal. This fact has an important bearing on the diagnosis between chorea and hemichorea, since the latter is characterised by hyperexcitability both to the galvanic and to the faradic current. In flaccid chorea we never meet with signs of DR.

Electro-therapeutics.—Static electricity is to be preferred for the treatment of this disorder. If this fails, we may have recourse to the galvanic current, which has given good results in the hands of *A. Weill.* In the flaccid form of chorea we may with advantage employ rhythmic galvano-faradisation.

Procedure.—When static electricity is employed, the patient should be exposed to the static bath during a period of 15 to 20 minutes (176 and 336). The seance should be terminated by a static douche of 5 minutes. This should be repeated every other day.

Improvement is rapid, usually from 15 to 20 seances being sufficient for a cure.

Galvanic current.—*A. Weill* applies a cathode of 100 sq. cm. to the neck, and places the feet in a foot-bath joined to the positive pole.—Intensity, 20 to 30 milliamperes.—Duration, 20 minutes.—Seances three times a week.

In the flaccid type of chorea each muscular group may be treated with the rhythmic galvano-faradic current. An indifferent anode should be applied to the nape of the neck, and a cathode 3 to 5 cm. in diameter to the motor points. The faradic roller may also be employed.

414. **Myoclonus—Tic.**—Under the name myoclonus are included a number of morbid conditions, characterised by clonic convulsive movements. The most trivial of these is ordinary tic, or the involuntary winking of the eyelids. It also includes electric chorea and other forms of convulsive tic.

Franklinisation may be employed for this affection as for chorea.

Tic occurring in the face is best treated by the continuous current, a large cathode being applied to the neck, and an anode of variable size and shape to the affected region. The intensity should vary according to the area of the active electrode and the tolerance of the patient. From .1 to 1 milliampere may be given for each square centimetre of surface in the active anode.—Duration, 15 minutes.—Seances every other day.

415. **Professional cramp, writer's cramp.**—The static bath is the best mode of treatment for the various forms of professional cramp—writers' cramp, the telegraph-operators' cramp, the violinists' cramp, etc. The seances should be of 15 minutes, repeated every day or every other day.

We may also have recourse to the continuous current, the anode being applied to the affected muscles, and the cathode to the neck. The duration of the seance should be only a few minutes, and feeble intensities should be employed. These rules are not, however, absolute. We may also have recourse to cerebral galvanisation, by placing an electrode on either side of the head. This method has given good results in certain cases.

Although the action is somewhat uncertain, the electric treatment is the only one that yields satisfactory results in these cases.

416. **Hysteria.**—This is a morbid condition which manifests itself by symptoms of a most varied character. It is susceptible of treatment in two directions, general and symptomatic.

The general treatment should be directed to the so-called hysteric temperament. This is often recognisable, more especially in young girls, by one or more isolated symptoms, palpitations, suffocation, fanciful appetite, capricious character, etc. We may also meet with convulsive epileptiform hysteria with its severe attacks, or ordinary convulsive hysteria, or non-convulsive hysteria with its long string of symptoms, including paralysis, contracture, anæsthesia and trophic troubles.

The symptomatic treatment will be directed against the manifestations of hysteria. These should be carefully studied by the medical electrician, for he is often called upon to give a diagnosis in cases of great difficulty. Among the symptoms, those of paralysis, contracture, and trophic disturbances are the most important.

Hysterical paralysis, more especially hemiplegia, may simulate paralysis of organic origin. It but rarely affects the face.

Occasionally the muscles of one side of the face present a slight degree of contracture. We must be careful not to mistake this for paralysis of the opposite side, an error which is easily made, owing to the flaccid appearance of the normal muscles when compared with those of the affected side. These cases of hysterical paralysis are apparently due to an augmentation of the resistance to the nerve current at the synapses of contiguous neurones. (*Lépine.*)

Hysterical contracture generally sets in suddenly, whereas contracture due to organic causes commences in an insidious manner. We may easily be misled if we do not see these hysterical contractures at their commencement, or if we omit to examine them under chloroform. In certain cases the transference of these muscle contractures from one side to the other gives us a clue as to their nature.

Hysterical trophical disturbances are extremely difficult of diagnosis. Hysterical œdema, the so-called blue œdema, the painful hysterical breast, and hysterical muscular atrophy may be mistaken for more serious lesions. Hysterical atrophies are often quickly relieved by electrical treatment, and if the diagnosis has not been carefully made, the case might be considered as a case of medullary affection cured by electrical treatment. Clinically, hysterical atrophies differ from those of myelopathic origin in that they do not usually attain the same degree of severity, and are rarely accompanied by fibrillary contraction. We shall see that the two diseases may be easily distinguished by means of electro-diagnosis.

Electro-diagnosis.—The electrical resistance is greatly increased in hysteria, more especially in hysteria with alienation. (*Vigouroux, Charcot, d'Arman.*) This peculiarity is of but little assistance in diagnosis. It does not enable us to distinguish severe forms of hysteria from elipepsy, since in epilepsy there is also a considerable increase of electrical resistance, especially when mental alienation accompanies the epileptic symptoms.

Hysterical paralyses are distinguished by the fact that they never give rise to DR.

The areas of contracture and the areas of anæsthesia are frequently displaced under the action of the magnetic field. This phenomenon of transference in cases of hysteria is also a valuable diagnostic sign.

Transference also follows the application of the galvanic current, and even the application of metallic plates. These inconstant and inexplicable phenomena often prove useful as a means of diagnosis in doubtful cases.

In hysterical atrophy, both the galvanic and faradic excitability are diminished, but there is no reaction of degeneration. In certain exceptional cases where this occurs, it may be suspected that there is in addition some lesion of the medulla.

Electro-therapeutics.—The electric bath is the best general treatment for hysteria in every stage of the malady. The duration of an application should be gradually increased from 5 to 20 minutes and the seance may be repeated every day. The result varies according to circumstances. As in other methods of treatment, suggestion probably plays a certain rôle if the physician is happily able to inspire his patient with confidence. In addition to the moral cause, there is, however, a rational physical action, the result of which is independent of consciousness. The static bath acts both on the sensory and motor nervous mechanisms. If we regard hysteria as an anomaly of the nervous connection between the neurones, then the static current may be supposed to act by re-establishing the normal connections under the stimulus of high electrical potential. Static treatment may also benefit by inducing sleep and improving digestion.

If it is thought advisable to place the patient under a course of hydrotherapeutic treatment, it is best to give this and the electric treatment on alternate days, so as to avoid fatigue.

In cases where statical electricity has failed as a general means of treatment, high frequency currents may be tried.

2. *Symptomatic treatment* will vary according to the case. Widespread anæsthesia may be treated by the static bath, a pointed electrode being directed over the anæsthetic areas. This method is often followed by rapid improvement, but the good effect is seldom maintained after the first few seances. In order to obtain a permanent cure, the treatment must be prolonged. Sometimes, after a few minutes' application, there is a transference to the opposite side. If static treatment fails, we may try the faradic brush connected to the negative poles, using currents of feeble intensity. We may also have recourse to light rapid friction, or to high frequency currents applied with a glass electrode.

Hysterical paralysis and hemiplegia may be treated in the same way as anæsthesia, the former being often a concomitant of the latter, and tending to disappear at the same time. In these cases the negative faradic brush gives excellent results. We should at the same time begin to re-educate the muscles, commencing with simple movements and gradually going on to more complicated ones.

When the patient has regained confidence, the case is more than half cured.

Hysterical contracture, unlike contractures of organic origin, may be successfully treated by direct stimulation of the muscles by faradisation, electric friction, statical sparks, or high frequency currents. *Laquerrière* and *Delherm* employ the energetic stimulation of the opposing muscles. Good results are also obtained by the continuous current of very feeble intensity applied for an hour or more. The same may be said of the statical effleuve, and the action of the magnetic field.

Globus hystericus, cutaneous hyperæsthesia, and the various hysterical pains may be treated by positive galvanisation of feeble intensity.

The obstinate vomiting of hysteria may often be relieved by galvanisation of the vagus. (*Decroly.*)

The great variety of treatment and the alternation of success and failure, shew that there is no general rule, and that each case of hysteria must be treated on its own merits.

417. **Neurasthenia.**—Among the various neuroses, this disease, sometimes known under the name of *Beard's* disease, is very susceptible to electrical treatment. We shall, however, be liable to disappointment if we treat as neurasthenia all the affections included under that designation by the public and occasionally by medical practitioners. Unable to give a name to a number of indefinite nervous affections, it is the fashion to class as neurasthenic, a number of affections which in no way resemble *Beard's* disease. We are often called on to treat these so-called neurasthenics, whom the doctors in despair have sent to baths, to the sea, to the mountains, and as a last resource to the medical electrician. True neurasthenia presents symptoms of cerebral asthenia with depressed spirits, and intellectual fatigue. There is, moreover, muscular weakness, insomnia, dyspepsia, and diverse pains, cephalgia, back-ache, vertigo, neurocardiac disturbances, with hyperexcitability of the genital organs, or impotence. In general the blood-pressure is below normal, although there is a form of neurasthenia, which we may call pseudo-neurasthenia, with supra-normal blood-pressure. This requires a totally different treatment. There is also a form of hereditary neurasthenia in which all treatment is useless.

With regard to electro-diagnosis, there is not much to be said. The diminution of electrical resistance which has been observed in some cases is by no means constant.

Electro-therapeutics.—The treatment varies according to the predominating symptoms. The best treatment is the static bath, which may be increased in intensity and duration as the patient is able to bear it. The occurrence of insomnia will warn us if we are exceeding the beneficial dose. We may commence with 5 minutes, and gradually increase up to 45 minutes.

In general the negative static bath should be preferred, but if there is insomnia we may give the positive bath, the patient being connected to the positive pole of the static machine. In female patients where there is menorrhagia, static treatment is contra-indicated.

Some authors consider that neurasthenia is an affection of the sympathetic, and recommended the galvanisation of the solar plexus and its branches by the method of *Betton Massey.* A large anode of 250 sq. cm. is placed over the abdomen, and a large cathode also of 250 sq. cm. on the lumbar region.—Intensity, 50 to 250 milliamperes.—Duration, 15 minutes.—Seances every second day.

In cases of low blood pressure, if there is no tendency to insomnia, I have obtained good results from the employment of high frequency currents. The patient is seated between two high frequency spirals, arranged so as to produce bipolar effleuvation. The spirals are wound in opposite directions and joined up so that the excitation in each spiral opposes that in the other. (138.) One of the spirals is at the back of the patient, and he is connected to it by means of an electrode applied to the nape of the neck. The other spiral is in front, and has an electrode with multiple points directed on the abdominal region, care being taken to obviate any danger of sparking. *Albert Weill* has also obtained excellent results by this method. A seance of 10 to 15 minutes may be given every other day.

Larat has successfully employed the hydroelectric bath with sinusoidal currents. He gives the static bath and the hydroelectric bath on alternate days. The duration of the bath is 20 to 25 minutes, and its intensity is gradually increased until it produces slight tetanisation of the muscles.

The above are the procedures for general treatment. We may now review more in detail the treatment of each symptom.

Headache and cerebral asthenia may be treated by the static douche given with the aid of *Truchot's* apparatus, or by means of non-metallic excitors. In some cases the continuous current appears to give better results. An anode of 100 sq. cm. is applied to the nape of the neck, and a cathode of 50 sq. cm. to the forehead.—Intensity, 20 milliamperes.—Duration, 10 minutes (*Castex*).

In cases where there are neuralgic pains, the use of an active anode is preferable. Where cerebral asthenia is the prominent symptom, I have obtained excellent results from the employment of the high frequency douche. For this purpose we may use the effleuve from a cup suspended overhead and connected to a resonator, as in *Truchot's* apparatus. After the patient has been treated by the bipolar method directed to the solar plexus, the seance may be terminated by treating the headache and cerebral asthenia by effleuves directed on the head. For this purpose the pointed electrode on the abdomen is replaced by a metal plate and the cup overhead is connected to the spiral behind the patient by means of a flexible conductor.

The *pains in the back* are best treated by continuous positive galvanisation, as in lumbago. The faradic brush also gives excellent results. We may also treat it by revulsive methods, using the high frequency current with glass electrode, or a bare brush or ball electrode, according to the tolerance of the patient.

The *low blood-pressure* may be relieved by sparking or effleuves of high frequency directed on the spine, by the static spark, or by electric friction. The seances should be short. The excitor should be passed three or four times over the spine, which produces a considerable elevation of blood pressure, as shewn by the sphygmo-manometer (*Moutier*). The duration and intensity of the seances is limited by the tendency to insomnia, which is often aggravated by the treatment.

In cases where there is *hyper-tension* of the pulse, *Moutier* advises the use of auto-conduction to lower the arterial blood-pressure.

Tachycardia is best treated by galvanisation of the pneumo-gastric. A large cathode is placed over the epigastrium, and an anode of at least 20 cm. over the left cardia.—Intensity, 8 milliamperes.—Duration, 10 minutes.

In the treatment of *sexual impotence,* we may use negative galvanisation of the inguinal region and perineum with an electrode of 20 sq. cm. moved to and fro. Intensity 2 to 10 milliamperes.—Duration, 10 to 15 minutes.—Seances every other day. If there is hyperexcitability, the same treatment may be employed, using the active anode.

We often see cases of neurasthenia improve under treatment by vibro-therapy or by railway journeys, just as they are improved by any violent impression or any novelty. This may be the explanation of the favourable results obtained by *Hirt* by intense galvano-faradisation of the lower limbs.

418. **Exophthalmic goitre.—Graves' disease or Basedow's disease.**—All authorities are united in the opinion that exophthalmic goitre is particularly amenable to treatment by electrical methods. Medical treatment is of such little use in these cases that surgical aid has been invoked to

divide the sympathetic or remove the thyroid gland—a procedure which has often proved fatal. Electricity is, therefore, the only rational treatment. The results of galvanisation of the thyroid body have thrown a good deal of light on the pathogenesis of this disease.

Exophthalmic goitre appears to be due to a disturbance of the internal secretion of the thyroid gland. This is a specific affection, and does not in any way correspond to the symptoms due to removal or absence of the organ. This explains the failure of the treatment by thyroid extract noticed by authors like *Dreyfus-Brisac* and *Béclère*. The alteration of the secretion reacts on the medullary centres, producing nuclear paralysis of the vagus, and paralysis of the vaso-motor centres. There are no visible lesions of the nervous system.

The disease is, in fact, a neurosis of the medulla, caused by a disturbance in the internal secretion of the thyroid gland. The following are the symptoms: *Tachycardia,* caused by disturbance of the vagus. There is no alteration of the rhythm of the heart, but there may be hypertrophy, due to increased activity of the organ, or insufficiency of the valves caused by dilatation.—*Dyspnœa* often due to the same cause.—*Exophthalmia,* sometimes accompanied by ophthalmoplegia, or paralysis of the extrinsic muscles of the eye.—*Hypertrophy* of the thyroid body.—*Trembling,* occasionally accompanied by choroeic movements.—*Paralysis,* a paraplegia of a definite type, unaccompanied by visceral or vesical troubles; in contra-distinction to paralysis of spinal origin. The distinction may be made with the aid of electro-diagnosis. In addition to these, we may get nervous troubles and psychic disturbances of various sorts, with elevation of the peripheric temperature, amenorrhœa and impotence.

In treating a case of *Basedow's* disease, we should not forget that the malady is fatal in 20 per cent. of all cases, and that grave accidents may supervene in the course of its evolution, caused by a paroxysm or a hæmorrhage. The friends of the patient should be warned of this possibility, so that the electrical treatment may not be blamed for an accident due to the progress of the disease.

Electro-diagnosis.—a. *Electrical resistance.*—In this disease the resistance is considerably diminished, due in all probability to the disturbance of the vaso-motor system and the increased perspiration. In health the electrical resistance may be considerably reduced by placing the subject in a vapour bath.

b. Where there is cardiac hypertrophy, the *measurement of the heart* by the orthodiagraphic method will give valuable information as to the progress of the disease. (426.)

c. Where *paraplegia* exists, it may be as well to test the muscles. The absence of DR will set at rest the question of any medullar affection.

Electro-therapeutics.—We have already said that electrotherapy is universally accepted as the treatment of exophthalmic goitre. *Rockwell, Vigouroux, Deléage, Bordier, Larat, Sollier, Régnier,* and others have published observations and statistics which leave no doubt as to the efficacy of the treatment. The cases of failure are those in which the so-called electric treatment is carried out by means of a small coil and two small pads applied as chance directs on either side of the neck.

According to *Prof. Joffroy,* when the treatment is carried out in a rational manner, with strong galvanic currents, the measure of success attained is far in advance of any other method.

The following is the mode of procedure:

a. Galvanisation should be used by preference. The cathode is to be placed on the goitre in consequence of the softening caused by the negative pole. It should be of 60 to 100 sq. cm. and should cover the goitre and the whole of the surrounding region. A large anode of at least 200 sq. cm. should be placed on the nape of the neck. It is important to keep the active anode in absolute contact with the skin. I make use of a layer of absorbent cotton wool between two layers of gauze, and over it I place an ordinary concave electrode.—Intensity, 30 to 40 milliamperes.—Duration, 15 minutes.—Seances every day or every other day.

b. In addition to the galvanisation of the goitre the faradic current may be used to stimulate the orbicularis palpebrarum, whose motor point will be found at the external angle of the orbit. A small olive-shape electrode may be used, the indifferent electrode being placed on the nape of the neck. Duration, one minute. We may also faradise the superior branch of the facial nerve, whose motor point is a little external to the above. The cervical ganglion of the sympathetic may also be stimulated by placing the electrode under the angle of the jaw, between the hyoid bone and the sterno-mastoid. In this situation the pulsation of the carotid artery, usually exaggerated in this disease, may be readily felt on pressing the electrode and inclining the head towards the side which is being treated. One minute's application should be made on either side. Finally, the precordial region may be faradised by placing the active anode in the 3d left intercostal space, 2 centimetres from the sternum.—Duration, 2 to 3 minutes.

Vigouroux has obtained good results by the faradisation of the goitre itself without any application of galvanism.

The average duration of treatment for *Basedow's* disease is three months. The results are as a rule most encouraging. The goitre decreases in size from the commencement of the treatment and this is soon followed by a cessation of the trembling and tachycardia. The exophthalmia is the last symptom to disappear.

Exophthalmic goitre is very often associated with other forms of neurosis. The appropriate treatment for these should be given in addition to the treatment for goitre.

419. **Parkinson's disease.**—Paralysis agitans or *Parkinson's* disease has not hitherto proved amenable to electrical treatment. In one case that came under my notice, the trembling greatly diminished under the influence of galvanism. The continuous current may be employed, using an arm-bath for the anode and a cathode to the nape of the neck.—Intensity, 20 milliamperes.—Seances, 15 to 20 minutes every other day.

420. **Somnambulism.**—The best treatment of this affection is the static bath, followed by the static douche. *Bordier* reports a successful case.

421. **Other nervous affections.**—Electricity has proved of service in a number of other nervous troubles, such as incontrollable vomiting, hiccough, nervous aphonia,—œsphageal spasm, vaginismus, and noises in the ears. These will be discussed in the chapter devoted to each organ.

Hiccough, par. 529.
Nervous vomiting, par. 532.
Aphonia, par. 517.
Oesophageal spasm, par. 530.
Vaganismus, par. 457.
Noises in the ears, par. 520.

G. Local Affections of Nervous Origin.

422. **Raynaud's disease (Local asphyxia of the extremities—Senile gangrene).**—Most of the topical diseases of nervous origin will be found described under the organs or tissues affected, *e.g.* scleroderma (492)

and skin diseases. We shall only allude here to *Raynaud's* disease and to the perforating ulcer of the sole of the foot and palm of the hand.

Raynaud's disease, which has a great analogy to ordinary chilblains, is the result of local vascular spasm.

Raynaud treated it by means of the constant current, with an intensity of 7 to 8 milliamperes, an arm-bath being used for the cathode and an indifferent anode being applied to the nape of the neck. Duration, 10 minutes.

Peter, and after him *Bordier,* used the ascending current with an intensity of 15 to 30 milliamperes.

In hysterical or neurasthenic cases, the static effleuve may be used in addition to the galvanic current. (*Plicque.*)

423. **Perforating ulcer.**—This is usually situated on the sole of the foot, or on the great toe. The ulcer, whether caused by a cerebral or a spinal lesion, has no natural tendency to repair. For this disease electricity is a radical means of cure.

The treatment consists in faradisation of the posterior tibial nerve (*Crocq, Hann*). A pad connected to the negative pole is applied to the extremity of the foot beyond the ulcer, while another pad is applied to the posterior tibial nerve behind the internal malleolus.

H. Anaesthesia.

424. **Electric treatment of anæsthesia.**—Anæsthesia is a symptom common to a number of neuroses and other affections of the nerves or the nerve centres. The electric treatment of the symptom itself does not vary to any great extent.

It may be of interest to determine the exact nature of the anæsthesia by means of electro-diagnosis, using for that purpose both the galvanic and faradic currents. The exploration should be made in the same way as for motor excitability. *Bordier* has determined the topography of normal sensibility to the galvanic current.

The best treatment of anæsthesia is that described by *Duchenne* of Boulogne. The faradic current is employed, with a metallic brush connected to the negative pole. The application may be made in three methods.

1. *Transcurrent faradisation,* the brush being simply moved over the affected regions.

2. *Electric fustigation,* the skin being struck with the extremity of the brush.

3. *The electric moxa,* the brush being left for some seconds at rest on the skin. This is a very painful method of treatment.

In certain cases we may obtain good results from the use of the galvanic brush connected to the negative pole. There is, however, great danger of burning the patient, which may be followed by subsequent scarring.

The use of the metallic brush is much to be preferred. Hysterical anæsthesia may be treated by the application of the continuous current by means of large electrodes, or bare metallic plates. (416.)

CHAPTER II.

THE VASCULAR AND LYMPHATIC SYSTEMS.

425. **Affections of the heart and large vessels.**—In this chapter we shall study the use of radioscopy as a means of diagnosis in these diseases.

We will suppose that the operator has a focus-tube mounted on a movable carrier as in Fig. 40, similar to that which I exhibited to the Congress of Boulogne in 1899. *Dr. Béclère* has since greatly contributed to the perfection of this apparatus by adding the iris-diaphragm. The following is the mode of examination for the study of the heart, the large vessels and the mediastinum. The patient is placed vertically in front of the stand, with his frontal plane parallel to the plane of the stand. The screen is also placed parallel to the stand. The tube can be moved in any direction by means of cords, but all its motions are in one plane. It can thus irradiate the object at every possible angle, giving a different silhouette for each position.

The examination should be begun by symmetric irradiation of the mediastinum. For this purpose the focus-tube should be placed either behind the sternum or spine,—the normal ray being in the antero-posterior median plane. In this position the shadow of the sternum and of the spine are superposed. The direction of the normal ray is indicated by the shadow of a metallic cross placed in front of the focus-tube. On the right side, projecting beyond the sterno-rachidian shadow we may see the right auricle beating and the shadow of the great vessels at the base of the heart.

Projecting beyond the left margin of the sterno-rachidian shadow, we see the ventricular portion of the heart. In some subjects, at the moment of deep inspiration, a clear space is visible below the heart. To see this the focus-tube must be lowered.

An oblique view of the mediastinal region may be obtained by moving the focus-tube to the right or left, or by rotating the patient about a vertical axis. In this way the mediastinal shadow is moved to the right or left of the external or spinal shadow. It is well to habituate oneself to the appearance of the normal mediastinum as viewed from the front or rear.

In this way an approximate estimate may be made of the extent of the cardiac shadow and of the volume of the aorta.

One may observe the heart beats, as well as any displacement of the heart or mediastinum.

We do not get such good results from lateral examination, *i.e.,* with the sagittal plane of the patient parallel to the screen.

There are two signs of pericardiac effusion, *viz.,* diminution of the heart's motion of contraction, and alteration of the size and shape of the cardiac shadow. This is usually globular, or with a notch at the top.

A displacement *en masse* of the cardiac shadow is observed in many diseases, *e.g.* pleurisy, ascites, tumour, etc. (*Bouchard, Bergonié* and *Carrière.*)

The normal pulsation of the aortic arch is best observed by placing the patient in the right frontal oblique position. The aortic pulsation is increased in chlorosis, exophthalmic goitre and other diseases in which there is an exaggeration of the peripheric pulsation. It is also increased in aortic insufficiency (*Bouchard*) and even in aortic stenosis

(*Béclère*), and to a still greater extent in aneurism of the aorta.

Aneurism of the innominate artery is very perceptible behind the right sterno-clavicular angle.

The appreciation of the changes in the volume of the heart is of the utmost importance in radio-diagnosis of affections of the vascular system. This subject is further treated in par. 426.

Electro-therapeutics.—Affections of the heart are not as a rule amenable to electrical treatment. *Larat* obtained good results from the electric bath with sinusoidal currents, in affections of the heart, with weakened systole, but without myocarditis or arterio-sclerosis. Compensation was re-established, the angina was diminished and diuresis was increased. The modus operandi appears to be an increased activity of the circulation following contraction of the skeletal muscles.

Hornung of Marbach reports 56 cases treated by sinusoidal currents with more or less success.

For aneurism of the aorta, we may refer the reader to par. 427.

426. **Cardiac hypertrophy — augmentation of the cardiac area—Orthodiagraphy.**—The cardiac area may be measured by radiography or radioscopy, with a fixed tube and conical projection. By a simple calculation we may estimate the real from the apparent area. A simple method due to *Variot* and *Chicotot* enables us to obtain the real area at once.

The method by conical projection, however, necessarily introduces certain errors. To be exact, we need to know the distance of the anticathode from the point where the tangential rays touch the heart. Moreover, the distance of the screen must be accurately determined, in order to compare observations in different patients. Again, the tangential points, *i.e.*, the points at which the cone of rays touches the heart, are not all in the same frontal plane and they vary according to the distance of the focus-tube, the volume of the heart, its position and its inclination.

All these causes of error would be removed if we could measure the heart directly by means of orthogonal projection with a parallel beam.

The first orthodiagraphs were made about the same time in Germany by *Prof. Moritz* and in France in *Bouchard's* laboratory, where my method of vertical orthodiagraphy was employed. Since then, an apparatus has been made in Germany in which a style or inscribing point is attached to the focus-tube. The focus-tube is moved in the rear of the patient by means of a system of jointed levers. The style, which is kept perpendicular to the plane of the screen, follows the movements of the focus-tube, and makes a trace on a chart placed parallel to the screen. When the patient is placed opposite the tube the position of the normal ray is indicated by the shadow of the style in the centre of an opaque ring. By moving the focus-tube, the normal ray is made to pass round the contour of the heart, while at the same time the style makes a corresponding trace on the chart. This apparatus was designed by *Prof. Moritz* in 1900. It may be employed either in the horizontal or the vertical direction. The latter position, which is the most convenient for clinical examination, has the disadvantage that it is difficult to keep the frontal plane of the patient parallel with the plane in which the focus-tube moves. Another disadvantage is that the movable screen being small, gives but a partial view of the chest. It is moreover a cumbrous apparatus.

In *Prof. Bouchard's* laboratory we adapt my movable focus tube holder for orthodiagraphy by the addition of a screen holder to the apparatus used for all ordinary clinical examinations.

Fig. 67 represents this apparatus. The screen is placed

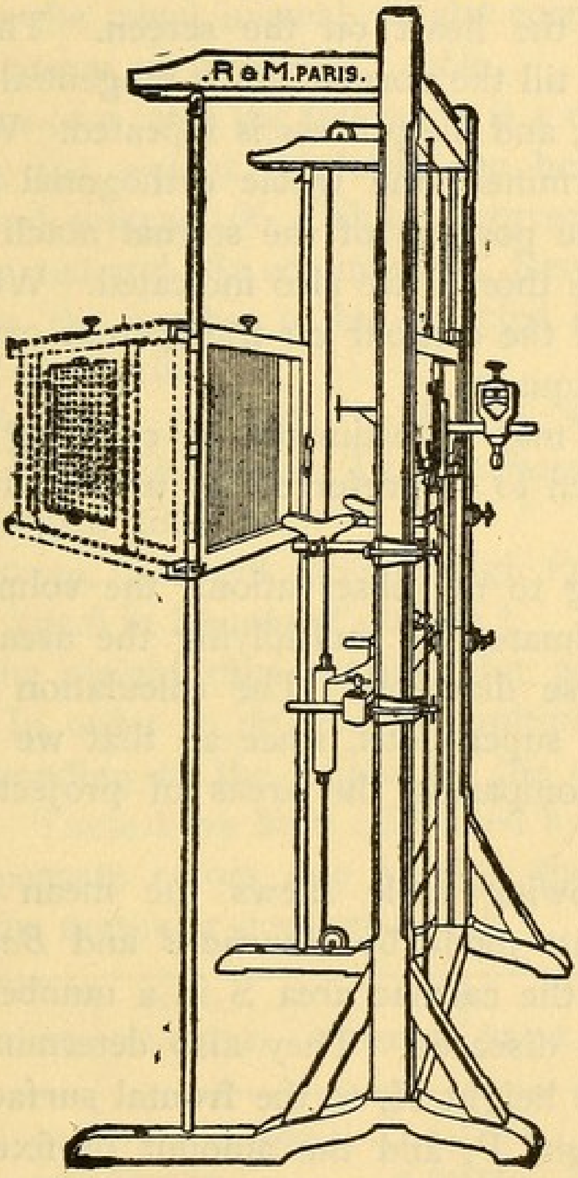


Fig. 76.

in a frame which is supported by two rods in a position parallel to the plane of the stand. These rods can be removed at will.

The following is the mode of using the apparatus. The patient is placed opposite the stand, his arms resting on two lateral supports, and the fluorescent screen is adjusted at a convenient height. By means of the cords, the normal ray is brought to a position tangential to the heart. We may now draw with a *Faber's* pencil a small part of the contour of the heart on the screen. The focus-tube is then moved till the normal ray is tangential to another spot of the heart, and the process is repeated. With six to eight points determined, the whole orthogonal contour can be drawn. The position of the sternal notch and the lateral limits of the thorax are also indicated. We may then take a tracing of the contour on transparent paper divided into centimetre squares.

The area may be estimated by counting the squares or, what is much to be preferred, by means of *Amsler's* planimeter.

According to my observations, the volume of the heart may be estimated by multiplying the area by one-half of its transverse diameter. The calculation of the volume, however, is superfluous, since all that we require is some means of comparing the areas of projection in different cases.

The following table shews the mean of a series of measurements made by *Bouchard* and *Balthazard.* They determined the cardiac area S in a number of cases, both normal and diseased. They also determined the ratio of the patient's height H, to the frontal surface of the thorax T, the weight P, and the amount of fixed albumen An. The frontal surface of the thorax is the product of the breadth at the level of the xyphoid cartilage, and the depth from the sternal notch to the diaphragm.

	S	$\frac{S}{H}$	$\frac{S}{T}$	$\frac{S}{P}$	$\frac{S}{An}$
Men . . .	89.5	5.34	0.199	1.53	9.84
Women .	76	4.92	0.213	1.48	9.49

The ratio S/An is the most important. The following is *Bouchard's* rule for determining the weight of fixed albumen in the body.

1. Measure the height of the patient.

2. Determine the mean normal weight corresponding to that height by means of *Bouchard's* table.

In the absence of a table the following is a rough method of determining the weight. Multiply the height *in decimetres* by 8, and subtract 66. This is correct enough for heights between 140 and 182 centimetres. Between 182 and 185 centimetres, the number to be deducted is 67, and 68 for any height above this.

Example.—A man 155 cm. in height should weigh $15.5 \times 8 - 66 = 58$ kilograms. In *Bouchard's* tables the number given is 58.6 kilos.

A patient 170 cm. in height should weigh $17 \times 8 - 66 = 70$ kilograms. (70.6 in *Bouchard's* tables.)

3. Correct the weight thus obtained for age, build and musculature. In order to do this we multiply the normal weight corresponding to the height by the coefficients of age and build. These have been calculated by *Bouchard* in order to compensate errors due to age, the size of the skeleton, and the muscular development.

BUILD.	COEFF.	MUSCULATURE.	COEFF.	YEARS.	COEFF.
Very stout	1.12	Very strong	1.24	13	0.694
Stout	1.08	Strong	1.12	15	0.743
Rather stout	1.04	Rather strong	1.05	17	0.796
Medium	1	Medium	1	19	0.849
Rather slender	0.96	Feeble	0.95	21	0.888
Slender	0.93	Very feeble	0.90	23	0.923
Very slender	0.90			25	0.953
				27	0.974
				29	0.992

4. Since the fixed albumen represents 14.8 per cent of the normal weight, it is easy to determine the weight of fixed albumen in a patient whose height, age and build are given, since the normal weight can be calculated from these data. In addition to the foregoing, a correction should be made for the degree of muscularity of the patient. For a very strong musculature the fixed albumen will be 15.8 per cent instead of 14.8. The following is a table of corrections according to the degree of musculature:

Musculature	Fraction of weight present as fixed albumen.
Very strong	.1581
Strong	.1552
Rather strong	.1505
Medium	.148
Feeble	.1457
Very feeble	.1431

Let us take for an example a man of 32 years of age, of rather stout figure and rather strong musculature, 170 cm. in height.

His normal weight will be: $17 \times 8 - 66 = 70$ kilos.

Corrections for figure and musclature:

$$70 \times 1.04 \times 1.05 = 76.44 \text{ kilos.}$$

No correction for age.

Since his musculature is rather strong, we shall have for his fixed albumen: $76.44 \times .1505 = 11.50$ kilos.

5. We have thus obtained the weight of albumen if the patient is normal. Is he normal? The weighing machine will settle this question. If he weighs more than 76.44 kilos, the surplus is due to fat, and the fixed albumen will still be 11.5 kilos. If he weighs less than 76.44 kilos we must remember that a loss of 1 kilo corresponds to a loss of .140

kilos of fixed albumen. If the patient is 7 kilos under weight, we must deduct $7 \times .140 = .98$ kilos from the calculated weight of his albumen.

$$11.50 - .98 = 10.52 \text{ kilos}$$

In children the size of the heart is larger in proportion to the weight of the body.

In heart disease the ratio S/An is increased.

In tubercular patients in early stages of the disease, and in those who are inclined to phthisis, the ratio S/An is diminished, whereas in old tuberculous cases the ratio is increased in consequence of dilatation of the heart.

427. **Aneurism.**—In par. 425 we have seen the importance of the X-rays in the diagnosis of aneurism of the larger vessels. Electricity is also of great use in the treatment of this disease. Whenever an aneurism is operable it should be treated surgically, since electric treatment is only palliative, and a permanent cure is but rarely obtained.

When an aneurism is inoperable, as is the case with aneurism of the aorta, it should be treated by galvano-puncture.

Pravaz and *Guerard* in 1831 demonstrated the utility of galvano-puncture. They were followed by *Petrequin* and *Ciniselli,* and the technique was perfected by *Dujardin-Beaumetz* in 1877.

Mode of operating by position galvano-puncture for aneurism.—An iron or platinum needle covered with shellac up to ½ centimetre from the point is thrust to a depth of two or three centimetres into the aneurismal sac. It is then connected to the positive pole of the galvanic current, an indifferent cathode of 200 sq. cm. being placed on some distant part of the body.

A current of 30 milliamperes is passed for 30 to 60 minutes, and the operation is repeated every ten or fifteen days.

We will pass each point of the operation in review in detail, since the operation is a very delicate one, and demands great care.

1. *The galvano-puncture should be positive.* It is most important to make sure of the polarity of the needle before the operation. One can never be certain that the signs + and — on the instrument are correct. A workman may have altered the connections, or a current reverser may have been placed in the circuit. As a mistake in this point may be fatal by causing hæmorrhage, it is important to test the polarity of the needle immediately before the operation. This may be done by means of the usual pole-testing paper, or we may place the two wires in water with two inverted test tubes over them. Hydrogen will be disengaged from the negative pole, while the positive pole will be oxidized.

The reason for using the positive pole is as follows: The positive clot, *i.e.,* the chlorine clot, adheres to the needle and to the walls of the vessel and extends for some distance beyond the point of puncture. When, therefore, the needle is extracted, there is no hæmorrhage; on the other hand, the negative clot, *i.e.,* the clot formed round the sodium and other bases, is soft and spongy. In spite of its insulation, the walls of the vessel may be injured by the needle and hæmorrhage will follow the extraction of the needle.

2. *Choice of the needle.—Dujardin-Beaumetz* recommends the use of steel needles, because the Cl set free at the positive electrode forms a hæmostatic compound $FeCl_3$. *Larat* prefers a platinum needle, since the steel becomes rough and has a tendency to wound the vessel. The needle

should be 6½ centimetres in length, and 6 millimetres in diameter.

3. *The needle should be carefully insulated* with shellac throughout its whole length, with the exception of a small portion at the point. There should be only ½ to 1 mm. of bare metal, in order to avoid hæmorrhage. The insulation of the needle is as important as its polarity.

4. *Puncturing.*—The holder designed by *Dujardin-Beaumetz,* or some other needle holder, should be used. One may be certain of its proper position by noticing the rhythmic movement of its free end.

5. *The intensity* should be about 30 milliamperes. Some operators go up to 50 milliamperes, but a current above 30 milliamperes produces very severe pain, which is quite unnecessary. A number of needles may be employed simultaneously, each being connected to the positive pole.

Results.—For 24 hours after the operation there is considerable reaction, swelling, and increased sensibility. At the end of 3 to 8 seances the pulsation becomes less apparent and the wall of the vessel appears to thicken. The explanation of this reaction is not very clear, although coagulation of the fibrin of the blood plays a certain part. It is not always safe to interpret the phenomena occurring in a living vessel, through which blood is continually circulating, by those which happen in a test tube where the blood is at rest. In *Larat's* opinion, there is an electrolytic action on the internal surface of the aneurismal sac, and a curative endarteritis is set up, resulting in the deposition of successive layers of fibrin. The aneurisms which are most suitable for galvano-puncture are those which are easily accessible or those which, like aneurism of the aorta, project beneath the skin.

428. **Angioma—Vascular Nævus.**—From an electrical point of view, the angiomata may be divided into two cate-

gories. The first is simple angioma, flat or only slightly raised, in which there is multiplication of the smaller blood vessels without dilation. The second variety, the more important, is characterised by dilation of the blood vessels.

Between the two varieties there is only a difference of degree. In the former category we may include birth-marks, nævi vasculares, wine-marks, blood stains and the telangiectases of *Hebra*. In the second division we have raised nævi, projecting or cavernous angiomata, vascular tumours, erectile tumours, spongy aneurisms, and the venous telangiectases of *Schuh*.

Angioma may be treated by bipolar electrolysis after *Bergonié's* method. Two needles are thrust obliquely into the tumour. These can be kept parallel to one another by the use of a special needle-holder designed by *Bergonié*. They should be .8 millimetre in diameter, and should be covered nearly up to the point with a varnish of shellac. The distance between them may vary from 2 to 12 millimetres.

A constant current of 20 to 40 milliamperes should be used, with a duration of 3 to 5 minutes. According to *Bergonié*, as much as 40 milliamperes may be used for a large angioma.

The treatment is the same for the simpler variety as for the large lacunar angioma, in the interior of which there is a veritable lake of blood, analagous to that found in erectile tissue. In the latter case one must be careful not to cauterise the tissue, and to keep the bare point of the needle as far as possible from the wall of the vessel. It is not, however, so important in these cases to use only the positive pole as it is in the treatment of aneurism. The skin at the point of puncture should be watched. If it changes colour, there is some defect in the insulation of the needles. The current must be cut off, the needles withdrawn, and a puncture made in another situation with a fresh needle. The treatment may be repeated once a fortnight.

Electrolysis gives the best results in severe cases of angioma, or in simple angiomata which are raised and vascular. In the treatment of birth-marks it is doubtful whether it is advantageous to replace the red patches by cicatricial tissue. In these cases we may use weaker currents of 5 to 10 milliamperes with the bipolar method, with a duration of 15 to 30 seconds only for each puncture. In this way we obtain most excellent results.

Of late, *Bergonié* has employed a much simpler treatment for these angiomatous patches. It consists in the application of the high-frequency aigrette and sparks, using a bare metal electrode attached to the resonator. The violet coloured tissue begins at once to blanche. This is followed by an inflammatory reaction more or less violent, resulting in a cure of the subcutaneous affection, but leaving the epidermis somewhat discoloured.

The duration and intensity of the seances vary according to circumstances. *Guilloz* has also obtained good results from this treatment in acne rosacea. I have seen a very obstinate case of acne rosacea yield to this treatment, but it recurred, however, after some time.

Angiokeratoma, or dilatation of vessels without formation of new tissue, may also be treated by electrolysis.

429. **Varix—Varicose Ulcer—Phlebitis.**—In *Larat's* hands, the employment of the hydro-electric bath with sinusoidal currents has given good results in the treatment of varix. This was probably due to the stimulation of the venous circulation by general contraction of the muscles.

In cases of ulceration, the best treatment is by means of static effleuves or high frequency effleuves. The latter is most efficacious, promoting rapid healing.

Static effleuvation.—The patient is placed on the insulated stool and connected to the negative pole. The metal point connected to the positive pole should be directed on the ulcer, sufficiently far off to prevent the passage of sparks. The seance may be repeated every other day.

High frequency effleuves.—The resonator should be adjusted so as to give long effleuves. The patient is not insulated. The electrode for giving effleuves is supported on an insulated stand and connected to the resonator by a flexible wire. Duration, 10 to 15 minutes, repeated every other day.

Many explanations have been given of the rapid action of high frequency effleuves: among them, ozonisation, action on the trophic nerves, action of ultra-violet radiation on the nutrition of the tissues, etc.

Boudet of Paris has obtained good results from galvanisation.

Hæmorrhoids are also rapidly ameliorated by the local application of high frequency currents. (541.)

In cases of phlebitis, *M. A. Cleaves* prescribes negative labile galvanisation along the course of the vein, using 8 to 20 milliamperes, followed by the employment of the sinusoidal current.

430. **Oedema — Pseudoelephantiasis.** — Good results may be obtained from negative galvanisation. The leg should be enveloped in a large active cathode, the indifferent anode being placed on the loins. *Weill* obtained rapid improvement by this method, using a current of 50 milliamperes.

431. **Lymphangioma.** — Lymphangioma and macroglossia, which is only a local variety of the former, may be treated in the same way as angioma. This is best done by bipolar electrolysis, by means of two needles mounted in

Bergonié's handle. (428.) Intensity, 20 to 40 milliamperes except for the tongue, where we should not exceed an intensity of 10 milliamperes.

432. **Chronic Adenitis.**—Galvanisation often yields good results in procuring the absorption of the tumour. In tubercular adenitis there is not much hope of success, and if there is any sign of softening it is better to abstain from all electrical interference. At the commencement of all treatment of glandular enlargement, it is as well to warn the patient that suppuration may supervene in spite of the treatment.

A cathode of appropriate size should be applied to the tumour, with an indifferent anode of 150 to 200 sq. cm. on the nape of the neck or back. The intensity should be regulated so as to have an electrical intensity under the cathode of .5 milliamperes per sq. cm., *i.e.,* 10 milliamperes may be given with a cathode of 20 sq. cm. Duration of the seance 15 minutes.—Seances every two or three days.

433. **Leukæmia.**—Leukæmia, leucocythemia, or lymphadema is a morbid process characterised by an abnormal multiplication of the white cells of the blood and an increased proliferation of the adenoid tissue over the whole body, including the spleen and the lymphatic glands. Normally there are some 7,000 white cells in each cubic millimetre of blood, in the proportion of one white to 800 red cells. These white cells are of several varieties, and are found normally in the following proportions:

Lymphocytes, small cells of the size of the red corpusles, each possessing a single large nucleus. These are found more particularly in the lymphatic glands	2 per cent
Large Mononuclear Leucocytes, some of which shew a nucleus in process of division	36 per cent
Large Polynuclear Leucocytes	60 per cent
Eosinophile Leucocytes, so called on account of their granular contents being stained by eosin .	1 to 2 per cent

An increase in the number of white cells occurs in other diseases besides leukæmia. It occurs during the course of all the infectious diseases, and affects more especially the polynuclear leucocytes, whose proportion may rise to 80 per cent or more.

In *Lymphocythemia* the Lymphocytes more particularly are increased. In *Myelocythemia* there is an increase in all varieties of white cells, with a production of new forms, originating from the medulla of the long bones, or from myeloid neo-formations.

In all cases, whether acute or chronic, this disease has hitherto invariably proved fatal.

Radiodiagnosis. Radioscopy is of little use in diagnosis, except in so far as it may enable us to determine the condition of the mediastinal glands.

Radiotherapeutics. Before the introduction of the Röntgen rays, Medicine was completely disarmed in presence of this most fatal disease. At the present time we may assert that we possess in the X-rays an agency which is truly curative, and this in spite of many failures and a few instances of recurrence which have been recently reported.

In August, 1903, *Senn*[1] reported a case of myelogenic leukæmia of the splenic type cured by the X-rays. He irradiated the spleen, the sternum and the epiphyses of the long bones.

In the following year *Aubertin* and *Beaujard* found, immediately after irradiation of the spleen, a notable increase in the number of leucocytes in the blood. This was followed by a more marked decrease, and the white blood count sank far below its former level. As the seances are repeated the primary reaction becomes slower and weaker and finally ceases entirely. The diminution in the number of white cells is, however, permanent.[2]

[1] Medical Record, August, 1903.
[2] Archives Genéral de Médécine, 1905.

J. Capps and *J. Smith*[1] have confirmed the preliminary inflammatory reaction of the lymphoid organs, followed by a diminution of their volume. They consider that Radiotherapy has a remarkable effect, which is, however, not absolute. In certain cases the spleen does not regain its normal volume, and death may ensue even when this is the case, and the blood count has become normal. They also report frequent instances of recurrence.

Hynek, working in *Prof. Maixner's* clinic at Prague, has also drawn attention to the frequency of relapse. *Béclère* considers that a satisfactory result is almost certain in early cases, so much so that in the future Röntgentherapy may prove a means of diagnosis.[2]

It is at present impossible to explain the precise mode in which the X-rays act.

Heinecke[3] shews that in animals exposed to the X-rays there is a diminution of the size of the spleen and a disappearance of the malpighian follicles. There is a similar action on all the lymphoid organs, the lymphocytes being, of all cells, those which are most readily affected.

[1] Journal of American Medical Association, September, 1904.

[2] Béclère, Archives d'electricité médicale, July, 1905; De la Camp, Therapie der Gegenwart, March, 1905; Paul Krause, Fortschritte auf dem Gebiet der Röntgenstrahlen, Feb. and April, 1905; G. Dock, American Medicine, Dec., 1904; G. Dock, Archives of the Röntgen Ray, No. 60, 1905.

[3] Münchener medizinische Wochenschrift, Dec., 1903, and May, 1904.

CHAPTER III.

BONES AND JOINTS.

434. **Diseases of the bones and articulations.**—These affections are of interest to the medical electrician both from the point of view of diagnosis and of treatment.

The action of electrical therapeutics is very restricted in this direction. We may, however, be called on to treat hydroarthrosis or other affections of the joints due to traumatism, luxation, fracture, or injury to the neighbouring nerves or muscles (377).

It is, however, radio-diagnosis that will chiefly occupy our attention in this chapter. Radioscopic exploration is of the greatest service in the study of luxations, fractures, malformations, inflammatory affections and troubles of nutrition.

The radio-diagnosis of injuries of the bones and joints is often of the greatest importance in medico-legal enquiries, where no error in technique is permissible.

We shall give here the rules to be followed in the radiological examination of each region, and particularly of the limbs. These rules will enable us to define exactly what has been done, and to repeat the examination under the same conditions, at a future time.

435. **Radiodiagnosis of fractures and dislocations.**—1. The *position of the patient* should be defined. If the patient is interposed between the focus tube placed on his sternum and the screen placed on his back, the image will be that due to the superposition of a series of transverse or frontal sections of the body.

As long as they are parallel to the screen the images of each of these sections will be magnified, but not deformed. The total image will be best when the focus tube illuminates the centre of each section perpendicularly. When the patient is irradiated so that the frontal sections are not deformed, the image is said to be a *frontal radiograph,* the patient is said to be in the *frontal position,* and the plane of examination is the *frontal plane.*

Two positions are used for the examination of any part of the body, the frontal position and the *sagittal position,* at right angles to the former. Occasionally, in the examination of fractures and dislocations, an intermediate position may be required. This is defined by its relation to the two principal positions.

2. *The position of the focus tube* and the incidence of the rays must be defined. In the frontal position the rays may fall on the anterior or posterior surface of the body, and in the sagittal position they may fall either on the right or left surface. This is defined by saying the incidence is anterior or posterior, right or left. We may also define it as a posterior or anterior view, since we are supposed to be looking at the body from the opposite side, *i.e.,* the surface of emergence of the rays.

We have thus defined the position of the patient relative to the focus tube. The next thing is to define the direction of the rays falling on a given point of the body or of the plane of projection. In radioscopy we speak only of the direction of the rays falling on a *point of the body.* In radiography it is the incidence on a given *point on the plate* that is of importance. The ray usually chosen is the Normal Ray, *i.e.,* the ray which falls perpendicularly on the plane of examination and of projection.

In radioscopy the direction of this normal ray is shewn by the indicator of incidence placed in front of the tube. This indicator marks the normal to the plane of the tube carrier which passes through the apex of the cone of emission. Supose, for instance, we wish to define the exact position from which a skiagram of a broken rib was taken; we may say that the patient was placed in the sagittal plane and that the normal ray impinged on the nipple or any other defined point of the integument.

In radiography we place an index to coincide with the normal ray, so that its position may be indicated on the print, while at the same time we define the point of the body on which the normal ray impinges. This spot may be indicated by the intersection of two lines on the margin of the plate, as recommended by *M. Bertin-Sans.*

I must refer the reader to *Bouchard's* "Traité de radiologie" for the complete study of this question, and for a description of the principal methods used in practice. I will only allude to the means of defining more accurately a point on the surface of the body. At the Congress of Boulogne, in 1899, I suggested a general mode of procedure which I have found most useful.

It consists in defining a point by two measurements, one of which is its perpendicular distance from a given axis. For the arm the anterior brachial axis is a line drawn from the acromio-clavicular articulation through the centre of the hollow of the elbow joint and wrist. For the leg, the anterior crural axis passes from the anterior superior spine of the ilium, through the middle of the patella and the ankle. The second measurement is the distance of the perpendicular from the origin of the axis. The point is thus defined by an abscissa, the length of the perpendicular drawn to the axis, and an ordinate, the distance of the foot of the abscissa from the origin of the axis. The origin of the axis for the arm is the acromio-clavicular articulation; for the fore-arm the middle of the fold of the elbow; and for the thigh the iliac spine; for the thorax the medio-sternal axis has its origin in the middle of the superior border of the sternal notch.

I am thus able by means of an abridged formula to determine the conditions with the greatest exactitude.

Suppose, for example, a fore-arm is examined in the frontal position, with anterior incidence, as in Fig. 77, the

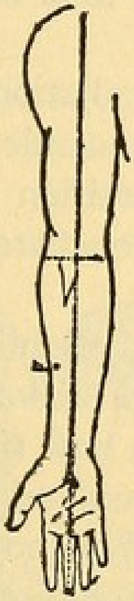


Fig. 77.

normal ray impinging on the point I. We measure the abscissa drawn from I to the axis, say 3 cm., and the distance of this from the fold of the arm, say 6 cm. Then we may write:

Right fore-arm—frontal position.
Anterior incidence.
Point of incidence of normal ray: {ordinate—6 cm.; abscissa (left)—3 cm.}

I usually note in addition the length of the axis of the limb and the circumference of the limb. This gives some idea of the size of the region under consideration. In addition the distance of the anticathode from the plate should be noted.

By this simple method we are able to work under precise conditions. With these data another operator, working under the conditions noted on the print, should produce precisely the same results. In this case nothing is left to chance.

Special cases.—In certain cases, as for instance in hip-disease, or where there is plaster splint, the plane of examination cannot be conveniently placed paralled to the plate. The position should then be indicated as accurately as possible.

In other instances the irradiation should be oblique. The normal ray may then fall outside the plate. In this case it is simpler to mark the position of the point of incidence of the oblique ray which irradiates the centre of the area under consideration.

The problem consists in defining the obliquity of the oblique ray with the same precision as the normal ray.

In par. 215 I have shown how this may be done by means of the indicator of incidence and the radiogoniometer. It may be useful to repeat the method here.

Practical method of determining the normal ray, or a definite oblique ray, in the diagnosis of surgical affections of the bones and joints.—Whatever make of couch is used, it should be provided with a tube-carrier furnished with an indicator of incidence, *i.e.,* a wire cross which is interposed in the course of the ray to be measured. A useful couch is that made by *Radiguet* and *Massiot* at my suggestion, and described in the *Archives d'Electricité Médicale* of February, 1902. If we wish to employ the normal ray we place on the plane of projection a fluorescent screen with a vertical style, as in the apparatus of *Virgilio Machado.* Or we may use my radiogoniometer, with the two indexes at 0°. The focus tube must then be adjusted so that the shadow of the style is reduced to a point, when the screen will be normally irradiated. The cross of the indicator may then be adjusted so that its intersection is projected on the centre of the screen.

If an oblique ray is to be employed, for instance one inclined to 20° to the right and 20° towards the head of the patient, we must make use of the radiogoniometer. This instrument is placed on the plane of support of the part under examination, with its longitudinal axis parallel to the

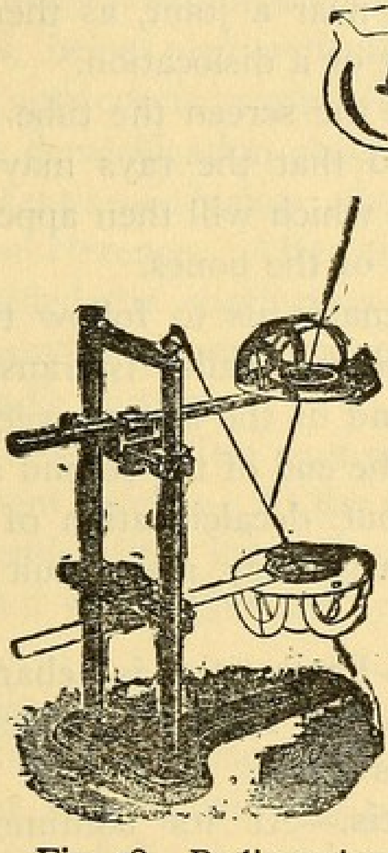


Fig. 78.—Radiogoniometer.

axis of the limb. The index is moved 20° to the right and 20° towards the head, and the focus tube adjusted till the shadow of the index on the screen is reduced to a point.

If, on the other hand, we have taken an observation with a certain oblique position of the tube and we desire to define it for further reference, we proceed by the inverse method. The stand of the radiogoniometer is placed as before, and the measuring arcs are moved until the shadow of their intersection falls on the centre of a small fluorescent screen. It is then only necessary to read and record the angles indicated.

435a. **Clinical results.**—A radioscopic examination will often suffice for diagnosis. When this is not the case, and the clinical symptoms point to a fracture, a radiograph should be taken. This should be done as a matter of routine when the fracture is near a joint, as there may also be a fracture into the joint or a dislocation.

In examining with the screen the tube should be moved in every direction, so that the rays may pass completely through the fracture, which will then appear distinctly contrasted with the ends of the bones.

The X-rays also enable us to follow the production of callus. At first the fibrous callus is transparent, becoming more visible at the end of the second week, and taking on its definite aspect at the end of the second month. As *Prof. Imbert* has pointed out, decalcification of the bone, manifested by greater transparency, may result from even slight injuries.

436. **Periostitis.**—Periostitis is characterised by a fusiform swelling around the bone, which is more transparent than the osseus tissue.

437. **Osteomyelitis.**—At its commencement osteomyelitis is not recognisable by means of the X-rays. Radio-diagnosis does not enable us to detect the formation of pus. This is unfortunate, as it is in the earlier stages that surgical intervention is most efficacious. Later on in the disease spots of greater transparency may be seen where the osseous tissue has been destroyed. When sequestra are formed radio-diagnosis is most useful, as it enables us to ascertain their exact position.

438. **Osseus Tuberculosis.**—Under radiological examination osseous tuberculosis, or white swelling, is made

manifest by the comparative transparency of the bone. In certain cases even advanced tuberculosis may sometimes be overlooked, caseous masses of the size of a hazel-nut not being differentiated from the neighbouring tissue.

According to most observers the bone in the neighbourhood of a tuberculous tumour becomes more transparent, owing to the decalcification which precedes the tuberculous invasion. This decalcification is not pathognomonic of osseous tuberculosis, being also noticeable in the arthritis of streptococcic or gonococcic origin (*Wertheim Salomonson*). It is akin to the decalcification observed by *Imbert* (435).

Electro-therapeutics.—During the early stages there should be no interference. After the inflammatory symptoms have subsided the continuous current may be used, and the accompanying muscular atrophy may be treated by the galvano-faradic current.

439. **Syphilis.**—Syphilitic gummata of the bones appear as transparent patches. At the same time there usually appear on the ends of the long bones certain neoformations of the periosteum which give the syphilitic bone a distinctive appearance.

440. Arthritis.—*Radio-diagnosis.* — Under radiological examination arthritis is recognisable by the ill-defined outlines of the joint, varying with the nature of the exudation, and the congestion of the synovial membrane.

There is also an alteration in the appearance of the line of separation between the articular ends of the bones. In later stages the disappearance of this line indicates an alteration of the cartilages, which may be entirely destroyed. What is of even more importance, a radiological examination will reveal the condition of the ends of the bone.

Electro-therapeutics.—Arthritis is frequently benefited by electric treatment, although we are not as yet able to lay down a general rule of treatment. The arthritis following blenorrhagia has been treated with success by high frequency currents (*Dénoyès*) or by a continuous current of 40 to 60 milliamperes given twice a day, commencing with an hour and gradually diminishing to 15 minutes (*Delherm*).

In certain cases of acute arthritis *Bordier* has obtained good results by ionisation with salts of Lithium. A positive bath was used containing 2 per cent of Chloride of Lithium, rendered alkaline with 1 in 2000 of Lithia. In subacute forms it acts by transforming the insoluble urate of soda into the more soluble urate of lithium, one part of the former being soluble in 19,000 parts of water, while the latter is dissolved by 116 parts.

According to the opinion of *Apostoli, Berlioz, Laquerrière* and *Dénoyès,* high frequency currents should not be used in the acute arthritis of rheumatism during the febrile stage.

Prof. Bouchard made observations on the injection of salicylate of soda into the regions affected by rheumatism. This suggested to *Bergonié* and *Roques* the idea of treating this disease by electric ionisation, causing the salicylic ion to penetrate the diseased joints. I have had occasion to use this treatment on several occasions with the happiest results.

The proper way to practise ionisation is to immerse the extremity in a warm bath containing the electrolyte. This is joined to the positive pole if we desire to give the descending ions of lithium, or to the negative pole if we wish to cause the ascending ions of acids or salicin to penetrate the tissues. When one of the larger joints, such as the knee or shoulder, is to be treated, it should be previously washed with soap and alcohol. It should then be covered with a large electrode lined with cotton wool well soaked in the solution, and kept in good contact with the skin.

The strength of current employed will vary according to the tolerance of the patient, and also acording to the ion it is desired to use. Densities of .2 up to .7 or even 1 milliampere per square centimetre are usually well supported, so that with an electrode of 200 sq. cm. we can easily pass 40 to 120 milliamperes into the affected region. The duration of the seance will vary from 15 to 45 minutes, or an hour, according to the intensity of the current (247 and 267). The seances may be repeated every other day.

441. **Ankylosis.**—Ankylosis, which frequently occurs after arthritis or after surgical immobilisation, is greatly ameliorated by the continuous current. Some of the results are most surprising. *Walter Gwyer,* of New York, and *Leduc,* of Nantes, have published successful cases. On either side of the affected joint large electrodes are applied, soaked in a solution of NH_4Cl. A current of 20 to 150 milliamperes is passed for 10 to 30 minutes. The negative pole should be placed as near as possible to the part to be treated.

A radiological examination should be previously made, in order to judge of the state of the articular surfaces.

Radiotherapy may perhaps in the future render good service in these cases, but as yet it is too early to be able to speak with certainty.

442. **Chronic tendinous synovitis.**—Negative galvanisation is very efficacious in this affection (*Bordier*). The active cathode should be applied over the affected region with a current giving a density of .5 to .7 milliamperes per sq. cm.

443. **Hydarthrosis.**—In this disease the same treatment may be given. A large negative electrode should be applied over the affected joint. By this means the reabsorption of liquid is increased. Where galvanisation fails we may have recourse to the direct application of high frequency currents. The joint should be covered by a sheet of tin, which is applied directly to the skin. This is connected

to one extremity of the helix of self-induction. The other electrode, attached to the other extremity of the helix, is applied to any convenient part of the body. Seance every other day; duration, 10 minutes.

444. **Loose bodies in the joints.**—*Radio-diagnosis.*—I shall only allude to this subject in order to guard the reader against two principal errors. In the first place we may fail to recognise the presence of a movable body, even when partially ossified, unless we take care to get its shadow clear of the neighbouring bones of the joint.

The second error we are likely to fall into is to diagnose a movable body, when there is only some bony concretion, or a sesamoid bone developed in the tendons or ligaments of the joint.

445. **Disturbances of nutrition of the bones—Tumours —Malformations—Heberden's nodes.**—The X-rays have thrown new light on a number of diseases to which we can only just allude. These include *Paget's* disease, acromegaly, rickets, cretinism, myxœdema, osteomalacia, osseous tumours, the nodes of *Bouchard, Heberden's* nodes, the neurotic arthritis of tabes and of syringomyelia. Finally we may allude to the gouty infiltrations of the epiphyses, which are more transparent than normal bone on account of the greater permeability of urate of soda to the X-rays.

This enumeration, though necessarily incomplete, shows how vast is the field of exploration for the use of X-rays in diseases of the osseous and articular systems.

446. **Scoliosis—Rickets.**—Scoliosis is usually the result of rachitic disease of the bones, such as genu valgum, flat foot, or rachitic curvature of the bones of the leg. According to *Kirmisson, habitual scoliosis, i.e.,* scoliosis due to vicious habits at the time of adolescence, which we are sometimes called on to treat in young girls, is also a result of rachitis. Whatever part the mal-development of the osseous

system may play in the genesis of scoliosis there is no doubt that the muscular system also plays a most important part, and that most cases would be benefited if we could restore to the antagonising muscles their normal force and tonicity.

Electro-diagnosis and Radio-diagnosis. The rôle the muscular system plays in the orthopædic affections is a most important one. It is always advisable to test the muscles electrically before commencing treatment. *Bergonié* advises the practitioner in every case of scoliosis to test the muscles of the back, the neck and the thorax. If the faradic excitability is completely lost there will be little chance of successful treatment.

An examination by means of the X-rays is also of importance. The dorsal decubitus should be chosen, since the symptoms of scoliosis are much more marked when the muscles are relaxed. It may be necessary to interpose a cushion of cotton wool between the concavity of the back and the supporting couch to insure immobility.

By means of radiography we can examine the condition of the bones, the ankylosis of the vertebræ, the existence of osseous neo-formation, or any deviation or torsion of the spine. The latter condition may be recognised by the deviation of the spines of the vertebræ to the right or left of the axis of the spinal column. It is advisable also, in all cases of scoliosis, to examine the whole of the osseous system. In a rachitic subject the long bones are usually more slender than usual, whereas the extremities are enlarged.

Electro-therapeutics.—*Bergonié* has formulated the precise technique in the treatment of scoliosis. He uses a strong faradic current, with rhythmic interruptions. He employs a large tin electrode of 100 sq. cm., covered with several layers of absorbent cotton wool. The exact point of application is of considerable importance. *Bergonié* compares the vertebral column to a bow. If we stimulate the muscles on the concave side, we bend the bow, and increase the curvature still more. The convex side should, therefore, be treated by stimulation of the whole mass of the muscles in the vertebral groove. The electrodes may be moved from place to place till the best effect is produced, without taking much notice of the motor points. They should be placed at right angles to the spine, one above and the other below the convexity.

The seances may be of considerable duration, since with the rhythmic interruptions the muscles are not easily fatigued. By placing the patient in a comfortable position and fixing the electrodes by means of india-rubber bands, the treatment may be continued for an hour without fatigue, but every care should be taken to prevent the patient being frightened by the treatment. A seance may be given every other day, every day or twice a day, according to circumstances.

In cases of osteitis or arthritis faradisation is contra-indicated.

The hydro-electric bath with sinusoidal current has proved useful in the general treatment of rickets. Three baths may be given per week, each of 20 minutes' duration. Intensity, 20 milliamperes (*Sagretti, Gautier* and *Larat, Springer*).

Galvanisation of the spine has also been recommended by some authors (*A. Weill*).

CHAPTER IV.

ELECTRICAL TREATMENT IN GYNAECOLOGY.

447. **Metritis.**—The usual division into chronic and acute metritis, although somewhat antiquated, is of service here. In acute metritis electrical treatment is, as a rule, contra-indicated, whereas it is useful in chronic metritis.

This rule is subject to some modification. In acute metritis of gonococcic or streptococcic origin, electric treatment can do nothing but harm. There is, however, no definite distinction between an infectious metritis and ordinary uterine congestion, which is too often regarded as of purely microbic origin. Thus some authors qualify with the term acute metritis the uterine congestion due to atresia, or malformation, or caused by exposure to cold and fatigue, etc. In like manner the hæmorrhages of the menopause are often attributed to metritis, although infection is of quite secondary importance in these cases, and even the worst attacks are accompanied by only slight rise of temperature. The same may be said of post-partum hæmorrhagic metritis due to subinvolution of the uterus. In all these cases, where there is no infectious cause, electrical treatment is useful. We need not discuss this question of pseudo-metritis further, since the dominating symptom necessitating treatment is the hæmorrhage, which we shall allude to later on. (449.)

In conclusion we may say that electricity is contra-indicated in the treatment of true acute infective metritis with febrile reaction, pain and peritoneal complications. On the other hand, it is justified in cases of congestion, pseudo-metritis and in some true cases of metritis of a congestive rather than an infective type, where hæmorrhage is the principal symptom.

Chronic metritis generally follows an acute attack. It begins as endometritis of the mucous membrane. This increases in thickness and develops granulations and vegetations, which may be vascular, as in hæmorrhagic endometritis, or peduncular as in mucous polypi. On the other hand, the mucous membrane may become eroded or ulcerated or cystic, or the disease may invade the parenchyma, producing hypertrophy of the interstitial connective tissue, as in chronic hypertrophic metritis.

In all these forms of metritis electrical treatment is indicated, whether the dominant symptom is pain, leucorrhœa, dysmenorrhœa, membranous dysmenorrhœa, or hæmorrhage.

There is, however, one condition in which all electrical treatment is contra-indicated, and that is a diseased state of the uterine appendages. This may not be readily noticeable by ordinary clinical examination, but electro-diagnosis will establish it, if present, with certainty.

Electro-diagnosis.—The aim of electro-diagnosis is to inform us of the condition of the uterine appendages. For this purpose an indifferent electrode is placed on the abdomen and a platinum hysterometer is introduced into the uterus, each electrode being connected to one pole of a galvanic battery. The uterus is tested by passing a current of 50 milliamperes. If there is intolerance, or if there is any inflammatory reaction afterwards, the appendages may be suspected. If, on the contrary, the current can be increased to 100 or 150 milliamperes without severe pain or reaction, the uterine appendages may be considered healthy, and we may proceed to treat the case electrically.

If intolerance increases at each seance, it is probably due to some lesion of the appendages. If, on the contrary, the slight amount of intolerance at the commencement of the treatment diminishes, the case is probably one of hysteria, or the lesion of the uterine appendages is in a state of regression (*Apostoli*).

In some instances, when there is ovarian pain of uncertain nature, the faradic current may be used as a means of diagnosis. When this is hysterical it will usually yield rapidly to faradisation.

Electro-therapeutics.—When there is no contra-indication electricity is usually applied in the form of intra-uterine galvanisation.

This may be done in two ways:—

1. By means of a positive electrode consisting of a hysterometer of platinum or charcoal, which is not attacked by the chemical products set free at the poles.

2. By means of a positive soluble electrode, *i.e.,* one which is attacked by the current.

In both cases the indifferent cathode consists of an abdominal plate of at least 200 sq. cm. A speculum is first introduced, the patient being placed in the gynecological position. The neck of the uterus is then cleaned with a pledget of cotton wool moistened with sterilised water. This mode of producing asepsis is more efficacious than the use of the douche, since the sound only touches the lips of the os uteri, and the only precaution necessary is to avoid the introduction into the uterine cavity of the microorganisms of the vagina and vulva.

Uncorrodible Electrodes.—*Apostoli's* carbon electrode is more difficult to introduce than the platinum sound. The carbon electrode should be passed into the uterus with a screwing motion, until the fundus of the uterus is reached. It comes into close contact with the whole of the interior surface of the organ. *Bergonié* has constructed an electrode of platinum, formed of two spoon-shaped branches with their convexities outward. These can be separated and thus applied exactly to the opposite surfaces of the endometrium. If the platinum sound is used it should be turned in every direction so as to come into contact with every portion of the walls of the cavity.

The intensity of the current is gradually raised from 0 up to 50, 100, or even 150 milliamperes. The current is then maintained at its maximum for 8 minutes, *i.e.,* two minutes in each position of the platinum hysterometer. In my own practice I do not usually exceed 80 milliamperes. *Zimmern* advises the operator not to exceed 50 or 80 milliamperes, especially in hæmorrhagic metritis. He considers that the object to be kept in view is not so much the destruction of the mucous membrane as the stimulation of the uterine muscle and the production of coagulation by the polar products of decomposition. Some authorities are of the opinion that the good results of curetting are due not so much to the removal of the mucous membrane, as to the stimulation of the submucous tissue.

According to *Delbet,* one of the disadvantages of *electrical curettage* is the difficulty of limiting the destructive action. There is nothing to indicate when the mucous membrane is sufficiently destroyed, or at what moment the cauterisation will extend to the muscular tissue. There is thus some danger of acting too deeply, and of substituting a cicatricial tissue for the mucous membrane. On the other hand, if we do not carry the cauterisation deep enough the metritis will recur. Although the destructive action of the mucous membrane plays a certain rôle in the treatment of metritis, there are other actions, and notably the excitation of the uterine muscular tissue, which is very sensitive to the continuous current. At all events we have the testimony of experience to the efficacy of electric treatment. It is better not to exceed 80 milliamperes in any case of metritis, whether hæmorrhagic or not, except in obstinate cases which have previously resisted treatment. We must also take into account the extent of the surface of the electrode. With a large carbon electrode we may safely give a larger current than with a platinum sound.

2. *Soluble electrodes.*—Electrodes which are to be acted on by the galvanic current are usually made of copper (*Gautier, Cleaves, Goelet*) or silver (*Boisseau, du Rocher, Stouffs*), while *Leuilleux* recommends cadmium, *Popyalkowski* zinc, and *Debèdat* aluminium. When a soluble electrode is connected to the positive pole, and is brought into contact with the NaCl of the organic liquid, an oxychloride of copper or other metal is formed and deposited in the interstices of the tissue. Intensity, 40 milliamperes; duration, 15 to 20 minutes. The electrode should be slightly moved from time to time, so as to prevent its adhering to the walls of the uterus.

This method is more suitable for metritis caused by blenorrhagia.

After the seance a pad of gauze soaked in salol glycerine should be applied to the neck of the uterus. The patient should be kept in an horizontal position for an hour or two and should be kept at rest during the remainder of the day.

One or two seances may be given each week. A serosanguinolent discharge which gradually becomes serous follows each seance. On the following day the pad may be removed and an antiseptic injection given.

When the painful symptoms predominate in a case of metritis we should begin by faradisation of the uterus.

For this purpose *Apostoli's* bipolar electrode should be used. This consists of a hysterometer made of insulating material. At the extremity is a metallic ring which is joined to one terminal of the handle, while a second ring at some little distance from the first is connected to the other terminal. When these are put in communication with the secondary coil the lines of electric force are condensed around the mucous membrane in the neighbourhood of the ring.

In metritis due to atresia of the neck and womb, or to malformation, the cause of the malformation must be sought out and treated.

448. **Uterine Fibroma.**—A fibroma or fibromyoma may be situated in the uterine wall, the so-called interstitial fibroma, or it may be sub-peritoneal, either projecting from the peritoneal surface, or pediculated. Or it may project beneath the mucous membrane, forming a sub-mucous fibroma, or a fibrous polypus.

Interstitial and sub-mucous fibroma are frequently the cause of symptomatic metritis or hæmorrhage.

In diagnosing a fibroma we must guard against several sources of error. The patient may be enceinte, without her knowledge. There may be an ovarian cyst, or a uterine cyst, or a cancerous tumour. In the former case treatment by electricity is an unpardonable error, even more so in the case of the medical electrician than in that of the surgeon. In the second case, electrical treatment would be useless, and in the case of cancer it would be injurious.

If the existence of a uterine fibroma is diagnosed we should proceed to an examination of the condition of the uterine appendages. Any affection of these will contra-indicate the electrical treatment of the fibroma.

Electro-therapeutics.—In the treatment of fibroma there are three principal objects:—

1. To combat the hæmorrhage by means of positive galvanisation.

2. To control pain by means of the faradic current, or by positive galvanisation.

3. To oppose the evolution of the tumour itself, by positive galvanisation if there is tendency to hæmorrhage, or

negative galvanisation if the tumour is of considerable size.

Utero-abdominal or utero-sacral galvanisation.—The galvanisation should be carried out in the manner described under metritis. A platinum sound should be used rather than a carbon electrode, which is more difficult to introduce. The principal advantage of the latter consists in the extent of its contact with the mucous membrane. Except where there is much displacement, there is no objection to the use of the speculum. In this way the cleansing of the uterine neck can be more thoroughly performed, and the sound can be more easily introduced. The rings may render the introduction of the sound more difficult. If the canal is very much bent by the pressure of the tumour it may be necessary to bend the sound to a corresponding curve. It is only in the course of the first examination that we are likely to meet with any difficulty in this respect.

The indifferent electrode is placed on the abdomen or on the sacral region, according as the fibroma is in the anterior or posterior part of the uterus.

The active pole should be positive, except when the tumour is of considerable size, and there is no pain or hæmorrhage, in which case the negative electrode may be used in order to reduce the size more rapidly.

In hæmorrhagic cases the intensity should be from 40 to 80 milliamperes. If there is no hæmorrhage the current may be increased to 100 or 150 milliamperes; some authorities go as far as 200 to 300 milliamperes. Duration, 5 or 6 minutes; seances, every 2, 4 or 7 days, according to the reaction. In hæmorrhagic cases, every day.

These doses must be varied according to circumstances, some patients being only able to bear 40 milliamperes, even although there may be no affection of the uterine appendages. In this case the treatment will be more prolonged.

When using an intense positive current the sound may be found to adhere to the wall of the uterus. If this occurs the current should be slowly brought back to zero, and then reversed so as to allow a current of 10 milliamperes to pass in an inverse direction. The negative pole will soften the surface of the adherent slough and the sound will be easily disengaged. During the monthly period the treatment should be intermitted, but it may be recommenced on the 4th day if there is not much menorrhagia.

As we have already said, negative galvanisation should be employed in the treatment of fibromata of considerable size. The current should not exceed 150 milliamperes, in consequence of the tendency of the negative pole to provoke hæmorrhage.

Vagino-abdominal galvanisation.—If there is a great deformity of the canal of the neck of the uterus it may be impossible to introduce a sound into the uterus. In that case it is better not to employ intra-cervical galvanisation, but to place a positive pad in the posterior cul-de-sac and an indifferent negative plate on the abdomen.

M. A. Cleaves uses a novel method of vagino-galvanisation. By means of a special canula the vagina is kept full of water, and the galvanic pole is connected to this fluid electrode.

In cases of hyperæsthesia or slight implication of the uterine appendages we must have recourse to vagino-abdominal galvanisation.

Faradisation.—Faradisation should be especially employed in cases of painful fibroma. We may use either intra-uterine faradisation with the bipolar electrode, or the utero-abdominal, utero-sacral, or vagino-abdominal methods.

Contra-indications.—Electrical treatment is contra-indicated if there is any inflammation of the appendages, or any acute affection of the neighbouring organs, such as nephritis. Hæmophilia is another very unfavourable complication, and so is hysteria. Any suspicion of cancer will also act as a contra-indication. Sub-peritoneal fibromata, if pediculated, should not be treated unless for painful complications, in which case galvanisation should be preferred. Fibrous polypi should not be treated electrically.

449. **Uterine Hæmorrhage.**—Uterine hæmorrhage is common to a number of uterine affections. It is particularly prevalent in cases of fibroma and metritis. Under the influence of the microbic theories it has been usual to assign metritis as the cause of all hæmorrhages which are not due to tumour or trauma.

At the present time this is no longer permissible. We shall make a more detailed study of the causes of uterine hæmorrhage, since it is for hæmorrhage that the majority of uterine cases come under the notice of the medical electrician.

The following are the principal causes according to the classification of *Zimmern,* as set forth in his thesis published in Paris in 1901.

Non-Uterine Causes.—Affections of the circulation, mitral lesions; hepatic disease: lesions of the kidney: general infections, such as influenza, paludism or tuberculosis. Lastly, there are affections of the general health, such as chlorosis or neurasthenia.

Congestion of the Uterus without metritis.—These include the pseudo-metritis of virgins and of the menopause, and the pseudo-metritis caused by uterine deviation or malformation. To this group also belong the post-partum hæmorrhages due to arrest of involution, without septic infection.

Cancerous tumours.—These often set up subacute metritis. The premonitory hæmorrhages, due to metritis, are soon followed by the typical hæmorrhage of cancer, with serous or sero-sanguinolent discharge. This, in its turn, gives place in the later stages to the hæmorrhages of ulceration.

Other causes of uterine hæmorrhage are the fibromata and the varieties of true metritis already described, and the affections and inflammations of the uterine appendages, which latter more often cause menorrhagia.

Electro-diagnosis.—When a case comes to us with hæmorrhage, we must first discover the cause. Where we are in doubt whether the uterine appendages are involved, an electro-diagnosis should be made as described in par. 447. When there is no contra-indication, we may proceed to consider the propriety of electrical treatment.

It will be well here to offer some advice which students in electrotherapy should always bear in mind.

When a young female patient is brought to us complaining of a loss of blood from the vagina, it is either due to traumatism, which is rare, or it is a case of precocious menstruation. We should, therefore, avoid alike all gyneacological examination and electro-therapeutic treatment.

It should be remembered that menorrhagia is often the first sign of a mitral lesion. There may be some general cause, such as chlorosis, or some accidental congestion. We should be loth to make an examination in such a case, since with a little general treatment the patient will often get well in the course of a few months.

We should bear in mind the possibility of gonococcic infection even in the virgin, the causes of infection being of the most varied description. A definite diagnosis should be made, since treatment is most efficacious in the early stages of this disease.

When the patient is a young woman, we must think of the possibility of an abortion, which may have been overlooked, or may be concealed. If there is retention of the membranes, the trouble will only be increased by electrical treatment, and surgical intervention by curetting is required.

It is most important to avoid interference in the case of a gravid uterus. Where the menses are persistent it is easy to overlook the possibility of the patient being enceinte, In doubtful cases an expectant treatment will do no harm.

It is still more necessary to recommend prudence when the patient returns for a continuance of the treatment, after an interval of three to six months

At the approach of the menopause, we must not be deceived by a belated conception or the commencement of a cancerous growth. Either event would, of course, be a contra-indication for treatment.

Zimmern points out another possible error, of treatment rather than of diagnosis. In cases of menorrhagia and metrorrhagia of a more or less benignant, or neurasthenic type, one is very liable to treat the general health and neglect the particular symptoms. If such a case were submitted to static treatment, the hæmorrhage would be fatally augmented. Static electricity and high frequency currents have a special action on catamenial congestion.

Electro-therapeutics.—Electric treatment is contra-indicated in the following cases:

1. In the hæmorrhages of the menopause with cardiac or hepatic complications, or where there is great obesity or plethora. In such cases the hæmorrhages are salutary.

2. In post-partum hæmorrhages when there is retention of the membranes.

3. In acute metritis.

4. In cancerous affections of the uterus.

5. In inflammatory conditions of the uterine appendages.

6. It is inferior to curetting in old cases of fungous or polypoid endometritis. The presence of a polypus may of itself be regarded as a contra-indication.

Galvanisation is indicated in the following cases:

1. In hæmorrhagic metritis, having regard to the conditions already mentioned in par. 447.

2. In hæmorrhagic fibromata. (See par. 448.)

3. In post-partum hæmorrhage due to subinvolution of the uterus, not due to septic metritis, or retention. Faradisation may also be employed in these cases. We shall return to them later on.

4. In congestive hæmorrhages due to local causes. These may also be treated by faradisation.

Faradisation of the uterus is indicated whenever we desire to stimulate the contractions of the uterine muscle or to increase its tone.

It is most useful in the following cases:

1. Post-partum hæmorrhage due to subinvolution.

2. Hæmorrhage from congestion, occurring in the virgin.

3. Hæmorrhage of the menopause when there is neither true metritis nor tumour.

4. Hæmorrhage caused by pseudo-metritis and subacute metritis, where the infective action, if any such exists, is only secondary.

The electrical treatment of hæmorrhage, then, is limited to those cases where there is neither true metritis nor tumour. In these cases we may act on the uterine muscle either by galvanic or faradic current. These affections are described in par. 447, 448, 450.

Choice of Current and Technique.—Opinions are divided as to the choice of the galvanic or faradic currents, both of which increase the tone of the uterine muscle. The two forms may with advantage be combined. In the first five days after parturition, when it is desired to stimulate physiological contraction, *Zimmern* prefers the faradic current. On the other hand, the galvanic current should be employed when we desire to treat the mucous membrane as well as the muscles, as in congestive hæmorrhage, or pseudo-metritis of old standing.

Faradic treatment may be carried out in several ways. A thick wire coil should be used, with 30 to 50 interruptions per minute. The electrodes may be placed, one on the supra-pubic region, and the other over the sacrum. Or the current may be passed from the pubis or sacrum to the interior of the uterus, by means of a sound passed into the cavity. The current may also be passed from the pubis to the posterior cul de sac, by means of a pad in the vagina. Or finally we may use *Apostoli's* bi-polar hysterometer.

The seances should be short (5 to 10 minutes) and frequent, every day or every other day. The sinusoidal current or the undulatory current may be used instead of the faradic current. A galvanic current, periodically interrupted by means of the metronome, gives equally good results. The positive galvano-faradic current may also be employed.

The galvanic current is applied by means of a carbon electrode or a hysterometer of platinum, connected to the positive pole, an indifferent cathode being placed on the abdomen or sacrum. We may also place the indifferent cathode on the abdomen and a positive pad in the posterior cul de sac.

The use of soluble electrodes is not to be commended. Since the active agent in hæmostasis is acid, there would seem to be no advantage in using up this acid in the production of metallic oxychlorides. They are usually only employed in the hæmorrhages of metritis and pseudo-metritis, when *Gautier, Cleaves* and *Boisseau du Rocher* have seen very good results follow their use.

We will proceed to give the indications for treatment in each case.

For *congestive hæmorrhages* occurring in unmarried women, we commence with faradisation, the electrodes being placed on the lumbar and supra-pubic regions. From three to seven seances may be given per week. If this is not successful, hystero-abdominal galvanisation may be tried, or vagino-abdominal galvanisation with the positive pole in the posterior cul de sac. Intensity, 30 to 80 milliamperes.—Duration, 10 to 15 minutes.—Intervals of two to five days between the seances, according to the degree of reaction.—Each seance may be terminated by a few shocks of the variable state, or by a short application of the faradic current.

In *hæmorrhage occurring at the menopause* the same treatment may be followed, but we should commence with the utero-abdominal or the vagino-abdominal method.

Post-partum hæmorrhage due to subinvolution of the uterus, whether it is complicated by pseudo-metritis or not, is rarely cured by curetting, whereas it speedily yields to electrical treatment, in consequence of the action of the current on the uterine muscle. Faradisation is specially indicated during the five days which follow delivery (*Zimmern*). *Tripier* went so far as to use sacro-pubic faradisation systematically in all his cases of accouchement. By this means he was able to hasten the process of involution, and allow his patients to get up on the sixth day.

When the post-partum hæmorrhage occurs after the first five days, the continuous current should be preferred, using a positive platinum electrode in the interior of the uterus. Intensity, 30 to 40 milliamperes.—Duration, 5 to 20 minutes.—Seances with intervals of two to four days, according to reaction. The rapidity of the results is remarkable, all symptoms ceasing after a few seances.

450. **Cancer of the Uterus.**—We may refer the reader to par. 559 for the treatment of cancer in general. *Oudin* has designed a special focus-tube for the radiotherapeutic treatment of cancer of the neck of the uterus. It is constructed with a double-walled prolongation containing an in-

sulating liquid. This localising tube, which is introduced into the vagina, has a metal shield covering the whole surface, except at the termination. *E. W. Caldwell* has also designed a focus-tube in which the cathode stream strikes the wall of the tube, which acts as an anticathode (Archives d'Électri. Med., 1903, p. 104). *Belot's* localiser is also useful in this affection, as are the tubes designed by *Bouchacourt.*

451. **Atresia of the Uterine canal.**—The uterine canal may be dilated by means of electrolysis, the technique being similar to that used in stricture of the urethra. An indifferent electrode is placed on the abdomen, and a platinum hysterometer, covered nearly up to its extremity by an insulating sleeve, is passed into the canal. I have found *Newmann's* olivary electrode useful when mounted on a hysterometer well insulated up to the olive.

Intensity, 30 to 60 milliamperes; duration, 5 to 10 minutes. Seances repeated once a week.

452. **Uterine Deviation — Uterine Prolapse.** — Since uterine deviations usually result from congestion, or infective metritis, we should begin by treating the cause, and then proceed to treat the case by means of faradisation. In cases of retroflexion or retroversion, the platinum hysterometer may be introduced into the uterus, the indifferent electrode being placed on the abdomen. In cases of anteversion or anteflexion, the indifferent electrode should be placed on the sacrum. In these cases some authors employ a uterine and a rectal electrode. Whatever be the direction of the deviation, the rule is to faradise the opposite side. A thick wired coil should be used, with very slow interruptions, 1 or 2 per second, the negative pole being placed in the uterus. Duration, 5 to 10 minutes. Seances every other day.

It is useful to supplement the treatment by systematic massage.

Opinions are divided as to the success of this treatment. *Tripier* considers that the suspensory ligaments of the uterus may recover their tone under the action of the current, while *Larat* believes that faradisation acts by encouraging the peri-uterine exudations and diminishing the uterine engorgement.

The sinusoidal current may also be used in these cases, or the galvanic current with rhythmical interruptions. A current of 15 to 20 milliamperes will produce uterine contractions.

Uterine prolapse may be treated by the same means, and in this case also it is probable that the result is due to the resolvent action of the current. The failure of electrical treatment in serious cases of prolapse appears to point in the same direction.

453. **Uterine subinvolution without hæmorrhage.**— The treatment is the same as described for subinvolution with hæmorrhage. The uterus may be faradised or galvanised according to the rules laid down in par. 449.

454. **Disturbances of menstruation in young girls.**— There are a number of affections of menstruation, amenorrhœa, hypo-menorrhœa, hyper-menorrhœa, and dysmenorrhœa. The following are the cases we are most frequently called upon to treat:

1. *Infantile uterus. Amenorrhœa due to insufficient development of the uterus.*—When the ovaries are also arrested in their development the infantile uterus, or an insufficiently developed uterus will cause amenorrhœa. When, however, the ovaries are normally developed, dysmenorrhœa will occur. The child-like figure of the patient will often assist us in the diagnosis. If vaginal examination is permitted the neck of the uterus will be found long, thin and

small. This infantile uterus is a frequent cause of sterility. Electricity is a very efficacious means of treating such cases.

2. *Amenorrhœa due to general causes.*—Both amenorrhœa and hyper-menorrhœa are often due to general causes, chlorosis, anæmia, tuberculosis, obesity, hysteria, etc. Electricity may be used locally or as a means of treating the general condition.

3. *Menorrhagia or Hypermenorrhœa.*—The exaggeration of the menstrual flux or the too great frequency of the periods, is often associated with pseudo-metritis or congestion from various causes. For their treatment the reader should consult par. 447.

4. *Dysmenorrhœa.*—Dysmenorrhœa in young patients is an affection for which we are frequently consulted. It is characterised by pains which come on shortly before the period, with severe colic and lumbo-abdominal pains irradiating towards the thighs. The colic usually disappears with the advent of the menstrual flow. In membranous dysmenorrhœa the pains persist during the whole time of the period, and are sometimes followed by the expulsion of membranes and sanious discharges almost like an abortion.

The dysmenorrhœa may be due to an affection of the uterine appendages or of the uterus itself. We have already pointed out that when the ovaries are normally developed the infantile uterus may be a cause of dysmenorrhœa, on account of the congestion of the appendages which are disproportioned to the functional state of the uterus. We may in addition have some pathological congestion of the uterine appendages, or tubo-ovarian varicocele.

We shall show later on how electricity may be employed to combat congestion of the pelvic organs. It is one of our most useful agents for this purpose.

Dysmenorrhœa of uterine origin is usually due to atresia of the cervical canal, to displacements of the uterus, to pseudo-metritis or to congestion.

There are also varieties of dysmenorrhœa without apparent cause. There is an exaggeration of the physiological phenomena, and of the precatamenial pains. This may be due to an increased nervous susceptibility of the patient, or perhaps to an arthritic diathesis. In some of these cases spasm of the neck of the uterus appears to play an important part.

It may be readily understood how cautious we should be in intervening in these cases, and how easily we may be mistaken in prescribing electrical treatment, which acts like other emmenagogues by increasing uterine congestion.

Electro-therapeutics.—1. *Amenorrhœa or hypo-menorrhœa due to the infantile uterus* with but slight evidence of arrested development, may be treated by the general static bath, which produces congestion of the pelvic organs. Duration, 20 minutes, every other day. The seance may be terminated by strong sparking of the ovarian and lumbar regions. When the patient is properly earthed the sparks from a powerful static machine are well borne. The sparks from the high-frequency apparatus are less exciting to the nervous system and equally efficacious as a local stimulant and nervine tonic. The treatment should be continued for a month, the period frequently appearing at the end of that time. In slight cases the treatment may be resumed, giving three seances per week during the ensuing month. If the uterus is altogether infantile in type we should, if possible, begin with intra-uterine faradisation, using a platinum sound connected to the negative pole, and an indifferent electrode on the abdomen. A thick-wired coil should be used. With patience a well-curved sound may be introduced into the neck of the uterus, without destroying the hymen. The superiority of this mode of treatment over sacro-abdominal faradisation is so marked that it should be always used in cases of well-marked infantile uterus. Seance every other day for 5 to 15 minutes.

2. *Treatment of Amenorrhœa or hypomenorrhœa.*—The course of treatment is the same as the preceding, but intra-uterine faradisation is not necessary. The period usually makes its appearance after a month's treatment. The general health should be treated at the same time by suitable hygienic measures. Mechanotherapy or sismotherapy are of great use in these cases. Young girls, whether suffering from chlorosis or obesity as a result of bad hygienic conditions in institutions where physical culture is neglected, are speedily cured in the course of a few months. Whatever the abdominal state of nutrition, exercise and improved hygienic conditions tend to bring the system to a normal condition. In young girls who are nervous and very susceptible to electrical treatment, one may employ *Bigelow's* method of general galvanisation, one pole being applied to the nape of the neck and one to the feet by means of a salt foot bath. The treatment should be commenced a few days before the presumed date of appearance of the menses, and continued until the period occurs.

3. *Hypermenorrhœa or Menorrhagia.*—This should be treated in the same way as hæmorrhage from congestion in the virgin, par. 449.

4. *Dysmenorrhœa.*—The causes of dysmenorrhœa being so varied, the treatment is also very complicated.

If there is any suspicion of retardation of uterine development a vaginal examination should be made, if possible, to confirm the diagnosis. It may be treated as already described by utero-abdominal or sacro-abdominal faradisation.

The static bath or sparks from a static machine may also be employed with caution when there is hypomenorrhœa as well as dysmenorrhœa. A seance of 10 minutes should be given every day, commencing immediately after the termination of the preceding period. If the menstrual pain is not increased after the first month of treatment, the time of application may be increased. This method is very efficacious when there is retardation of uterine development. On the other hand, the tubo-ovarian congestion may be increased by electrical treatment out of all proportion to the state of the uterus. In this case faradisation only should be employed, as the crises of dysmenorrhœa will be increased by the application of static electricity. It is in this condition, when the congestive phenomena need to be attenuated, that the hydro-electric bath with sinusoidal current is of such service (*Larat*). The bath should be used for 20 minutes. For the first 15 minutes the electrodes should be applied to the back and the feet, and for the last 5 minutes to the back and the hypogastric region.

When the dysmenorrhœa is due to atresia of the cervix a rapid improvement is produced by negative galvanisation (451).

If there is pseudo-metritis, or congestion, producing deviation of the organ, either faradic or galvanic treatment is often followed by good results. In membranous dysmenorrhœa the uterus may be galvanised. Intensity, 60 to 100 milliamperes; duration, 10 minutes (447-452).

Where there is no apparent cause for the dysmenorrhœa we may try in succession the static bath, sparking, the faradic and the sinusoidal current, each method being continued for a month.

Static electricity and the faradic current have apparently opposite effects. When there is insufficient menstrual flow static electricity should be used; when there is an excess the faradic current should be preferred.

455. **Disturbances of menstruation in adults.**—Sexual activity often causes the disappearance of the troubles of

menstruation which affect young girls. On the other hand, it may add others due to infective metritis, or as the result of pregnancy or labour. Most of these complications have been discussed in previous pages.

Dysmenorrhœa due to stenosis of the neck and uterus as a complication of delivery, as well as tears, sloughs, or cicatrices, may be treated by negative electrolysis (451).

Dysmenorrhœa due to uterine displacement, after delivery may be treated by the method described in par. 452.

Amenorrhœa and hypomenorrhœa are much rarer in adult life. We may be called on to treat hyper-involution of the uterine muscles as a result of delivery. The treatment should consist in the local application of the continuous or faradic current. At the same time we may employ the static bath, which has so marked a congestive action on the pelvic organs.

The amenorrhœa or other menstrual disturbances following marriage are not to be treated. Certain hygienic rules may be laid down, and the physician should only intervene if the symptoms continue for some months.

456. **Neuralgia. Pain in the Pelvic Organs.**—For the treatment of ovarian neuralgia the reader should refer to par. 399. If there is no menorrhagia, pelvic neuralgia may be treated by the static bath or high-frequency currents, using the condensing couch and a branch current directed on the painful region. These neuralgias may also be treated by the galvanic current, or with faradic currents from a fine wire coil. The sacro-abdominal or utero-sacral methods may be employed, or we may use *Apostoli's* bipolar intra-uterine method.

457. **Affections of the Vagina—Vaginismus.**—The only affection of the vagina which interests us is vaginismus. It may be treated by the faradic current, using a thin wire coil. *Apostoli's* bipolar vaginal electrode should be used.

This consists of an insulated cylinder, to which are fixed two rings connected to the two terminals. The seances may be gradually prolonged up to half an hour. Vagino-abdominal faradisation may also be employed. High-frequency currents applied by means of dilating electrodes also give satisfactory results. Sismotherapy has a good effect, but is more difficult of application.

458. **Affections of the Vulva—Pruritus—Vegetations.**—Vulvar pruritus may be treated by high-frequency effleuves. Condylomata should be removed by galvano-cautery or by electrolysis, in the way described for vascular tumours (428).

459. **Vomiting of Pregnancy.**—When all other means have failed electrical treatment will often relieve this intractible affection. A cathode of at least 150 sq. cm. should be placed on the epigastric region. Two anodes of 20 to 40 sq. cm. coupled together are applied, one on each side, to the course of the vagi at the neck, *i.e.*, to the interval between the sternal and clavicular heads of the sterno-mastoid, immediately above the clavicle. The application should be made during a meal. The maximum intensity should be 10 to 15 milliamperes. In *Bordier's* hands this method has given good results. The current is turned on suddenly each time there is any sign of vomiting. After being allowed to pass for a few seconds, it is then gradually reduced to zero. After a few seances the attacks are brought under control, become less frequent and finally disappear.

460. **Radio-diagnosis in Obstetrics.**—We may determine the pubo-sacral diameter of the pelvis by means of ordinary clinical examination. By means of the X-rays, however, we are able also to measure the transverse and oblique diameters of the inlet. For details we may refer the reader to *Bouchard's "Traité de Radiologie,"* in which he will find a long dissertation by *Fabre* on this subject.

A. *Contremoulins' procedure.*—This consists in taking two successive skiagrams with different positions of the focus tube, without changing the position of the subject or the plane of projection. After the first negative is taken the plate is removed and a second one is placed in the same position. In each instance the normal point of incidence is indicated on the skiagram. A tracing of the salient points is taken and this is transferred to a rigid plate of zinc. By means of threads stretching from the points in the zinc plate the two cones of projection may be reconstructed, their apices corresponding to the two positions of the focus tube. The intersection of these cones will determine the size and position of the pelvic inlet. This area may be measured by means of a special apparatus.

B. *Stereoscopic Method of Marie and Ribaut.*—This is a general method designed by *Marie.* Two skiagrams are taken so as to give an image in relief. The distance between any two points may be measured by means of the steriometer. This is an elegant method which only requires the apparatus for radio-stereoscopic examination.

C. *Varnier's method.*—This method, which was one of the earliest, does not necessitate any special apparatus. It consists in the comparison of the skiagram of the pelvis to be measured with that of a standard pelvis, the size of which is known. A series of radiographs are made, each one from a pelvis of known dimensions. On comparing the radiograph in question with this scale we obtain its true dimensions. *Varnier* has shewn that this method gives correct results within small limits of error. The indispensable conditions are that the focus tube should be at a fixed distance, that the pelvis should be in all cases in the same position relative to the plate, and that the normal ray should always impinge on the same point of the pelvis. *Varnier* placed the focus tube at a distance of 50 centimetres and made the normal ray impinge on the centre of a line joining the anterior superior spines of the ilia.

The weak spot in this method is the unequal inclination of the pelvis in different cases. Moreover, the individual differences are exaggerated by the proximity of the focus tube to the patient. *Varnier* has attempted to obviate this by placing the focus tube at a distance of 2½ metres. (Long-distance radiography.)

Recent improvements have rendered it possible to operate at this distance without too long an exposure.

D. *Metric Radiography. Procedure of Fabre, Fochier and Destot.*—The following is the principle of this method. A rectangular metal frame, 32 cm. by 16 cm., is provided, the sides of which are divided into centimetres by well-marked indentations. This frame is placed as far as possible in the plane of the brim of the pelvis. The image of the frame and its divisions will undergo the same distortion as that of the brim of the pelvis. By joining up the divisions on the skiagram we may plot it out in squares, each corresponding to one square centimetre. In this way the true estimate of the brim may be obtained.

It is most convenient to place the patient in the frontal position, with posterior incidence of the normal ray. If a radiographic couch is not at our disposition the patient should be placed in a prone position. I find it of great advantage to use a couch with the focus tube beneath, and the plate above. The patient lies on her back. In order to place the frame in the plane of the inlet a line is traced across the back of the patient, passing through the two dimples forming the lateral angles of the lozenge of *Michaëlis.* The frame is placed around the body and its posterior border is made to coincide with this line, the anterior border being brought into contact with the upper border of the pubis. For anterior incidence the focus tube is placed 65 cm. off on the median line of the patient, at a point 20 centimetres above the posterior line just mentioned. When the incidence is posterior the focus tube is placed 65 centimetres off on a normal to the median line, 20 centimetres below the pubic line.

In ventral decubitus the method is the same, but the pubic border of the frame is placed in position first, the suprapubic line having been previously drawn across the thighs.

Other methods.—For an account of the methods employed by *Bouchacourt, Morin, Carlos, Santos* and others, we must refer the reader to *Fabre's* chapter in *Bouchard's* work.

461. **Labour and its complications.**—Electricity is but rarely used in obstetrical practice, although it is much superior to ergot as a stimulant of uterine contraction (*Radford, Baird, Brivois*). It is useful in the after treatment, more especially for hæmorrhage and subinvolution (449). *Tripier*, as we have seen, uses it systematically.

462. **Lactation.**—We can only briefly allude to the use of pneumatic massage in order to draw out the retracted nipple. This is effected by a pump which exhausts the air rhythmically, as a child does in sucking. The pump is driven by an electric motor. We may notice here the ingenious arrangement adopted in the treatment by sismotherapy or mechanical massage. By means of a small air-pump, suction, compression, or massage may be given at will.

By this means it might be possible to treat the depressed or umbilicated nipple in young women, a condition which may in later years interfere with suckling.

Franklinisation appears to be an energetic stimulant of glandular function. In cases where the secretion of milk is insufficient the static breeze or aigrette may be directed on the breast, a seance of 10 minutes being given every day or every other day.

CHAPTER V.

ANDROLOGY.

463. **Stricture of the Urethra.**—This affection is curable by electrical treatment, whether the stricture is inflammatory or cicatricial, although in the latter case the results are not so brilliant (*Desnos*). There are two methods of treatment, circular electrolysis and linear electrolysis, both of which are of incontestable value. The first was used by *Tripier* and *Mallez* in 1863, and more lately by *Newmann;* the latter by *Jardin,* and after him by *Fort.*

Spasmodic stricture of non-organic origin is, in most instances, amenable to faradisation.

Some authors consider that stricture should not be treated when accompanied by hæmorrhage or discharge (*Newmann*). The majority of medical electricians do not share this opinion.

464. **Treatment of Stricture by the linear method.**—This method, first employed by *Jardin,* was further elaborated by *Fort.* The electrode he used somewhat resembles *Maisonneuve's* urethrotome. The whole of the instrument is insulated, except a small flexible portion which represents the blade. Various modifications have since been introduced. The best known models are those of *Jardin, Gaiffe, Lavaux* and *Bergonié-Débédat.* The last has an adjustable projecting blade.

The electrolytic sound is connected to the negative pole and the indifferent anode is placed on the abdomen or elsewhere. The instrument, with the blade directed upwards, is introduced into the urethra as far as the stricture. The current is then turned on and gradually increased to 10, 15, 30, and even 50 milliamperes. Usually a current of 15 milliamperes is enough to sever the stricture. In consequence of the small surface of the blade the density of the current is considerable, and it is therefore not advisable to pass the electrolytic sound more than once.

Opinions differ as to the value of this procedure. Its opponents object that a wound is made in the urethra which may readily become infected, and which may give rise to a new cicatrix and a new stricture.

The result of this treatment is rapid, but it is not always durable.

In my opinion it is preferable to employ the circular method whenever possible. Linear electrolysis should be reserved for cases which cannot be treated by the circular method, or where it is important to cure the stricture quickly, in a single seance. The case usually requires to be completed by mechanical dilatation with a soft bougie.

465. **Treatment of Urethral Stricture by the circular method.**—This method, which was introduced by *Tripier* and *Mallez* in 1863, tends more and more to become the method par excellence for the treatment of stricture. An olive-shaped electrode connected to the negative pole is introduced up to the stricture. The current is passed between this point and an indifferent anode on the abdomen or other part of the body.

The following are the principal types of electrodes employed in circular electrolysis:

a.—*Newmann's olives.* These electrodes are ovoid in shape, and are attached to the extremity of an insulated conductor. In *Newmann's* model this conductor is rigid, whereas in that of *Gaillard* or of *Bordier* it is flexible. It is sometimes provided anteriorly with a filiform bougie to act as a director. When the stricture is in the anterior portion of the urethra many authors prefer an electrode in the shape of an acorn. The olive electrodes are calibrated in the same way as bougies.

After having carefully determined the position of the stricture, an olivary electrode two or three sizes larger than the calibre of the canal is passed up to that point. The current is then turned on and gradually increased. With slight pressure the instrument may be felt to pass the stricture without effort. The current is then gradually reduced to zero and the electrode is withdrawn. The intensity to be employed is 5, 10 or 15 milliamperes, according to the size of the electrode and the mechanical resistance of the tissues. The larger the electrode the less is the density for a given intensity of current.

b.—*Débédat's olive-shaped electrodes.* These differ from those of *Newmann* in that their larger extremity only is metallic, the anterior portion being of ivory and non-conducting.

This electrode is passed through the stricture and the current is turned on while it is being withdrawn.

This method of procedure may be used for valvular stricture with the concavity towards the bladder, but it is of little value in ordinary cases when it is impossible to penetrate the stricture except under the action of the current.

c.—*Vernay's* electrode. In this instrument the conducting part is in the front of the electrode.

d.—*The Ringed Bougies of Bergonié and Bordier. Bergonié* was the first to construct an electrolytic bougie, terminated by a ring instead of an olive. A metal wire was wound round the bougie a few centimetres from the end, and this wire was connected with a central conductor, the ring being partially sunk in the substance of the bougie.

Bordier replaced the wire by a metal ring projecting above the surface of the bougie. The edges of the ring are carefully rounded and a rivet passing through the bougie fixes it in position and puts it in metallic connection with the central conductor. *Bergonié* has modified the ring by giving it somewhat of a barrel shape, the diameter at the equator being greater than that at the extremities.

The mode of operation is the same. As soon as the ring or barrel is in contact with the stricture the current is turned on and gradually increased to 5 or 8 milliamperes. Under its action the bougie easily passes the stricture, and does not usually take more than a minute to do so. The ring is passed several times through the stricture, both backwards and forwards, without interrupting the current. The seances are repeated every three or four days till a No. 20 bougie on *Charriere's* scale will pass.

Comparison of the different systems.—It is difficult to choose betweeen these various modes of procedure. In my own practice I always employ *Bergonié's* when possible. Its chief advantages are:—

1. The ring is always in the axis of the canal, the extremity of the bougie acting as a director.

2. The apparatus is strong and flexible, and one is not afraid of leaving the olive in the passage, an accident which has more than once occurred. In my own case, working with an olive of No. 12 size on a flexible handle, I passed the instrument through the stricture without difficulty. On withdrawing it, however, I met with an unexpected resistance. Trusting to the power of the negative pole, I continued to pass a current of 5 to 15 milliamperes for more than 10 minutes, exercising very gentle traction. At last I succeeded in extricating the electrode. I congratulate myself on not having had an olive with an ivory back, or a bougie that had been weakened by age and use. An experience like this was quite enough to make one prefer a ringed bougie.

We must, however, have recourse to an olive-tipped electrode when the patient has a stricture of small calibre and cannot afford the time to dilate the urethra slowly. It may be impossible to dilate the urethra sufficiently to admit the anterior part of the ringed bougie. Even *Newmann's* electrodes with filiform director may not be able to pass. In this case we may take an olive-tipped electrode, and pass it as far as the stricture. With prudence and the use of a moderate current, there is not much danger of making a false passage.

Theory of circular electrolysis in the treatment of stricture.—In linear electrolysis there is a certain amount of destruction of tissue in consequence of the density of the current. This is not the case with circular electrolysis. *Newmann* and *Bordier* consider that there is a chemical action due to the separation of sodium at the negative pole, and that this chemical action, the so-called tertiary action of *Bergonié,* causes absorption of the thickening around the stricture. In *Bergonié's* opinion there is a true "electrolytic dilation." Under the influence of the liberated sodium ion the tissues become more supple, and more easily dilatable. The experiments of *Bergonié* and *Ravarit* show that the positive pole has a constrictive action on organic tubes, whereas the negative pole acts as a dilator. It is possible that both theories are true, and that under the influence of the current a physical dilatation facilitates the introduction of the bougie, while under the influence of the sodium ion there is also a chemical effect which produces absorption of the thickening in the tissue.

466. **Prostatitis—Hypertrophy of the prostate.**—Various electrical procedures have been employed with success in this affection.

1. *Intra-rectal application of high-frequency currents.*—The results of this treatment are equally good in hypertrophy of the prostate and in prostatitis of gonococcic origin. The

technique is the same as for anal fissure. Seances of 5 minutes may be given three times a week.

2. *Galvanisation.*—This consists of circular electrolysis, the negative pole being introduced into the urethra, with the indifferent anode on the perineum or in the rectum. Intensity, 10 milliamperes; duration, 5 minutes. Some authors give currents of much greater intensity. Electrodes have been designed which only act on the posterior wall of the urethra.

3. *Faradisation or Sinusoidal Voltaisation.*—The technique is the same as for galvanisation. The amelioration is often rapid. *Larat* employs the following procedure: He introduces an olivary electrode into the rectum at the level of the prostate. The indifferent electrode is placed on the abdomen. A sinusoidal current is employed as strong as the patient will bear. The results are very encouraging.

467. **Chronic glandular Urethritis.**—In this disease some authorities recommend the electrolysis of the crypt of *Morgagni,* with a blunt pointed electrode, and the glands of *Littré* with a sharp point. This may be carried out with the aid of the endoscope (*Rollmann, Mundorff*).

468. **Orchitis.**—In this disease *Doumer* has obtained good results from the use of the high frequency effleuve. *Picot, Dubois* and *Boyland* have made use of the continuous current with success. An appropriately shaped anode is applied to the testicle and the cathode is applied to the fold of the groin over the spermatic cord. From 6 to 20 milliamperes may be given, according to the degree of tolerance. Seance of 10 minutes every day or every other day. *Dubois* advises ionisation with a 20 per cent solution of iodide of potash.

For neuralgia of the testicle the reader should consult par. 379.

N.B.—It should be remembered in using radiotherapeutic treatment for affections of the testicle that the X-rays produce atrophy of the gland, with azoospermia and consequent sterility. We should be careful, therefore, to protect the testicles when we are treating neighbouring regions with the X-rays.

469. **Impotence.**—When this is due to a normal cause we should endeavor to act on the general health. I have frequently seen good results follow the use of the high frequency effleuve on the spine. We should not adhere too pertinaciously to one mode of treatment. The cure is half completed when the patient has regained his self-confidence.

470. **Seminal losses.**—The treatment will vary according to the cause. We usually begin with galvanisation, the anode being placed on the perineum and the cathode on the loins. Intensity, 15 to 20 milliamperes; duration, 5 minutes. When the spermatorrhœa is due to atony of the ejaculatory apparatus *Castex* advises the employment of the method described above for prostatitis; by means of an intra-urethral ring electrode at the level of the prostate, and a perineal indifferent electrode. A galvanic current is used, which is rhythmically reversed every four seconds. Intensity, 6 to 8 milliamperes; duration, 5 minutes.

Denis Courtade recommends faradisation with a fine wire coil. The anode is placed on the lumbar region and a cathode on the perineum. If this fails he recommends the direct faradisation of the vesiculæ seminales. The anode being placed on the loins, he introduces a carbon electrode into the rectum against the posterior surface of the vesiculæ seminales. Under these conditions it is better to employ the thick wire coil with slow interruptions. The treatment is completed by the use of the continuous current, giving 10 to 15 milliamperes with a high speed break. Total duration, 10 minutes. Three seances each week.

471. **Phimosis—Leduc's operation by Galvano-cautery.**—*Leduc,* of Nantes, has devised a means of operating on phimosis by galvano-cautery. The operation consists in the removal of a triangular piece of the prepuce. The base of this triangle is formed by the lower third of the preputial orifice, and the apex is at the root of the frenum. Cocaine may be used, by injecting a cubic centimetre of a 1 per cent solution into each side of the prepuce. The prepuce is then seized by a pair of forceps along each side of the triangle to be excised. With the knife of the galvano-cautery at a dull red heat the prepuce may then be divided just inside the blades of the forceps. When the sides of the triangle are detached the frenum is seized close up to the glans by a third pair of forceps, and the triangular piece of the prepuce is detached. If the galvano-cautery is not too hot there will be no hæmorrhage.

In the after-treatment the following antiseptic salve may be used:—

Hydrarg. oxide. rub.	.2 grammes
Acid. salicyl.	.2 grammes
Zinci oxid	2 grammes
Vaseline	20 grammes

The patient may continue to attend to his business. If the lips separate healing is delayed, but it is not necessary to use a suture.

CHAPTER VI.

AFFECTIONS OF THE KIDNEY, THE BLADDER AND THE URINARY ORGANS.

472. **Incontinence of Urine.**—In this chapter we shall only discuss true incontinence of urine, and not the incontinence due to retention, or that caused by calculus or tumour of the bladder.

The incontinence which is amenable to electrical treatment is of two kinds:

1. *Nocturnal incontinence of children.*—This is by some authors attributed to a special irritability of the bladder. The best authorities, however, attribute it to faulty co-ordination between the cerebral centres and the automatic centres in the lumbar region of the spinal cord, resulting in the loss of cerebral control over the lumbo-vesical reflexes. (*Lewis Jones, Archiv. d'Elect. Med.,* Nov. 15, 1899.)

2. *Incontinence of Urine of Adults,* both nocturnal and diurnal. This is due to failure of the sphincter, and seldom occurs in early life. This variety of incontinence is usually associated with lesion of the spinal cord.

Nocturnal incontinence in children.—All authorities are agreed as to the mode of treatment, although they may differ as to the pathogenesis; whether the symptom is due to irritability of the bladder, or default of cerebral control over the lumbar centres.

On account of the difficulty of catheterisation in children intra-urethral electrisation should be used only in exceptional cases.

The best method of procedure is to treat the lumbar and supra-pubic regions with a shower of static or high frequency sparks. A dozen seances may be given, each with a duration of from 2 to 4 minutes.

The faradic or rhythmic galvano-faradic current may also be used. One electrode should be placed on the loins and one on the perineum, vulva, or supra-pubic region. Duration, 6 to 7 minutes.

Incontinence due to failure of the sphincter. Nocturnal and diurnal incontinence.—This variety of incontinence, which is rarely met with in children, is best treated by intra-urethral faradisation (*Guyon*). An olivary electrode, such as that used in circular electrolysis, is introduced into the urethra till it reaches the sphincter. This point may be known by the sense of resistance felt by the operator and by the sensations of the patient. The olive is connected to the negative pole of the coil, while the indifferent anode is placed on the abdomen or lumbar region. The intensity of the current may be increased until we produce contractions of the abdominal muscles. Duration, 2 to 4 minutes. Seances every day or every other day. A result should be obtained in 10 to 15 seances. The procedure is suitable for either sex, and in many instances a favourable result is obtained after the first few seances.

Morton's currents may also be employed instead of the faradic current (*Bordier, Claus*). The patient is placed on a non-insulated couch. The chain of one of the condensers is earthed while the other is connected to the sound. The poles of the machine are first placed in contact and are then gently separated until there are 7 to 10 sparks per second. Duration, 5 minutes. Seances every day or every other day.

473. **Paralysis of the Bladder.**—The vesical plexus has two origins, one from the sympathetic and the other from the sacral nerves. The contraction of the sphincter is under the control of the sympathetic, whereas the contrac-

tion of the bladder is under the control of the sacral plexus. In cases where both the body and the neck of the bladder are paralysed we may get retention from paralysis of the bladder succeeding incontinence from paralysis of the neck. This is especially the case during a course of electrical treatment, and is due to the fact that the paralysis of the sacral nerves supplying the body is much more obstinate than paralysis of the sympathetic supplying the neck.

Electro-therapeutics.—In addition to treatment for the removal of the cause we may faradise the bladder directly. For this purpose we introduce a weak solution of boric acid .7 per cent, by means of a catheter, or by pressure without a catheter, as in *Lavaux's* method.

An electrode with an insulated conductor is introduced into the bladder, and is connected to the negative pole of a thick-wired coil. The indifferent anode is placed on the loins. Duration, 5 minutes. The rhythmic galvanic current may also be applied. Intensity, 10 to 15 milliamperes.

In paralysis due to lesions of the central nervous system *Courtade* recommends galvanisation of the spine with the ascending or descending current, the labile electrode being placed on the spine, and the other electrode on the perineum. Intensity, 15 to 25 milliamperes. We may also employ labile faradisation of the dorso-lumbar and abdomino-crural region with the negative pole, the positive pole being placed on the perineum.

474. **Urinary Calculi.**—It is not easy to diagnose urinary calculi, whether situated in the kidney, the ureter, or the bladder, by means of the X-rays. These regions are not very transparent, and the calculi, not being very opaque, do not contrast well with their surroundings.

Vesical calculi are much better diagnosed by the sound, so that we need only refer here to calculi of the kidney and ureter.

Calculi formed of urates are the most transparent, and are hardly visible. Phosphatic or oxalic calculi are more opaque. It should be remembered that the opacity of a body to X-rays is proportional to its density. Thus calculi of urate of ammonia are least visible, then come the urates of soda, magnesium, potassium, and calcium in the order of their atomic weights. Uric acid calculi are very transparent. The oxalates and phosphates of calcium are, on the contrary, much more opaque than the surrounding tissues.

For the discovery of urinary calculi it is useless to employ rays of too great penetration. The maximum degree of hardness should correspond to No. 6 on *Benoist's* radio-chromometer. *Béclère* recommends the use of No. 5 or No. 6.

The second precaution is to diminish the excessive illumination of the neighbouring regions. For this purpose a lead diaphragm is useful. The iris-diaphragm of *Béclère* gives excellent results.

The apparatus designed by *Albers-Schönberg* constitutes at the same time a compressor to diminish the thickness of the soft parts, and a diaphragm limiting the field of vision. It is a lead cylinder 10 cm. in diameter and 22 cm. long. One end receives the focus tube and is furnished with a diaphragm 3 cm. in diameter. The lower end of the tube is used to compress the tissues of the abdomen.

With the aid of this instrument, in favourable cases, we are able to make out the image of renal calculi on the screen. Sterio-radiography also renders good service in the detection of calculi.

475. **Other affections.**—Various means of treatment have been recommended in nephritis, hot air, light baths (*Gautier* and *Larat*), and high-frequency currents (*Boinet* and *Caillol de Poncy*). All of these methods are said to have produced a diminution of albumen in the urine. As *Dénoyès*

remarks, a review of these observations at least proves that albuminuria need not be considered a contra-indication to electrical treatment.

CHAPTER VII.

SKIN DISEASES.

476. **Eczema.**— In all its varieties, eczema may be considered to be an autotoxic dermatosis, *i.e.*, an affection of the skin produced by toxins elaborated by the individual himself, as a result of faulty alimentation or from some other cause. The local manifestation is an epiphenomenon, and general as well as local treatment is needed for the cure of the disease.

There are two varieties of eczema, the acute and chronic, with numerous intermediary forms. We are usually called on to treat the chronic form, although both varieties are amenable to electric treatment.

Electrotherapy.—The best form of electrical treatment is static electricity and high frequency currents. We may also use the X-rays, or hydro-electric baths with sinusoidal currents.

a. *Franklinisation* gives admirable results (*Doumer, Leloir* and *Monell*). The patient is placed on an insulated stool and connected to one of the poles of the machine. *Bordier* recommends the negative pole. As electrode connected to the other pole, he used a single point, or a multiple-pointed electrode, or a brush made of birch. The duration of the application is variable, depending on the circumstances, but a minimum of 10 minutes on each area is recommended. The total duration of each seance is 20 to 30 minutes, repeated every day or every second day. The vesicles begin to dry up after the second day.

In true seborrhœic eczema static electricity does not appear to give such good results. (*Brocq.*) This, however, yields rapidly to high frequency currents.

b. *High frequency currents* may be applied by means of the brush effleuve or by *Oudin's* condensing electrode. Their effect is very rapid. An application of 10 minutes may be given three times a week on each region. This form of electric energy is specially adapted to this disease, since, besides its local action, it has a general action on the organism, augmenting organic combustion.

In arthritic eczema *Oudin's* experiments shew that while auto-induction is useful, it can only be regarded as part of the necessary treatment. The local action is manifested by considerable vasodilatation. Pearls of sweat appear over the whole region, and an inflammatory reaction occurs, accompanied by the cessation of pruritis. These results are due, not only to the action of the high frequency currents in the organic cells and the termination of the nerves, but possibly to an attenuation of the toxins, such as has been demonstrated *in vitro* by the experiments of *d'Arsonval* and *Charrin.* Whatever be the interpretation, there is no doubt that high frequency treatment has a curative action, both general and local. We have all seen other untreated patches disappear during the treatment of an eczematous region. I systematically submit patients suffering from arthritic eczema to treatment by auto-induction, before beginning any local treatment. The auto-induction is carried out by placing the patient between high frequency spirals as described in par. 138.

c. *Hydro-electric baths* with sinusoidal currents have proved useful in the hands of *Gautier* and *Larat,* especially in obstinate cases of prurigenous eczema. *Brocq* is more reserved in his opinion, but *Guimbail* strongly recommends them.

d. *Hot air baths* and the insufflation of hot air have also been employed in the treatment of eczema.

e. *The X-rays* have given most satisfactory results in the hands of a number of experimenters, among whom are *Hahn, Albers Schönberg, Scholtz, Williams, Freund, Schiff, Grunmach* and *Pusey*.

Notwithstanding their success, the method cannot be said to be firmly established. To those desirous of making the experiment, we recommend rays of penetration No. 5 or No. 6 on *Benoist's* scale. Dose 3H to 4H in a single seance, or in several exposures at intervals of two or three days.

477. **Urticaria.**—Electrotherapy may be employed in cases of chronic urticaria. It is difficult to decide whether urticaria is due to an affection of the nervous system or to auto-intoxication. Static electricity or high frequency may be employed. This should be applied in the manner described in the paragraph on the treatment of pruritus (478). *Gautier, Larat* and *Guimbail* have had good results from the use of the hydro-electric bath with sinusoidal currents.

478. **Pruritus.**—Essential pruritus, the neuroderma of *Brocq,* is the result of an auto-intoxication, and is dependent on a special nervous state, either local or general. It is this form which is most amenable to electrical treatment. Static electricity, high frequency, or the X-rays may be employed.

a. *Static electricity.—Leloir* and *Doumer* have treated in this way a number of cases of pruritus of the vulva, the anus, and the extremities, together with some cases of general pruritus. In localised pruritus the use of the static bath, and static effleuve, has been most encouraging. *Brocq* and *Bissérié* have also had good results with static electricity, even where the symptoms have approached those of neurodermatitis.

The treatment should be commenced by a static bath of 5 to 8 minutes' duration. Afterwards the static effleuve may be directed on the affected region by means of a point or brush electrode. The brush should be connected by preference to the negative pole and held at a distance of 20 centimetres from the skin, for a period of 5 to 10 minutes. The treatment may be occasionally increased, even up to sparking, with advantage, and will vary according to the susceptibility of the patient. The seances may be repeated every day, or every second day. The success is often rapid.

b. *High frequency.*—In pruritus there is a double reason for the employment of high frequency currents. When there is any arthritic tendency or any interference with nutrition, it will act on the general health; on the other hand, it will act locally in a more efficacious manner than static electricity.

The observations of *Oudin* leave no doubt as to the efficacy of high frequency currents in neuroderma. In order to gain the double advantage of general and local action, the patient should be subjected to treatment by auto-conduction and effleuvation at the same time. A seance of auto-induction of 15 minutes' duration may be followed by an effleuvation of 5 to 15 minutes on each region, repeated every day, or every other day.

c. *X-rays.*—X-rays, in doses of 3 H or 4 H, often produce a rapid remission of pruritus. Rays of No. 4 or No. 5 on *Benoist's* scale should be used.

479.—**Psoriasis.**—The experiments made by *Brocq* and *Bissérié* on the application of static effleuvation for psoriasis gave no results. High frequency treatment, on the contrary, is very efficacious. *Oudin* attaches the metallic brush to the extremity of the resonator, and directs it for some seconds on each patch, thus obtaining the maximum revulsive effect, the spark being spread over the surface of the scales.

The first result of an application is an evanescent phase of vaso-constriction, followed by diffuse redness, accompanied by a sensation of heat and smarting. If there is any pruritus, this disappears after the first application. The seances may be repeated every two days.

Recent patches disappear after a few seances, while those of longer duration may demand some months of treatment.

Some authors recommend the arc light for the treatment of this disease (*M. A. Cleaves*).

The X-rays, first employed by *Albers Schönberg,* have attained the first place among the curative agents employed for psoriasis.

If the psoriasis is disseminated, *Scholtz* treats it with the X-rays without using any shield to protect the healthy skin. He places the focus tube at a distance of 40 centimetres, and gives an exposure of 15 to 20 minutes. It is in his opinion advantageous to irradiate the neighbouring skin. *Ullmann* considers the *Röntgen* rays as the treatment par excellence for psoriasis. *Belot* has treated several cases, employing No. 5 rays and a dose of 4 H to 6 H in one or two seances. Shortly after the exposure, the red colour of the patch is modified and the healthy skin around the edges becomes brown. From 15 to 20 days afterwards, the scales fall off, leaving a reddish surface, slightly hyperæmic, which soon becomes pigmented. A weak ointment of ichthyol or lead may be applied, or the yellow oxide of mercury, or chrysarobin plaster (*Scholtz*).

480. **Prurigo.**—We have not had sufficient experience to determine the efficacy of electrical treatment in this disease. *Brocq* and *Bissérié* have seen good results from high frequency treatment, in a case which was almost one of *Hebra's* prurigo.

High frequency effleuvation should be used in a systematic manner. The X-rays may also prove of service. *Belot* reports a case of cure of *Hebra's* prurigo by means of a single application, with a dose of 4 H or 5 H, employing rays of penetration No. 4 to No. 5.

481. **Lupus erythematosus (Cazenove's Lupus).**—This affection, which is characterised by redness and squamæ, presents two perfectly distinct types. It is important to distinguish these for purposes of treatment. *The aberrant type* of *lupus erythematosus* is always symmetrical, and is localised on the cheeks, the dorsum of the nose and ears. It is characterised by its capricious process, disappearing and then reappearing, even during the course of treatment. *The fixed type of lupus erythematosus,* which may be localised on any point of the face, presents a great analogy to tuberculous lupus, even if it be not itself tuberculous (*Brocq*).

Electrotherapy — Radiotherapy. — All authorities are agreed that phototherapy does not give such good results in erythematous lupus, as it does in tubercular lupus (*Frochhammer, Sabouraud, Leredde* and *Pautrier*). We should take into consideration the distinction between the two forms of lupus erythematosus. The fixed form should be treated in the same manner as tubercular lupus; *i.e.,* by *Finsen* light, while the symmetrical aberrant type is best attacked by high frequency currents. This is proved by *Brocq's* statistics, given in *Jacquot's* thesis (Paris, 1901). It would seem that in the future the X-rays are destined to play an important rôle in the treatment of this affection.

The following is the line of treatment we recommend in cases of *Cazenove's* lupus.

1. In a case of fixed lupus erythematosus, the *Finsen* light should be applied. If this is not available, we should have recourse to the X-rays. The older methods of scarification and galvano-cautery have fallen into disuse. The reader should consult par. 482 for the technique, which is identical with that for tuberculous lupus.

2. In a case of symmetrical aberrant lupus erythematosus, we should have recourse to high frequency treatment. (*Brocq, Bissérié,* 1897.) For this purpose we use an electrode with a glass handle. The intensity should be regulated by the adjustment of the resonator, or by means of *Bissérié's* regulating electrode. The first application should be a very moderate one. Five days afterwards a second application may be given, the intensity being increased if the reaction has not been sufficient. It must not be forgotten that the aberrant form is centrifugal, *i.e.,* that the affected area has a tendency to heal at the centre, while spreading at the periphery. In treating it, therefore, we should always pass beyond the limits of the affected area. The seances may be repeated once, twice, or three times a week, according to the tolerance of the patient and the intensity of the reactions. When the reaction is violent, we may be compelled to wait for a couple of weeks to allow it to subside. This does not in any way interfere with the treatment. The duration of irradiation of each patch should be from one to three minutes.

The result of high frequency treatment is intense redness. This is of good augury, as it is an index of the intensity of the reaction. The affected area becomes covered by a thin crust, which soon falls off, leaving a shining and red surface. The crust reforms again and again, till finally the diseased tissue is replaced by a healthy surface. As the cure approaches, new crusts no longer appear, and there is only a desiccation of the affected area. The intensity and frequency of the seances may then be diminished. From 25 to 70 applications are required. (*Brocq, Bissérié, Jacquot.*)

482. **Tuberculous Lupus.**—The lesion of lupus consists of tubercles or small miliary nodules of the size of a pin's head. These may be agglomerated together or dis-

seminated, sometimes ulcerating, and sometimes forming cicatricial aspects of the disease. The tubercles do not usually project much above the surface of the skin. They may be easily seen on pressing down the surface with a glass spatula, and may then be recognised by their colour, which is that of barley-sugar. When it is considered how deeply the tubercles penetrate into the subdermic tissue, it may easily be understood how difficult it was to treat lupus before the discovery of radiotherapy. Ablation, curetting and caustics often leave behind cicatrices as disfiguring as the original lesion. Surgical interference, moreover, does not guard against complications or recurrences. At the present time we seldom have recourse to these methods of treatment.

Electro-therapeutics and radio-therapeutics.—Galvano-cauterisation is rarely required. By plunging the point of a galvano-cautery into the diseased tissue we may give rise to violent reaction, and produce cicatrisation, but it does not act equally on all the diseased tissues, a reproach which may also be brought against the treatment by scarification. It is, moreover, painful and tedious. At the present day we have at our disposal two modes of treatment, *viz.,* the Finsen light and the X-rays, each of which is vastly superior to cauterisation.

We may, therefore, proceed at once to treat a case of lupus by one or other of these means. The only other modes of treatment at all comparable are scarification and galvano-cautery. Ablation should be reserved for those cases where the lesions are small, in an early stage of evolution, and situated in regions where the cicatrix will not cause disfigurement.

a. *Phototherapy.*—This may be applied by means of *Finsen's* apparatus, or any of the more modern lamps. We can especially recommend *Marie's* installation (231) on account of the ease with which it is applied, and the firm pressure which it enables us to exercise during the whole period of exposure. *Lortet* and *Genoud's* apparatus has also given excellent results in the hands of many experimenters, among them *Leredde* and *Pautrier*. (230.)

The incandescent lamp is not particularly adapted for phototherapy, as the violet and ultra-violet rays are the most potent for therapeutic purposes. It would be interesting to try the mercury vapour lamp of *Cooper-Hewitt*, which gives only violet and ultra-violet rays. The negative effleuve from a static machine is also a source of radiation which should prove useful in phototherapy.

With *Marie's* or *Lortet* and *Genoud's* lamp, the duration of the seances should be from 20 or 30 minutes up to an hour. With the *Finsen* light it must be at least an hour. Phenomena of reaction set in from 12 to 48 hours after exposure. These consist of redness, swelling, œdema, with serous discharge and the formation of crusts. This reaction, which lasts about 8 days, is necessary and is of good augury. The length of the interval before the appearance of reaction is in general proportional to the length of the exposure.

Phototherapy acts by setting up a sclerogenous process in the skin. This fibro-sclerous tissue is developed with great regularity and uniformity, and not in isolated foci, as after scarification or galvano-cautery.

An exposure may be given once a week on each patch of lupus.

The skin should be carefully treated during the period of reaction. For the first few days we may apply an ointment consisting of

Lanoline	10 grammes
Vaseline	5 grammes
Liquor calcis	10 grammes

When there is a discharge, we must be on our guard against infection, erysipelas, etc. The skin should be washed with boiled water or a three per cent solution of borax. When the crusts have fallen off we may diminish congestion and prevent the formation of new crusts by applying an ointment composed of:

Oxide of Zinc	aa 10 grammes
Starch	
Lanoline	
Vaseline	

These crusts should be removed before each seance. This should be done by moist applications or by washing with soft soap. Any previous treatment by scraping or otherwise interferes with the successful result, probably by the formation of trails of cicatricial tissue.

b. *Röntgen-therapy.*—Since the early observations of *Kümmen, Schiff* and *Freund,* a large number of successful results have been published. The technique of the procedure is not as yet established with any certainty. It is only of late that we have been able to measure the dose of this new therapeutic agency, even approximately, by means of *Benoist's* radiochromometer and *Holzknecht's* chromoradiometer. Moreover, the skin affected with lupus does not always react in the same manner, and we have not as yet sufficient data to enable us to choose between the various modes of treatment recommended.

Schiff, A. Schönberg, Hahn, Kümmel, Williams, Oudin and others sedulously avoid all dermatitis, giving short exposures two or three times a week. Other observers give exposures at longer intervals and endeavour to set up the first degree of radio-dermatitis. According to *Belot,* a dose of 4 H or 5 H of No. 5 rays will produce erythema and swelling of the lupoid tissue, while 8 H or 9 H will produce superficial ulceration. Other practitioners do not hesitate to set up intense radiodermatitis so as to produce superficial necrosis (*Lion, Scholtz*).

The following is the technique employed by *Oudin:* He uses a moderately hard focus tube, with an equivalent spark-gap of about 10 centimetres. The healthy skin is shielded by a lead mask which should be earthed. The anticathode is placed at a distance of 20 centimetres from the skin. The current in the primary is 4 amperes and 16 volts, with 15 interruptions per second. He gives an exposure every day, beginning with one minute and increasing the duration by half a minute every day. Now and again he allows a week's interval, in order to judge the effects, and guard against radiodermatitis.

My own conclusions are as follows: In cases where phototherapy has not been successful, or where it is not available, Röntgen-therapy should be employed. This has some drawbacks, such as the danger of radio-dermatitis, but it has also great advantages in the wider area of its action, its painlessness, the greater facility of its application, and the absence of any necessity for compression.

In the opinion of *Lancashire,* we should have recourse to radiotherapy in all cases of extensive lupus, or of lupus affecting the mucous membrane.

As regards the mode of operation, I would recommend the use of rays of No. 5 or No. 6 on *Benoist's* scale, with exposures repeated two or three times a week, avoiding any reaction greater than a superficial erythema.

For all treatment of skin disease, except epilation, I believe this to be a better mode of treatment than more intense exposures at longer intervals. In studying the injurious effects of the X-rays, we are met by the fact that frequently repeated exposures with small doses produce a far more profound modification of the cell tissue than does a temporary dermatitis followed by cicatrisation. Moreover, as long as the dosage of the X-rays is in so unsatisfactory a state, we should proceed with the greatest caution.

Radium-therapy.—The thesis of *Blandamour,* published in Paris in 1902, contains some interesting information on this subject, obtained in the wards under *Danlos.* He used specimens of radium of which the radio-activity was from 5,000 to 19,000 times that of uranium. The total duration of exposure varied from 24 to 48 hours. We have not as yet had sufficient experience of this therapeutic agent to be able to give precise rules for its application.

483.—**Acne.**—Under the term acne we group all the various lesions of the pilo-sebaceous system. This includes acne acuminata with comedones, acne rosacea, and hypertrophic acne, which is the ultimate form or acne rosacea. In all forms of acne, and particularly in the acne simplex of puberty, the X-rays give remarkably good results. This is testified by *Gautier* in 1897, by *Ullmann, Schiff* and *Freund, Scholtz, Pusey* and others. The X-rays act as an irritant, or more probably by producing atrophy of the sebaceous glands.

484. **Acne Rosacea.**—This disease presents different aspects. In some instances there is merely dilatation of the capillary vessels and telangiectases. In other cases the inflammatory and seborrhœic symptoms are more noticeable, while in hypertrophic acne the inflammatory symptoms have gone on to the production of a true hypertrophy of the skin. (485.)

Electrolysis.—When there are numerous dilated prominent vessels or telangiectases, the case is best treated by electrolysis. The technique is described by *Brocq.* An electrolytic needle connected to the negative pole of a galvanic battery is introduced into the skin parallel to the vessel. The bipolar method with a current of 1 to 5 milliamperes may also be used, as described for nævi in par. 487. In this way we are able to cure the worst cases of telangiectases in a few sittings. *Vasticar* advocates a particular method of electrolysis combined with scarification, the blades of the scarificator being connected to the negative pole[1].

X-rays.—Radiotherapy appears destined to render valuable services in the treatment of acne rosacea. In this, as for all radiotherapeutic treatment[2], the focus tube should be enclosed in a lead lined box. The orifice of the localiser should be large enough for the cone of rays to include the whole of the affected area when placed at a distance of 30 centimetres from the anticathode. The sound skin should be protected by thin sheets of lead, in which an aperture is made corresponding to the lesion. The anticathode should be placed 30 centimetres from the skin. An exposure of 5 or 6 minutes may be given every day or every other day, with rays of penetration No. 5 on *Benoist's* scale. After the sixth seance "the skin desquamates slightly, the acne rosacea becomes paler, and the vessels become less visible. White streaks appear in the affected area and the tissues become gradually paler." (*Larat* and *Gautier.*)

High-frequency.—This may be applied in the same way as for lupus erythematosus. It often gives most excellent results. (*Oudin.*) *Guilloz* has also successfully employed the aigrette with small sparks. Static electricity does not appear to be so efficacious.

Phototherapy.—*Finsen* applied this method for the cure of acne rosacea; it has also given excellent results in the hands of *Leredde.* He considers it to be the treatment par excellence for chronic cases, and has had no instance of failure in a series of nine cases which he has treated. The same technique may be employed as in cases of lupus.

485. **Hypertrophic Acne — Rhinophyma.** — Hyper-

[1] Vasticar. International congress of Electrology pue Radiology, Paris, 1900, p. 672.

[2] Belot. Radiotheraoy in skin diseases. Description of his localiser. (*Rebman,* 1005.)

trophic acne is frequently the ultimate phase of acne rosacea. Its usual seat is the nose, which presents characteristic bosses with small crater-like depressions in the centre, shewing the position of the sebaceous follicles.

If hypertrophic acne is accompanied by telangiectases, they may be treated by electrolysis. If they are accompanied by comedones, we may use the same treatment as for acne punctata.

The most difficult point is the glandular and fibrous hypertrophy. Glandular hypertrophy may be treated by electrolysis, after the technique employed for comedones and acne punctata. (486.) The intensity is regulated by the volume of the gland. The hyperplasia of the fibrous tissue may be treated by galvano-cauterisation or by electrolysis. A negative needle should be used, with a current of 5 to 6 milliamperes, for 8 to 15 seconds.

486. **Acne punctata—Comedones.**—This is seen chiefly on the alæ of the nose, the forehead and the temples. It consists of a number of black points, formed by sebaceous secretion of the glands.

Electric treatment may be necessary in severe cases which do not yield to the ordinary treatment of removal of the comedones by pressure.

The point of the electrolytic needle is introduced into the glandular orifice, where the comedo is situated, and a current of 2 to 3 milliamperes is passed for a few seconds. The comedo is thus evacuated, and the gland undergoes fibro-cicatricial transformation.

The X-rays have also been employed with success in this affection.

487. **Non-vascular Naevi.**—Vascular nævi have been studied in a previous chapter (par. 428). We shall treat here only of non-vascular nævi, which may be smooth, hypertrophic, or covered with hair.

The *hairy nævus* may be treated by electrolysis as described under hypertrichosis. When the hairs have been destroyed, the base speedily disappears, and the nævus is flattened. A slight degree of pigmentation remains.

Hypertrophic nævus may also be treated by electrolysis by passing a negative electrolytic needle through its base. A current of 2 to 3 milliamperes is then passed until the needle becomes loose. Two or three repetitions are sufficient for small nævi. In large nævi a series of parallel punctures is made 5 mm. apart, followed by a second series at right angles to the first. A lotion of camphorated spirit should be applied after each application. *Brocq,* whose mode of procedure is here described, leaves the wound exposed to the air, and has never had any accidental complication.

The nævus is temporarily increased in size, but speedily shrinks up completely. *Brocq* considers galvano-cauterisation to be the best means of treatment. For nævi of considerable size he advises removal by surgical means.

Smooth pigmentary nævi are not much benefited by treatment, electrolysis having but little effect on pigmentation.

488. **Sycosis.**—The best treatment of this affection is high frequency effleuves and sparking. We have, however, at present no adequate statistics on the subject. In two cases of obstinate sycosis of the upper lip, *Leredde* and *Pautrier* obtained good results by phototherapy. *Freund* and *Schiff* have had equally good results with the X-rays[1]. When there are purulent pockets with deep infiltration, radiotherapy is useless and even dangerous, on account of the facility with which radio-dermatitis occurs in diseased tissues. Rays of penetration No. 5 should be employed, with doses of 3 H to 5 H, according to the region affected[2].

[1] Freund and Schiff. Semaine Médicale, June 7, 1899.

[2] Belot. Radiotherapy in Skin Diseases. (*Rebman,* 1905.)

Brocq recommends galvano-cauterisation. The small pustules should be opened as they make their appearance, using a fine galvano-cautery point for the purpose.

489. **Cicatricial Tissue — Keloid.** — There are three ways of treating keloid—electrolysis (*Hardaway* and *Brocq*), sparks from a static machine and X-rays. The latter are especially indicated on account of their resolvent action on cicatricial tissue.

Derville gives the preference to static sparks, while many authors agree with *Hardaway* and *Brocq* in recommending electrolysis.

Electrolysis.—The following is *Brocq's* technique for the electrolysis of keloid. After estimating the thickness of the tumour, a bead of sealing-wax is placed on the needle, so as to prevent it penetrating beyond the proper depth. An indifferent anode is placed on any part of the body, and the needle, connected to the negative pole, is plunged into the tumour. The current is then turned on, being gradually increased to 6 milliamperes and kept at this point for 8 to 15 seconds. "A few moments after the current begins to pass, the needle becomes surrounded by a tiny white area. A disintegration of the tissues ensues, and white or yellowish rays seem to radiate from the needle. When these rays have grown to a length of 4 mm. or 5 mm. the needle will be felt to move freely in the tissue. At this stage the current should be stopped. A fresh puncture may then be made at such a distance from the first that the bleached area around each will touch. The whole surface of the keloid is treated in the same manner, so as to completely cover it with the white spots. It is then covered by a plaster of chrysophanic acid, or one of the many plasters which have been found useful in the treatment of keloid[1].

[1] Brocq. Traitement des dermatoses, p. 203.

Brocq objects to the use of multiple needles in the same handle, since it is difficult to act with precision.

The seance may be repeated every week, with a continuance of the treatment until there is a regression of the lesion.

The result is not so much a disappearance of the keloid, as an arrest of its development, followed by retraction.

When the electrolytic action is exhausted, *Brocq* recommends the completion of the treatment by means of linear scarification, together with mercurial and chrysophanic plasters.

Radiotherapy.—The first successful case was reported by *Herschell Harris*[1]. Later on cases were reported by *Barney, Fordyce, Fox, Varney, Williams, Taylor, Bissérié* and *Belot*. *Belot* obtained a complete cure with six exposures of 7 H, during a period of 5 months.

One may either give massive doses of 5 H to 7 H every fortnight or three weeks, or give a short seance every two or three days, with a total dose of 10 H in the course of a month.

The treatment of sclerous and cicatricial tissue is the same as that for keloid. *Leduc* of Nantes pointed out the action of the continuous current in the reduction of cicatrices of the skin and subcutaneous tissue. In this manner he was able to cure disfiguring cicatrices which had resisted every other mode of treatment. The indifferent anode is placed on the back and a cathode of appropriate form is applied to the cicatrix. A current of 15 to 25 milliamperes is passed for 15 minutes, and this may be repeated every two or three days. According to *Leduc*, there is an advantage in moistening the electrode with a solution of salt, probably on account of the Na ion being carried into the skin.

490. **Xanthoma.**—This affection consists of yellowish

[1] Williams. The Röntgen Ray in Medicine and Surgery.

patches, flat or slightly raised, which occur on different parts of the body. Xanthelasma of the eyelids is a variety of this disorder. This may be treated with negative electrolysis in the same way as keloid. *Bordier* has obtained successful results, without any recurrence. (Par. 547.)

491. **Ephelides.**—These are greyish or brown spots of abnormal pigmentation due to the action of sun-light. The rational treatment would be to keep the patient in darkness. While this might be possible in a severe disease, such as variola, it is not so for slight disfigurement caused by freckles, which improve and frequently disappear during the winter.

We are, however, not entirely without resource in the treatment of this affection. Pigmentation is produced by exposure to light. In all animals, it is the dorsal surface, that which is more exposed to the light, which is the deeper in colour. In general we must regard pigmentation then as a means of defence of the organism against the luminous rays, and more especially the chemical rays of the spectrum. This is easily understood, for the rays are absorbed by pigment, while the white skin allows them to penetrate more deeply. For example, a child who is once burnt by the sun at the seaside is very rarely affected again, as the pigmentation produced by the first attack protects the skin. A slight wash of Indian ink will entirely protect the skin from the action of the sun's rays, the spot under the paint remaining white, while the surrounding region becomes erythematous and pigmented.

Starting from the idea that the luminous radiations of long wave length act in a manner opposed to that of the shorter waves, I have exposed freckled and pigmented patients to the action of the red rays.

It is well known that the fogging of a photographic plate may be prevented or in some cases removed by exposure to a red light.

Bar has also noted that radiodermatitis is ameliorated by phototherapy with red light.

Although the procedure is not without effect, it does not prove very efficacious. We may advise patients liable to freckle to sift out the higher frequencies of solar radiation as much as possible by the use of red parasols, veils and hats, and to shield the skin when exposed to the sun by one of the many mechanical applications which absorb the chemical rays.

With regard to electro-therapeutic intervention, we may remember that vaso-dilatation is also a mode of protection of the skin against the actinic rays. The rôle of vaso-dilatation in the formation of ephelides is not well understood. High frequency may perhaps prove of use in this affection.

492. **Scleroderma.**—This is an affection of trophoneurotic origin, characterised by an induration of the skin, followed by atrophy of some of its elements. It may be general or partial, as in the various forms of morphœa, scleroderma in patches or bands, sclerodactylia. When generalised and progressive it is a very serious malady, and treatment has but little effect.

The electrical resistance is found to be increased over the areas affected, more especially where the local temperature is lowest.

Either the galvanic current or franklinisation may be used in the treatment of scleroderma. Both methods have been followed with success after other modes of treatment had failed.

Continuous current.—*Erb* recommends galvanisation of the spine and the sympathetic ganglion in the neck, after which he uses a negative electric roller over the affected regions. *Hallopeau* has used the same method with success.

In circumscribed sclerosis, *Brocq* makes use of galvanisation in the same manner as used in the treatment of keloid.

He uses a patinum-iridium needle, with a stop of sealing wax fixed at an appropriate distance from the point. This is connected to the negative pole and plunged into the scleroid tissue. Care should be taken not to overpass the boundaries of the scleroid tissue, or persistent induration may be set up. If the disease is superficial, the needle may be introduced parallel with the skin.

The indifferent anode may be placed on any part of the body. The intensity may vary from .5 to 10 milliamperes, according to the tolerance of the patient. When a white froth forms around the needle, accompanied by a brownish halo, the current should be interrupted. The punctures should be close enough for the white circles to touch without intersecting. The usual distance is 8 or 12 millimetres.

After the seance, we may use a lotion of camphorated spirit with 1 in 500 sublimate solution, after which *Vidal's* red plaster, or *Vigo's* plaster may be used, changing it every 24 hours. (*Brocq,* Traité des dermatoses.) The seances may be repeated every week. The progress of the disease is usually arrested after the second or third seance.

It is difficult to choose between the methods of procedure,—that of *Erb* and *Hallopeau,* which consists of galvanisation of the spine and of the diseased skin, and that of *Brocq,* which consists of electrolysis of the sclerosed patches.

In generalised scleroderma, *Erb's* method is undoubtedly the best.

In localised scleroderma, we should begin by *Erb's* method, reserving galvano-puncture for a later stage. *Brocq* points out that electrolysis has more than a local action. Patches adjacent to those under treatment frequently disappear in consequence of the action of the galvanic current. It is, moreover, a general principle to commence treatment by the more simple methods, and those which are more exempt from risk.

Static electricity.—In some cases the static effleuve gives remarkable results. *Boisseau du Rocher* reports a case, and I myself know of another, which has been radically cured by static electricity. On the other hand, I have met with a case where the method failed, probably in consequence of want of power in the static machine employed.

X-rays.—The X-rays have also been employed with success in a case of scleroderma in patches. No. 5 rays were employed, in doses of 5 H to 8 H, every three weeks.

493. **Warts.**—*Bissérié* has obtained excellent results from high frequency currents in a case of flat confluent warts of the face. The best results, however, are obtained by galvano-puncture and electrolysis.

The indifferent anode may be placed anywhere on the body. A steel or platinum needle connected to the negative pole is introduced into the wart, and a current of 4 milliamperes is passed. After a few seconds, the wart blanches, and in one to three minutes it becomes swollen like a blister. The current may then be interrupted. After each application the wound should be washed with camphorated spirit.

The wart becomes brown and then black, and falls off from the 8th to the 12th day, without leaving any scar.

More recently the X-rays have been employed in the treatment of warts and cutaneous horns. (*Sjöngren* and *Sederholm*, *Scholtz*, *Vernay* and *Belot*[1].)

Belot reports cases of flattened warts of the face cured by a single exposure of 4 H, and a cutaneous horn of the nose, which disappeared after two exposures with No. 6 rays, the first of 10 H, and the second a fortnight later, of 3 H. He also relates cures of multiple warts in the hands

[1] Belot. Radiotherapy in skin diseases. (*Rebman*, 1905.)

of children disappearing after three seances of 8 H, 7 H and 4 H, respectively, with an interval of 12 to 15 days between the seances.

494. **Epithelioma (Cancroid, epitheleal or cutaneous cancer; primitive or rodent cancer.)**.—Since the introduction of X-rays, they have almost entirely replaced galvano-puncture in the treatment of epithelioma, although, according to *Bordier*, the latter method gives excellent results. The needle is thrust into the tumour parallel to its greatest diameter, so as to reach the healthy tissue on each side. A current of 15 milliamperes is passed for 5 to 6 minutes and the process is repeated, the needle being kept parallel to the first insertion or at an angle of 18° to it.

A voluminous slough is formed, which gradually hardens and in the course of some weeks becomes detached.

At the present time, however, cutaneous epithelioma is always treated by the X-rays. The technique is described in the article on Cancer in paragraph 559.

495. **Mycosis Fungoides.**—This is a disease of neoplastic origin, with some resemblance to sarcoma.

Mycosis fungoides usually commences by patches of redness, which retain their colour under pressure. It is accompanied by violent itching, and may take on a lichenoid appearance. This is the erythematous stage. Later on the lichenoid patches become warty, forming small tumours, accompanied by redness. The case terminates in cachexia and death, all medication being quite useless.

Since the introduction of radiotherapy there has been an enormous advance in the treatment of this disease. *Scholtz, Hyde, Marsh, Jamieson, A. E. Carrier* and *Morelle* have published successful cases. *Belot* and *Civatte*[1] treated two cases of mycosis fungoides in *Dr. Brocq's* clinique. Their results prove that the treatment is able, at all events, to

[1] Belot. Radiotherapy in skin diseases.

ameliorate the condition of the patient, and that we may reasonably hope for a definite cure of the disease.

The following is the mode of procedure followed by *Belot* and *Civatte*. Rays of penetration No. 4 or 5 were used and each tumour was irradiated with a dose of 10 H, in two exposures, with an interval of 24 hours. The pruritus was alleviated all at once, and from the 10th to the 20th day the tumour began to diminish in size. A second dose was then given. Ultimately the tumours entirely disappeared, the result being identical for each group of tumours.

The technique to be employed will be more fully discussed under the article Sarcoma. *Scholtz* did not obtain such good results, although he set up a superficial necrosis of the tumours. Comparison of methods will be rendered possible when the means of measurement for X-rays shall enable us to compare the reports of different authors.

496. **Hypertrichosis—Epilation.**—Although not in itself a disease, hypertrichosis is of great interest to the medical electrician. It may be a cause of great disfigurement, but more important is its effect on the nervous system of the patient, being a subject of perpetual preoccupation, and often resulting in melancholia and exclusion from society.

The question of intervention is a difficult one to decide. We have to take into consideration both the degree of deformity and the mental and nervous condition of the patient.

The following considerations are the rules which should guide us in the treatment of hypertrichosis; they are derived in great measure from the manual of *Dr. Brocq*.

Indications for Intervention.—We should generally consent to the request for intervention when the hypertrichosis occurs in the case of a girl or a young woman, whereas the same conditions would not warrant our interference in older women. After the age of 45 we should operate only in cases of very great deformity. In the male, intervention is hardly ever permissible.

In the case of a girl or young woman, where it is of importance to suppress commencing hypertrichosis, or prevent its further development, we may proceed as follows:

1. If the disfigurement consists only of a growth of down which has no tendency to turn into hairs, the physician should refuse to interfere. When these cause disfigurement in consequence of their number or dark colour, we may prescribe drying powders, such as starch and salicylic acid, which to a certain extent hinder the growth of down. Or we may use peroxide of hydrogen to bleach the hairs.

Depilatories and caustics of all sorts should be absolutely forbidden. Electrolysis is out of the question for so insignificant a trouble, and an increased growth of hairs in the neighbourhood often follows treatment of a region covered with down. When the growth consists of strong hairs, treatment by means of the X-rays is indicated, but the larger hairs are more difficult to destroy.

Moreover, the technique is not as yet well established, so as to guard against any accidental complications, which may be worse than the original deformity.

2. When the growth of down has a tendency to become coarser and to form hairs on the face, chest, or the breasts, we should no longer hesitate. No time should be lost, as the hairs will certainly grow stronger and the treatment of hair is much more difficult than that of down. The most certain method is that of electrolysis. The patient should, however, be warned that the treatment is very tedious, since all the down must be resolutely attacked, and electrolysis frequently acts as a stimulant to the growth of hair on neighbouring parts, so that after the first few seances an increased growth of hair may be observed around the area under treatment.

3. When the patient exhibits a strong hairy growth we must be guided by the number of hairs and the degree of deformity. If the disfigurement is not great, we should decline to intervene. If the hairs are sparsely scattered we may employ electrolysis, but if they are more thickly set, we should have recourse to the X-rays.

In women over 45 we should, if possible, avoid intervention. In the case of male patients we should refuse to interfere unless there is some affection of the skin demanding epilation, or in exceptional cases of growth of hair on the dorsum of the nose or between the eyebrows. We should not accede to the request sometimes made to us to destroy hairs growing too low on the forehead, or on the cheek bones, the neck or ears.

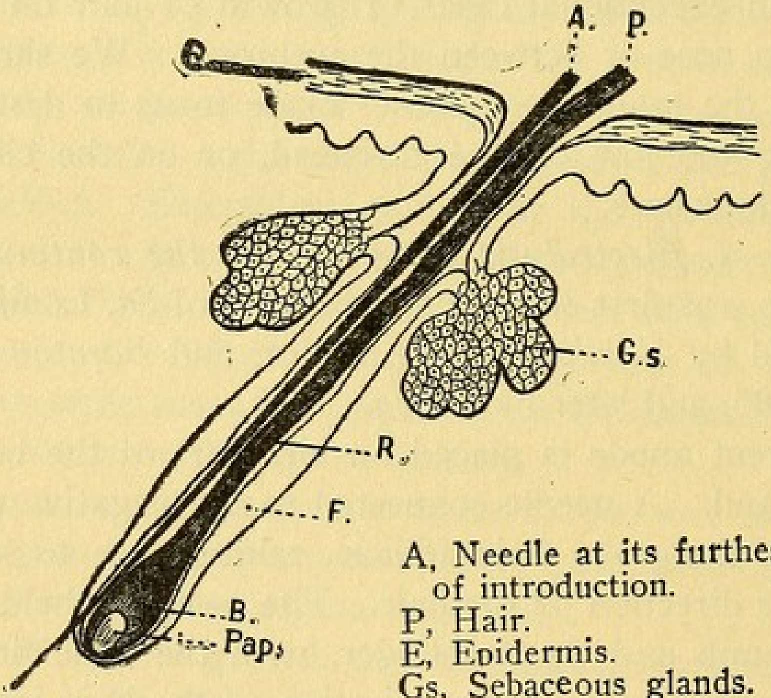
Technique.—1. *Electrolysis by means of the continuous current.* This was first employed by *Michel* of St. Louis, in 1875, followed by *Hardaway* in America, and *Baratoux* in France, in 1886, and later by *Brocq.*

An indifferent anode is placed on any part of the body, usually the hand. A needle connected to the negative pole is introduced along the hair follicle, taking care to keep parallel to the direction of the hair. The needle is held between the thumb and the forefinger, with the little finger resting on the skin. The catheterisation of the hair follicle is easy, the needle being passed onwards until resistance is met with, when the current is turned on.

All the necessary apparatus should be close to the patient; a small portable table mounted on wheels is most convenient. The choice of the needle is most important. *Brocq* recommends one made of gold or platino-iridium, 20 millimetres long, fixed in a cylindrical handle. *Brocq's* needle is curved to an angle of 45°, the bend being 6 millimetres from the point. The curve facilitates the introduction of the needle and the bend serves as a point to indicate the depth to which the needle has penetrated.

The point of the needle should be blunt, so as to obviate the danger of making a false passage during the catheterisation of the pilary canal.

As soon as we encounter the resistance which shews that the point of the needle has reached the end of the infundibulum, the current is turned on, and the point of the needle is gently moved so as to bring it in contact with the papilla and pass beyond it for a distance of one millimetre. (Fig. 79.)



A, Needle at its furthest point of introduction.
P, Hair.
E, Epidermis.
Gs, Sebaceous glands.
R, Root of hair.
F, Hair follicle.
B, Hair bulb.
Pap, Papilla.

Fig. 79.

By proceeding in this manner, and keeping parallel to the hair, the needle passes along in the direction of the hair without resistance, and if a false passage is made, one feels it instantly. On the contrary, when the current is turned on before the introduction of the needle, it is easy to penetrate the dermis and make a false passage without feeling any sense of resistance.

It is difficult to determine exactly the length of time the current should be turned on, in order to complete the destruction of the hair papilla.

We know when the papilla is destroyed, by the hair yielding to slight traction. Occasionally, however, the hair does not come out easily until some ten minutes after the electrolysis, and yet the current has been of sufficient duration and intensity to completely destroy the papilla. The guiding sign is the appearance of froth and of a very characteristic brown halo round the orifice of the hair follicle. On the appearance of froth, the current should be allowed to pass for a few seconds longer and then stopped.

The following are *Brocq's* values for the duration and intensity of the current:

For fine down, 1 milliampere for 5 to 10 seconds.

For a hair of moderate size, 2 to 3 milliamperes for 5 to 10 seconds.

For a coarse hair, 4 to 5 milliamperes for 10 to 20 seconds.

After the operation, each puncture is followed by the appearance of a small, clear vesicle, and the skin becomes somewhat tumefied. *Brocq* recommends that this should be touched with camphorated spirit night and morning till cicatrisation is complete. Small crusts are formed, which soon fall off, leaving reddish spots which gradually disappear.

With nervous patients, the question of rendering the skin insensible may arise. For this purpose we may have resource to freezing with chloride of ethyl, to the injection of cocaine, or to the direct application of high frequency currents. The following is the order of sensibility of different regions under epilation. The centre of the upper lip, the edges of the eyelids, the lower lip, the neck, the lateral part of the upper lip and the nipples. The susceptibility varies in different individuals.

Accidental complications sometimes occur. On the needle being withdrawn, a drop of blood may appear, or there may be small subdermic hæmorrhages.

If the currents have been too prolonged and intense, some inflammation may ensue. In this case a starch poultice should be applied.

The most disagreeable contretemps is the formation of a cicatrix, in the form of a white point or depression, or even a slight ulceration. A faulty technique may cause severe cicatrisation or even the formation of cheloid.

Scarring may be avoided by not operating on a number of hairs in close proximity at one sitting, and by reducing as far as possible the intensity and the time of treatment for each hair. In a seance of 20 to 25 minutes, we should not operate on more than 30 to 40 coarse hairs, 35 to 60 of medium strength, or 50 to 100 fine downy hairs. (*Brocq.*) A seance may be given every other day, every day or even twice a day, but we should never operate on two neighbouring hairs at a less interval than forty-eight hours.

Of the hairs treated, we may estimate that 10 to 20 per cent will grow again, and on the chin this may occur as many as four or five times. The patient should be seen at intervals of two months, for some time after the termination of the treatment by electrolysis.

We may better appreciate how serious a task it is to attack a case of hypertrichosis, when we consider that there are from 1,000 to 9,000 hairs on the chin, and about 1,000 on the upper lip. We may well understand that both patient and surgeon have need of patience and courage. It is well to warn the patient of what she has to expect, the length of the treatment, the pain of the operation and the partial regrowth of the hair. It is also well to remember that there will not be any great change in the aspect of the face till after the epilation is nearly completed.

2. *The X-rays.*—At its first inception, radiotherapy was regarded with enthusiasm as a new method of epilation, *Schiff* and *Freund* were the first to use the X-rays as a depilating agent, and still consider it to be the treatment par excellence for hypertrichosis. *Freund* employs hard tubes, with frequent short seances. The hair is usually shed at the 20th to the 25th exposure. From six to eight weeks afterwards, the hairs begin to grow again. One or two supplementary exposures must then be made at intervals of a month, and this should be continued for 12 to 18 months. It is important not to set up any reaction of the skin, other than epilation. Other authors have followed the method of *Schiff* and *Freund* with good results. Occasionally complications, other than dematitis, are met with, atrophy of the skin, telangiectasis and pigmentation. The treatment is, therefore, not without danger and should be reserved for cases in which the disfigurement is considerable.

Atrophy of the hair papilla is apt to be followed by atrophy of the skin. To produce the one without the other is a question of accurate dosage, all the more difficult since each age, each region, and each variety of skin requires a different dose. It should be remembered also that the fine down is shed more easily than the coarser hairs, and that a small dose may stimulate the growth. This peculiarity may be of service to us in the treatment of alopecia, but it is a great drawback in the treatment of hypertrichosis.

The following is the technique formulated by *Belot* whilst working in *Dr. Brocq's* laboratory.

He employs several series of seances at intervals of two months.

1st Series.—Quality, No. 5 on *Benoist's* scale. Quantity, 3 H to 4 H in one or more seances. Distance of the focus tube, 15 cm. In treating convex surfaces, the tube should be placed further off so as to equalise the irradiation and to diminish the obliquity of the rays at the periphery.

2d Series.—After an interval of 30 or 40 days, the hairs begin to grow again. A new series of irradiations should be given, with a total dose of 3 H or 4 H, and rays of the same penetration. As an after-cure, an exposure of 2 H should be given every 2 months, and this should be continued for a period of two years, when in favourable cases a complete cure results.

497. **Tinea due to Cryptogamic growth.—Diseases in which total epilation is required.**—The employment of the X-rays has produced an enormous improvement in the treatment of these diseases. Hitherto the treatment of ringworm and the like has been most unsatisfactory, since the parasitic growth extends to the affected hairs and is, therefore, inaccessible to the action of external agents. With mechanical epilation, the hair breaks at its weakest part, and the development of the cryptogamic growth continues.

The technique of the radiotherapeutic treatment of tinea has been gradually evolved, thanks to *Freund* in 1896, *Schiff* in 1900, *Oudin* and *Barthelemy, Gaston, Vieira* and *Nicoulau, Brocq, Bissérié, Belot* and *Sabouraud.*

Each patch of tinea, including a narrow margin of sound skin, should be framed in a **lead shield,** to protect the adjacent parts from the action of the rays.

The focus-tube should be placed at a distance of 15 cm. from the scalp.

The X-rays used should correspond to No. 4 or No. 5 on *Benoist's* scale.

The dose given should be from 4 H for a child to 6 H for an adult.

The following is the course of the phenomena which ensue: About the 7th day a slight erythema makes its appearance over the whole of the irradiated region, and the hairs fall out spontaneously on the 15th day. Their depilation may be hastened by daily friction with soap, or with a solution of tincture of iodine in 5 times its volume of spirits of wine.

When the hair begins to grow again, the new hair pushes its way through a healthy tissue. This is due to the fact that the epithelial cells of the old hair sheath take no part in the formation of the new epithelial bud which grows into the new papilla. The tinea is completely cured as soon as the new growth has taken place, which occurs in 10 to 12 weeks after the operation.

A certain amount of staphylococcic folliculitis may occur during the course of treatment. This is supposed to be due to the obliquity of the X-rays which fall on the convexity of the scalp. It may in great measure be prevented by a daily treatment with the following liniment as prescribed by Sabouraud:

Sulphur Precip.	15 grammes
Alcohol, 90%	15 grammes
Aq. Distil. ad.	100 grammes

498. **Favus.**—Favus is amenable to radiotherapeutic treatment in the same way as ringworm. Although the hairs in this disease are not so brittle, mechanical epilation is far from satisfactory. The walls of the hair follicle are invaded by the achorion, which is the cause of the disease. It is better, therefore, to inhibit the growth of the papilla for a time.

The technique for the treatment of favus is the same as for that of tinea tonsurans.

499. **Alopecia—"Pelade."** *High Frequency Treatment.*—The true nature of this affection is not as yet well established. *Bordier* was the first to demonstrate the admirable effects of high frequency on this disease.

Bordier treats each patch as follows: *Oudin's* electrode with glass handle is connected to the extremity of the resonator, and the electrode is passed over the surface of the affected scalp for 4 or 5 minutes, with the result that an intense vaso-motor reaction is produced. After the seance, there is some rubefaction, and a slight crust forms during the following days. After an interval to allow the crust to separate a second seance is given, and this may be repeated for a month or six weeks.

The regrowth of hair is white at first, but soon becomes darker.[1]

X-rays.—It is well known that the X-rays in strong doses act as a depilating agent. In small doses, however, they seem to act in a contrary manner, by exciting the physiological function of the papilla. Hence they may be used in the treatment of "pelade" and other alopecias.

They were used in this way by *Kienböck* in 1900, and subsequently by *Holzknecht.*

Belot recommends the use of rays corresponding to No. 4 or No. 5 on *Benoist's* scale, with a dose of 3 H or 4 H, and an interval of a fortnight between the seances. The dose must be varied according to circumstances, and should not produce any reaction above the first degree.

According to *Holzknecht's* observations, in cases of alopecia, the diseased papilla is stimulated by the X-rays more easily than the normal papilla.

It is difficult to procure sufficient data for a correct estimation of the value of X-rays in this disease, since, as is well known, many cases of alopecia areata get well without treatment.

Phototherapy has also been recommended by certain authors in the treatment of this disease.

500. **Chilblains.**—Chilblains are rapidly improved by the static effleuve. (*Theille, Doumer* and others.)

[1] Archives d'Electricité Médicale, April 15, 1901.

I have also obtained good results with the high frequency effleuve, while *Tripier* extols the faradic current in the treatment of chilblains.

501. **Wrinkles.**—The faradic roller, connected to a fine wire coil, may be used for the removal of wrinkles.

It acts by exciting the vitality of the elements in the integument, and may thus prevent or even remove lines and wrinkles on the face. According to *Larat,* the treatment may be continued indefinitely, and as one of the ordinary procedures of the toilet, while vibratory massage may be employed at the same time.

502. **Hyperhydrosis.**—According to *Pusey,* axillary hyperhydrosis is ameliorated by radiotherapy, probably in consequence of the atrophy of the glands, caused by the action of the X-rays. The dose varies with the affected region.

In the treatment of the axillary region, *Belot* recommends a dose of 4 H with rays of penetration No. 5.

CHAPTER VIII.

DISEASES DUE TO DEFECTS OF NUTRITION.

503. **The rôle of electricity in the treatment of the diathesis due to diminished nutrition.**—*Bouchard* thus defines the diathesis which shews itself at a certain period of life:

"Cell life consists of the unstability and mobility of the cell contents. There is a constant penetration of new matter, and a constant expulsion of the same, assimilating metamorphosis, and dissimilating transformation.

"The cell is a vortex, whose velocity of rotation may vary within certain limits, but beyond those limits reduction or exaggeration of its motion cannot take place without producing physiological alteration."

The alteration of nutrition has a secondary effect on the constitution of the various humours of the body. Like all permanent causes, it produces at last a chronic alteration of the tissues.

Gout, lithiasis, obesity, migraine, etc., are examples of pathological states depending on some slackening of nutrition.

Electrical science has enriched the therapeutic arsenal with forces which I believe are able to modify these diatheses, and to obviate their manifestations, if not to cure the disease they produce. Numberless facts witness to the efficacy of electrotherapeutics in these diseases; experiment has established that which theory had presaged.

It has long been known that change in environment, or alteration in hygiene, in a word, any modifications of the external conditions of existence, bring with them corresponding changes in the constitution and in the temperament of all living beings, the *constitution* being the static state of the individual, the characteristics of his architecture and structure, while *temperament* is the dynamic state, characterising his nutrition and functional activity.

Among these external conditions, there are some which have presided over the genesis of living beings from their origin until now; such as the radiations of the solar spectrum, the mean temperature of the air, etc.

Other factors, not less essential, affect the relations of the cells with their interior environment.

The study of biological physics has shewn us some of these, the phenomena of electro-capillarity and electro-osmosis, of the surface tension of liquids, of imbibition, evaporation, and oxidation.

The more we advance in the study of biology, the more we become aware of the enormous importance of the rôle played by electricity in vital phenomena, either as cause or effect. This becomes still more prominent if we admit with *Maxwell* that all radiations transmitted by transverse oscillations of the ether are in fact electrical manifestations.

We can readily understand how any change in the normal conditions of existence may cause an enduring perturbation in the phenomena of cell life, and impress on the elements of the tissues a mode of nutrition and a habit which may not only persist in the individual, but be transmitted to his descendants.

This alteration may be of a temporary character, lasting only as long as the cause of perturbation persists, or it may be permanent, and thus create a new type which will depend for its continued existence on its adaptability to the condition of its environment.

When an individual is born with a constitution and a temperament thus modified, suitable hygienic conditions may enable him to pass through the same stages of development as his ancestors, and obviate to a certain degree the ulterior manifestations of his diathesis.

The suitable hygienic conditions are, however, usually impossible, since social conditions as a rule contribute to push the individual down the incline caused by his morbid antecedents.

In such a case normal hygienic conditions are no longer of avail; we must call in the aid of some intermittent therapeutic procedure. In the first rank of these is electricity, a force which plays so large a part in vital phenomena.

It may well be conceived that an individual who has not received from his surroundings a sufficient amount of external energy in the form of radiations, etc., will, under the influence of intense irradiations, recover a temporary activity of his cells which habit may finally render permanent. At the present day we are in possession of wide resources in this respect. We can submit the organism to the most varied radiations. We can employ waves of short wave length which traverse the body in the same way that the luminous rays pass through a transparent substance, and in their transit affect the deepest as well as the most superficial tissues. Other irradiations have a localised action, more especially on the integuments, while still others with longer wave lengths have an electric rather than an optic effect, if I may so express myself, and affect the organism by a general influence, which varies with each phase.

The term *influence* is somewhat obscure, but it may be easily understood if we suppose the wave length to be increased indefinitely. In the limiting case when this becomes infinite we are dealing with static electricity.

Current electricity would also seem to be the best means of influencing the various electro-capillary phenomena which take place between the organic elements of the tissues. It is true that our mode of electrical application is a somewhat rough method of doing this, but practical experience in the treatment of gout and obesity shews that it is efficacious.

Passive gymnastics of smooth and striped muscle are best carried out by electric currents of varying intensity, aided by massage or mechanical therapy. By awakening and stimulating the sluggish activity of the tissues, this may aid the organism to resume its normal functions.

There is always a tendency to return to a normal state, and hence we often succeed in our endeavours, although we can only act blindly by a rough stimulation of the organism.

We are, therefore, well armed against the diathesis of retarded nutrition. Among the various electrical methods we must endeavour to find the one best adapted for each case without being discouraged by apparent failure, or deterred by the scepticism of our patients.

Now and again we shall be rewarded by remarkable success, shewing that we have at our disposal a means of treatment which will become more and more certain and efficacious as our knowledge of its action increases.

504. **Gout**—*Radio-diagnosis.*—The tophi consisting of urate of soda are transparent to the X-rays. The aspect of a gouty hand contrasts greatly with that of a healthy one. The bones appear perfectly normal, with here and there white spots corresponding to the tophi. In advanced cases the articulation may be seen to be altered by loss of osseous substances, especially in the spongy tissue of the epiphyses.

Electro-therapeutics.—The general treatment of gout consists in stimulating the nutritive exchanges by auto-induction, or by continuous currents of high intensity, or by franklinisation, or sinusoidal currents.

Local treatment consists in endeavouring to dissolve the deposit of urates by means of ionisation with a solution of one of the lithium salts.

I.—*General treatment of gout by auto-conduction.*—For auto-conduction the patient is placed in the middle of *d'Arsonval's* large solenoid, or between two flat spirals. These should be mounted so that the windings are in the same direction, with 8 to 12 turns in circuit, and the excitation of both spirals should be homologous. A seance of 20 to 40 minutes should be given every day or every other day (138).

II.—*Galvanisation and Ionisation with Lithium.*—The patient may be subjected to galvanisation of high intensity, which may be utilised at the same time for local lithium ionisation (*Guilloz*).

The region affected with local deposits of urate of soda is immersed in a bath containing a 2 per cent solution of chloride of lithium, to which .5 per 1000 of caustic lithia is added.

The bath is connected to the negative pole, while the indifferent cathode is placed as far as possible from the affected part, in order that the current may traverse a large portion of the body.

Intensity, 50 to 200 milliamperes; duration of seance, 30 to 45 minutes. One seance every day.

Guilloz has shown that independently of the local action of the lithium, the continuous current augments the nutritive activity, more especially with regard to the fats and hydro-carbons, as is proved by the character of the dejecta.

Locally, the lithium ion attacks the deposit of urate of soda, transforming this into the more soluble urate of lithium, and thus breaks down the tophi. Acute attacks of gout are easily amenable to treatment, and in chronic cases from 20 to 30 seances are usually sufficient to relieve the articular swellings.

III.—*Larat* recommends the use of *hydro-electric baths with sinusoidal currents.*

Various other modes of treatment may be employed, such as the static douche, high frequency condensation, hot air baths, and light baths. The effect of the latter is principally due to heat.

According to the therapeutic method formulated by *Guilloz,* the general rules for the treatment of gout are:—

1. In the treatment of the local affection use strong galvanic currents with transport of the lithium ion.

2. Terminate the treatment with a seance of auto-conduction.

505. **Lithiasis**—*Radio-diagnosis.*—Urinary calculi have already been discussed in the chapter on urinary diseases. Biliary calculi, whether formed in the gall bladder, the gall ducts or the liver, are not easily diagnosed by means of the X-rays. This is due to the opacity of the surrounding tissue, and to the great transparency of cholesterin.

On passing into the intestines these calculi may become covered with a layer of carbonate of lime, which renders them more visible.

Electro-therapeutics.—The indications are the same as for gout, auto-conduction and galvanisation of great intensity being employed.

Under this treatment the percentage of urea, of uric acid, and of phosphoric acid in the urine is raised, the caloric radiation of the body is augmented, and general organic combustion is increased.

The continuous current is applied in the way described by *Guilloz* for the treatment of obesity (506).

Auto-conduction may be carried out by means of *d'Arsonval's* large solenoid, or by placing the patient between two spirals. The duration of the seances should be 20 or 40 minutes every day or every other day.

In cases of gravel *Larat* recommends the hydro-electric bath with sinusoidal currents. Its diuretic action, he says, is comparable to that of the Vittel or Contrexeville waters.

506. **Obesity.**—In an individual with normal constitution and normal temperament, there is a constant ratio between the various constituents of the body. According to *Von Noorden* and *Bouchard* the following is the normal composition per kilogramme of body weight:—

Fixed albumen	148 grammes
Circulatory albumen	12 grammes
Fat	130 grammes
Water	660 grammes
Mineral matter	50 grammes
	1000 grammes

This proportion will vary with the constitution of the individual. A well-built subject with strong bony framework will have a lesser proportion of albumen and fat. Another with strong muscular development will have an increased proportion of fixed albumen.

A patient of medium framework, who is over weight, must have an excess of adipose tissue.

Bouchard defines the "adiposity" of a patient as the ratio of his fat weight to that of a normal subject. To obtain this ratio the following data are required:—

1. The height of the patient.

2. The normal weight corresponding to that height. This may be determined by *Bouchard's* table.

In the absence of the table we may arrive at the normal weight by multiplying the height in decimetres by 8 and deducting 66 (426).

3. The build of the bony frame-work. This must be estimated and the normal weight multiplied by the corresponding coefficient.

4. Muscular Development.—The degree of muscular development should be determined and the normal weight multiplied by the corresponding coefficient found in *Bouchard's* tables.

5. Age of the patient. If this is under 30 years a correction should be made for age, by multiplying by a third coefficient.

The following are the coefficients for build, musculature and age:—

Coefficient of Osseous Development.		Coefficient of Musculature.		Coefficient of Age.	
BUILD.	COEFF.	MUSCULATURE.	COEFF.	YEARS.	COEFF.
				13	0.694
Very stout	1.12			15	0.743
Stout	1.08	Very strong	1.24	17	0.796
Rather stout	1.04	Strong	1.12	19	0.849
Medium	1.00	Rather strong	1.05	21	0.888
Rather slender	0.96	Medium	1.00	23	0.923
Slender	0.93	Feeble	0.95	25	0.953
Very slender	0.90	Very feeble	0.90	27	0.974
				29	0.992

Take for example a patient 32 years of age, measuring 170 cm. in height, with large bones and strong muscular development. Had he been of medium build and muscle his weight should be 70 kilos. $(17 \times 8 - 66 = 70.)$ Multiplying this by the coefficients for build and musculature given in the table, his normal weight should be

$$70 \times 1.08 \times 1.12 = 84.6 \text{ kilos.}$$

6. The weight of the patient must be compared with the normal weight. If it is greater the excess is wholly due to fat.

If, on the other hand, it is less than normal, the loss of weight is due to general emaciation, each kilo of flesh corresponding to a loss of only 210 grammes of fat.

Given the above data we may determine the degree of adiposity in the following manner:—

Normally 13 per cent of the body weight is fat. The normal weight of fat in the above example will, therefore, be $\frac{13}{100}$ of 70, or 9.1 kilos.

We must add to this the amount that the patient is overweight, taking into consideration his build and muscularity, for this is all fat. Supposing he weighs 90 kilos. Since his normal weight is 84.6, he has an excess of 5.4 kilos of fat.

Therefore his total amount of fat = normal fat + excess fat = 9.1 + 5.4 = 14.5 kilos.

The *degree of adiposity* is the ratio of the actual amount to the normal amount $= \frac{14.5}{9.1}$ or 1.59.

On the contrary, suppose that the patient weighs less than he should, say 74.6 kilos, he has lost 10 kilos of flesh, only 21 per cent of which is fat, *i.e.*, 2.1 kilos. The total weight of his fat will be 9.1 — 2.1 = 7 kilos. His adiposity will, therefore, be $\frac{7}{9.1} = .769$.

The value of the adiposity may fall as low as .05 or go up to 12. Thus the individual we have taken as an example may fall to .45 kilos of fat or go up to 109 kilos, which would make his total weight 184.5 kilos, if, as we have supposed, he is muscular and well developed.

Adiposity is not corpulence. Corpulence is the relation of weight to height. It varies with the muscularity, the build, and the adiposity.

Adiposity and corpulence usually vary simultaneously, but they are not identical.

I have entered somewhat fully into this definition of adiposity, so that we may have accurate data to start from in the electric treatment of this affection. The most difficult part of the question is the just appreciation of the coefficients of musculature and osseous development.

We must appeal to physiological physics for further light on this subject, whether it be by an examination of the skeleton by means of the X-rays, or the measurement of muscles by ordinary physical methods.

Electrotherapy of Obesity. 1. *Treatment by continuous current.* (*Guilloz*).—Large electrodes of cotton-wool or felt well moistened with hot water may be applied to the abdomen, the thighs, the nates and the loins.

The electrodes connected to the negative pole should have an area rather larger than those joined to the positive pole. The intensity may be gradually raised to 150 milliamperes. Seances of 30 minutes or an hour may be repeated every day.

Later on we may employ in addition the faradisation of the muscles of the abdomen, the nates and the thighs. It must not be forgotten that in many of these cases there is some weakness of heart which may contra-indicate all gymnastic treatment of the muscles during the first part of the treatment.

By this means we may ensure the loss of 8 to 15 kilos in the course of a month. We should previously keep the patient under observation. The time to intervene electrically is when in consequence of dietetic treatment the patient has ceased to increase in weight, but the weight remains stationary.

2. *High Frequency Currents.*—While the continuous current is generally well supported, other forms of electricity are not well borne by patients suffering from obesity. Even high frequency currents applied by means of auto-conduction sometimes produce heart pains and acceleration of the pulse, especially where there is fatty degeneration of the myocardium.

3. *Procedure for the gymnastic treatment of the muscles.*—We have already said that it is advisable to follow up the galvanic treatment, by faradisation of the muscles.

In the treatment of obesity *Larat* employs the hydro-electric bath with sinusoidal current. He begins with a bath of 15 minutes, and increases the time up to 40 minutes. Any circulatory troubles he regards as a contra-indication for treatment.

Massage and passive movements may be used as adjuvants to the electrical treatment.

4. *Radio-therapeutic Treatment.*—With the exception of high frequency and heat employed as a sudatory, we have not been very successful in using radiations of various wave length as a means of influencing the nutritional activity of the tissues. The light bath has been recommended by many authorities, but it is probable that its action is due solely to the heat which accompanies the light.

It is difficult sometimes to choose among the various modes of electrical treatment. Obesity, above all other diseases, needs a varied treatment, more especially in the case of women, when inertia is often almost complete.

The fundamental treatment is galvanisation. To this we may add faradisation, auto-induction, active and passive gymnastics and the hydro-electric bath. The treatment is costly and tedious. Galvanisation is more efficacious, in my opinion, than all other modes of procedure.

Local collections of adipose tissue.—The treatment is the same, galvanisation with large electrodes, faradisation, and active or passive gymnastics of the part affected.

507. **Diabetes.**—We are not in a position to decide with certainty as to the value of electricity in this disease.

D'Arsonval and *Charrin*, and later *Apostoli* and *Berlioz*, published very encouraging results of auto-conduction.

I have myself seen amelioration and even disappearance of glycosuria as a consequence of auto-conduction. The patient was placed between two spirals, and seances of 20 or 30 minutes were given every other day.

In presence of the contradictory results obtained by different authorities we must reserve our judgment.

In all of our cases there was an increase of strength and an improvement of the general health.

The static bath has also given good results in the hands of several observers.

508. **Chronic Rheumatism.** — Articular rheumatism, and pseudo-rheumatism of infective origin, such as gonorrhœal rheumatism, are caused by definite infective organisms. The cause of chronic rheumatism is much more obscure, the more so because it often follows an acute infective rheumatism. At all events as *Bouchard* has shewn, chronic rheumatism is an arthritic disease, and we should therefore treat the arthritic diathesis as well as the local manifestations of the disease.

Radio-diagnosis.—When the joints are affected examination by the X-rays is useful. The transparent line usually seen between the ends of the bone will be absent if the articular cartilages are destroyed. We should also look for any deformity of the epiphysis, and for osteophytes.

In a later stage the bones appear more transparent on account of the decalcification of the osseous tissue.

Electro-therapy.—There are two principle indications for treatment:—

1. The arthritic diathesis.

2. The local manifestations of the disease.

General treatment.—This consists in the use of auto-conduction, fardisation, or the hydro-electric bath with sinusoidal current. (*Larat.*) Auto-conduction may be employed with *d'Arsonval's* large solenoid, or by placing the patient between two spirals. Seances of 20 to 40 minutes repeated every day or every other day.

Local treatment.—This consists in applications of the continuous current with salicylic ionisation. The technique of this procedure has already been described in the article on arthritis (440).

The reader should also consult the article on torticollis, lumbago and muscular rheumatism (379).

CHAPTER IX.

DISEASES OF THE MOUTH, THROAT, NOSE, LARYNX AND EARS.

I. The Nose and Nasal Fossæ.

509. Deviation and Growths of the Septum Nasi.—Bipolar electrolysis may be used in the treatment of deviation, or for the removal of cartilaginous and osseous growths or thickening.

With the aid of a nasal speculum two steel needles are thrust into the growth at a slight distance apart and parallel to one another.

The needles are 7 to 10 cm. in length and .5 to 1 mm. in diameter. They are insulated for the greater part of their length by means of an india-rubber tube. *E. Castex* has devised a special pair of forceps, which enables them to be introduced without intercepting the view. When the needles have been placed in position the speculum may be withdrawn and the needles connected to the battery.

A current of 20 to 30 milliamperes is passed for 3 to 5 minutes. The current is then gradually reduced to zero, and reversed for 30 to 60 seconds with a current of 20 milliamperes. This is again gradually reduced to zero and the needles are withdrawn.

This reversal of the current enables us to withdraw the positive needle without any danger of its adhering to the tissues.

The mucous membrane may be rendered insensible by the use of cocaine. One or two applications are usually sufficient.

The slough comes away in from 8 to 10 days. It is useless to use the monopolar method in affections of the nose. The bipolar method enables us to localise the action.

510. **Polypi of the Naso-Pharynx.**—Electric treatment of the naso-pharynx was first employed by *Nélaton.* A polypus in this situation may be destroyed by means of bipolar electrolysis. Two needles are used, 1 to 1½ millimetres in diameter. After having been softened these are bent to the proper curve and are then rehardened.

They are covered to within a short distance of the point with a tube of india-rubber, or *Chatterton's* insulating ribbon. The needles are introduced into the polypus and a current of 20 to 40 milliamperes is passed for 5 to 10 minutes. The current is then gradually reduced to zero and reversed for 30 to 60 seconds.

The reversed current, after having been raised to 20 milliamperes, is again reduced to zero, and the needles withdrawn. In this way the positive needle may be withdrawn without adhering to the tissues and without any loss of blood. Usually a few seances at intervals of a fortnight are sufficient. When only a few remnants of the tumour remain treatment may be completed by the monopolar method.

Garel, of Lyon, has designed a fork with three platino-iridium teeth. The two outer ones are connected to the negative pole, while the middle one is insulated and connected to the positive pole. Before using the instrument the handle should be well covered by insulating ribbon. Any one of these methods may be employed in cases where surgical ablation is not urgent.

511. **Ozœna.**—This affection is most obstinate to ordinary treatment, whereas electrotherapy gives excellent results.

Electrolysis is the mode of treatment par excellence. First employed by *Gautier, Jouslain, Favier,* and *Larat* in

1892, it was introduced at Brussels by *Cheval, Capart* and *Bayer* in 1895, and in Vienna by *Rettvi.*

The reports of all these observers is the same. Cure is invariable in recent cases, and even in those of long standing a great improvement is obtainable.

Recently *Moure* of Bordeaux has thrown some doubt on the treatment, as he has met with cases of rapid recurrence. It is probable that his technique was not exactly the same as that of the observers in Belgium and Vienna. Whatever may be our opinion as to the permanency of the result, the utility of the procedure in undoubted.

Two methods may be employed, that of *Schall,* who uses electrodes of cotton-wool, or that of *Cheval,* who employs a positive copper needle and a negative needle of steel.

Cheval's process.—The nasal mucous membrane is carefully cleaned and rendered insensible by means of a 5 per cent solution of cocaine. Two needles are used, one of copper, one millimetre in diameter, insulated by a thin india-rubber tube up to a short distance from its point, the other of steel, similarly insulated. The copper needle is introduced into the mucous membrane of the middle turbinated bone, or by piercing the bone to reach the concave surface, which is usually the most affected. The needle should be kept parallel to the lower border of the bone. It should penetrate about 3 centimetres, or 2 centimetres in the case of children. The steel needle may then be introduced into the mucous membrane of the inferior turbinated bone on the same side.

The copper needle should then be connected to the positive and the steel needle to the negative pole.

The current should be turned on gradually and raised to 8 to 20 milliamperes for 10 to 15 minutes. *Cheval* goes up to 30 milliamperes. The current should then be gradually reduced to zero, reversed and raised to 30 milliamperes in the opposite direction, after which it should be again reduced to zero. The needles may then be readily withdrawn. Several seances should be given at intervals of a week.

The active agent is the oxychloride of copper formed by the liberated Cl, at the positive pole. After each seance there are symptoms of pain, conjunctival congestion, and lachrymation, which, however, disappear after a few days.

Bayer has reported the occurrence of violent pain after this operation. In one case, in which the patient was also suffering from suppurative otitis, a fatal termination ensued, although the electric current did not exceed 10 milliamperes. It is impossible to decide whether these results were due to accident, or, as *Larat* supposes, to some defect in the galvanometer employed.

Schall's procedure.—This consists in introducing a moist negative electrode into one nostril, and a positive electrode composed of a plug of cotton wool impregnated with copper into the other. The positive electrode is formed in the following manner. The end of a copper rod is enveloped in cotton wool and this is plunged into a warm solution of silver nitrate acidulated with tartaric acid. A metallic deposit of copper is formed on the plug of wool. In *Schall's* procedure the intensity should be 15 milliamperes for a period of ten minutes.

Two other processes have been employed, one by *Dionisio* and the other by *Bordier*. *Dionisio* recommends phototherapy in the treatment of ozœna, basing his conclusion on a considerable number of cases. He employs tubes of crystal, on which he concentrates the light of a small incandescent lamp cooled by water circulation, and supported on a water cooled handle. A description of his procedure may be found in the Archives d'Electricté Médicale, 1903, p. 452.

Bordier and *Collet* obtain good results from high frequency currents, applied locally by means of a small electrode with a glass handle introduced into the nostrils. After two minutes' application they submit the mucous membrane of the pharynx to the same treatment, depressing the tongue with an ordinary spatula.

512. **Anosmia.**—Anosmia may be treated by extra-nasal galvanisation, the active anode being a plug of cotton wool placed on the bridge of the nose, the negative electrode being placed on the neck. Intensity, 6 milliamperes. —Duration, 2 minutes.

Endo-nasal galvanisation is more efficacious. A moistened plug of cotton wool, fixed to the end of an insulated probe, is introduced as far as possible into the nasal fossæ. A second electrode is placed on the root of the nose, or on the nape of the neck. The treatment is commenced by continuous galvanisation, the negative pole being intra-nasal. (See par. 380.) A seance of 5 minutes may be given, with an intensity of 3 to 5 milliamperes, concluding with faradisation from a thick-wired coil.

According to *Courtade,* the intensity of the current should be just sufficient to be perceived, and no more.

II. The Mouth.

513. **Papilloma of the Mouth.**—This may be treated by negative monopolar electrolysis. A steel or platinum needle, insulated nearly up to the point, is thrust into the base of the tumour. An indifferent anode of 100 sq. cm. is placed on the nape of the neck. A current of from 5 to 8 milliamperes is passed for 5 or 10 minutes. A single seance suffices, the slough becoming detached in from 8 to 10 days.

514. **Glossoplegia—Atrophy of the tongue.**—Paralysis

of the tongue due to peripheral causes is very rare, and usually results from traumatism.

The treatment consists in faradisation of the muscles, or if the paralysis is due to neuritis, in galvanisation of the nerve. As shown in Plate I, the motor point of the hypoglossal nerve is found behind and below the great cornu of the hyoid bone. The motor points of the cervical muscles are also shewn in the same plate. We may also treat the tongue directly by means of the rhythmic faradic current, or the rhythmic galvano-faradic current.

An electrode for this purpose may be improvised by passing a thick copper wire through a bit of india-rubber tubing, tying a plug of cotton wool to one end.

Atrophy of the tongue due to peripheric injury of the nerve may be treated in the same way.

515. **Teeth—The production of Analgesia by high frequency currents.**—*Regnier* and *Didsbury* have produced anæsthesia in teeth during extraction or stopping by means of high frequency currents. The following details may be of interest to those who wish to repeat their experiments. The electrode is made from a cast of the region to be anæsthetised. The cast is covered with a metallic powder and a thin sheet of tin foil moistened with a paste of asbestos.

This electrode is connected to the resonator of a high frequency apparatus. The analgesic properties of high frequency currents may be of use in cases where other means of producing anæsthesia are contra-indicated.

III. The Larynx.

516. **Paralysis and Neuritis of the Recurrent Laryngeal Nerve**— *Radio-diagnosis.*—The cause of laryngeal paralysis is often involved in obscurity, and radio-diagnosis may be of great service in clearing up the etiology of the case, when due to some lesion in the mediastinum. *Mignon*

quotes two cases of aneurism of the aorta diagnosed by the X-rays[1].

Laryngeal paralysis may be treated by external rhythmic faradisation. An electrode of suitable form and curve is applied to the neck on the paralysed side. This is joined to the negative pole of the coil, an indifferent electrode being placed on the nape of the neck. The current is rhythmically interrupted by means of the metronome, so as to give one second of contraction alternating with one second of rest. A seance of 10 minutes may be given every other day.

If the paralysis is on both sides, we may employ an electrode, such as that of *Gouguenheim,* embracing both sides of the larynx.

The affection may also be treated by endolaryngeal faradisation. (*Morell-Mackenzie.*) The application of this treatment is the business of the laryngologist rather than the medical electrician, and the same may be said of endolaryngeal galvanisation for neuritis of the recurrent laryngeal nerves.

517. **Hysterical Aphonia.**—The best method is to treat the laryngeal region with a shower of sparks from a static machine or from a high frequency apparatus. The faradic brush may also be applied. (*Meyer.*)

518. **Vocal Fatigue.—Influence of Electricity on the Voice of Singers.**—*Moutier* shewed the good effects of the static effleuve in vocal fatigue. The patient is placed on the insulated stool and connected to the negative pole of a static machine. A brush discharge from the positive pole is then directed on the open mouth.

Seances of 15 to 30 minutes may be given every other day. The voice gains in pitch, the high notes being taken more easily. High frequency currents give similar results.

[1] Traité de Radiologie Médicale. Bouchard, p. 922.

IV. The Ear.

519. **Labyrinthine Otitis—Deafness due to lesion of the labyrinth or lesion of the Acoustic nerve—Hysterical deafness—** *Electro-diagnosis.*—The galvanic testing of the acoustic nerve is made by placing the active electrode on the tragus in front of the external auditory meatus, and the indifferent electrode electrode on the nape of the neck. It gives the following results (*Brenner,* 1863; *Erb,* 1869):

Usually in the healthy subject, no sensation is produced with either pole, by gradually raising the intensity or by suddenly opening and closing the circuit. In only one case in ten is there any response on the part of the nerve. In that case KC appears first and afterwards AO. No response is obtained to KO or AC.

The sound produced by KC is brief and fairly loud. It is often followed by a faint sound which is prolonged for a moment and then disappears. If we allow the current to flow for a few seconds, the nerve reacts more readily. (Secondary excitability of *Brenner.*) If the current is passed for some minutes in one direction, and then in the reverse direction, we sometimes get inversion of the formula of excitation. (Tertiary reaction of *Brenner.*) It may happen that the left ear will respond to excitation of the right ear. In this case the inverse formula of excitation is observed, *i.e.,* the left ear responds as if an electrode of contrary sign were applied to its tragus. This is probably due to the fact that when the indifferent electrode is placed on the neck, a virtual electrode of the same sign is formed near the opposite ear, the lines of flux being disseminated through the head. This so-called paradoxical reaction is only met with in pathological cases.

The meaning of these reactions is susceptible of different interpretations. The healthier the ear, the less it reacts to alterations of the electric state, since the acoustic nerve is stimulated with difficulty. It becomes excitable by reason of certain pathological states, which increase the conductivity of the tissues of the external ear, *e.g.* furunculosis, otitis media, etc. It may also become more excitable in consequence of abnormal irritability of the acoustic nerve itself, due to cerebral tumour, meningitis, traumatism, etc.

In ordinary inflammatory lesions of the external or middle ear, electrical examination is unnecessary. It may be useful in suspected cases of labyrinthine otitis, or in intracranial affections in their early stages.

In hysterical or tabetic deafness the reaction is normal.

In some instances the existence of the auditory reaction is of good augury. This is the case where the nerve is undergoing degeneration, as in labyrinthine deafness of long standing. The response proves that the degeneration is not complete, but the nerve is the seat of some inflammatory affection.

One may say, then, that where there is no disease of the external or middle ear, any reaction to a feeble current of 5 or 6 milliamperes makes one suspect hyperæmia of the labyrinth or of the trunk of the acoustic nerve.[1]

Electro-therapy.—Hysterical deafness is especially benefited by the use of electricity. The continuous current should be employed. The active electrode should be connected to the positive pole (*Erb*) and the current should be interrupted from time to time, so as to arouse the excitability of the nerve.

Duchenne of Boulogne employs the faradic current in hysterical deafness, stimulating the tympanum directly by aid of an ear bath connected to one pole of the coil. We may also employ *Roumailhac's* special electrode for this purpose.

520. **Noises in the ears.**—*Dénoyès, Imbert* and *Marquès* have demonstrated the good effects of high frequency cur-

[1] Gradenigo, 1888, in Barret, Arch. d'Elect. Méd., April 15, 1902.

rents in the treatment of noises in the ears, when these are not associated with suppurative otitis. The best method is to pass the fine wire brush, or a condensing electrode, over the mastoid process and in front of the external auditory meatus.

Effleuves or sparks may be given according to the tolerance of the patient. According to *Imbert* and *Marquès* this method should be systematically employed in all cases of noises in the ears, especially if caused by sclerous otitis, hysteria or neurasthenia.

Good results are also obtained with the continuous current, after the technique of *Brenner* and *Erb*. The active anode is applied on the tragus, the indifferent cathode being placed on the nape of the neck. A current of 5 to 8 milliamperes, or even 10 milliamperes, may be used for 5 to 20 minutes.

In cases of vertigo accompanied by noises in the ears, *Libotte*[1] has obtained good results by using the static breeze.

521. **Otitis.**—We have seen that noises in the ears, due to sclerous otitis, are often cured by electricity. (520.) Electrical treatment is also useful in deafness from labyrinthine otitis. (514.) We shall here treat briefly the acute affections of the middle ear.

According to *Mounier*, when an acute otitis is declining, it is advisable to faradise the ear. Faradisation acts by hastening the reabsorption of exudation, and remedying the post-inflammatory paresis of the muscle of the middle ear.

Bergonié has used this method with success in the treatment of sclerous otitis media, using a rhythmic faradic current, interrupted by means of a metronome.

He employs *Roumaiehac's* auricular electrode, the indifferent electrode being placed on the nape of the neck. By

[1] Libotte. Archives d'Electricité Médicale, 1903, p. 109.

this means he obtains a direct action on the muscles of the middle ear, in addition to the "faradic massage" of the tympanum.

The intensity should be increased until slight contraction of the muscles of the face is produced. Seances may be given every day or every second day for 20 to 30 minutes.

In conclusion, we may draw attention to *Dionisio's* results[1] of treatment by phototherapy in chronic purulent otitis of the middle ear. By his method, the light of an incandescent lamp is projected on to the tympanum by means of a speculum.

522. **Contractions of the eustachian tube.**—Contraction of the eustachian tube may be treated by circular electrolysis in the same manner as that described for stricture of the urethra.

Copper bougies are used, from No. 3 to No. 6 on the French scale. These are passed through a silver catheter, which is insulated externally. The catheter is introduced up to the stricture, and then the bougie is passed through it. The catheter is then connected to the negative pole and a current of 2 milliamperes is passed, which may be increased up to 5 milliamperes if the patient will bear it. Under slight pressure, the sound may be felt to penetrate the stricture. The seance should not exceed 2 to 5 minutes in duration. (*Duel.*)

[1] Archives d'Electricité Médicale, July 15, 1903.

CHAPTER X.

DISEASES OF THE RESPIRATORY PASSAGES.

523. **Pulmonary Tuberculosis.**—*Radio-diagnosis.*—Pulmonary tuberculosis is one of the diseases whose diagnosis has been substantially advanced by the aid of the X-rays. They are most useful in the early stages, when as yet there are no physical signs and bacteriological examination gives negative results. Since it is most important to be able to diagnose the disease in this early stage, when it is still curable, radio-diagnosis has taken a prominent place in medicine. For a further study of this question we may refer the reader to the excellent article by *Dr. Le Noir* in *Prof. Bouchard's* Traité de Radiologie Médicale.

A. *Doubtful period.*—When the thorax is irradiated in the frontal position, so that the normal ray falls on the sternum or spine, the two sides of the pulmonary region should be equally illuminated. During inspiration the luminosity is increased. The diaphragm, which is naturally raised on the right side, is seen to oscillate equally on both sides. The ribs are also seen to be equally elevated on either side by the movements of inspiration. Disease of the lungs is to be suspected when there is an inequality of luminosity on the two sides, or any interference with the physiological movements.

Even in health the right apex of the lung may be slightly less transparent than the left. This is due to the increased muscular development on the right side. This should not mislead us when we remember that there is usually greater resonance on that side.

In the exploration of the thorax it is convenient to use the special holder for carrying the focus tube, and the incidence-indicator described in par. 214. By its means we can irradiate any given region at any angle.

To appreciate slight differences of opacity, we may, as *Claude* advises, place a metal object, such as a key, between the focus-tube and the patient on either side. A slight difference of pulmonary opacity will greatly alter the clearness of outline of an object thus interposed.

The examination of the lungs, the diaphragm and the ribs should be followed by that of the mediastinum.

The examination of the mediastinal glands should be made by oblique illumination of the thorax. The focus-tube should be moved round from side to side and the screen held obliquely on the opposite side. Except with very oblique rays, the intensity of the X-rays is the same in every direction. The illumination is, therefore, equally good in the oblique and in the frontal position. (199.)

We may also rotate the patient on a vertical axis while keeping the fluorescent screen parallel to the plane of the tube-holder.

The examination should be terminated by determining the area of the heart. In patients predisposed to tuberculosis, the heart area is usually diminished. The best way of estimating the diminution is to measure the heart area S, and compare it with the weight of fixed albumen of the patient A. The normal value of the ratio S/A for an adult is 9.8 for men and 9.5 for women. This ratio is diminished in patients predisposed to tuberculosis. In children the heart is relatively larger.

B. *When the presence of tuberculosis is established* by clinical signs and the presence of bacilli in the sputum, the X-rays will still be of service in following the evolution of the disease. A description of the shadows given by the various alterations in pulmonary tissue will be found in the article by *Le Noir*.

All lesions increase the opacity, with the one exception of excavations which are empty. These shew as transparent patches surrounded by darker areas.

The presence of secondary lesions, pleurisy, sclerosis, etc., may greatly modify the appearance. These will be described in par. 524.

Electro-therapeutics.—Every form of electric energy and every variety of radiation has been tried in the treatment of tuberculosis. As in all other modes of treatment, good results have been reported. In spite of perfectly honest observations by competent observers, we are forced to the conclusion that neither the X-rays nor the high frequency currents, nor any other form of electric energy, has proved itself of much use in this disease.

Of all modes of electric treatment, the most satisfactory and the most hopeful is that by high frequency currents.[1]

The most important experiments in this respect have been made by *Lagriffoul*[2].

The experiments were made on over 30 guniea pigs, thus obviating any accidental errors, or any possible objection on the score of suggestion. The following are the author's conclusions:

"The treatment by moderate effleuvation exercised a favourable influence on the progress of tuberculosis. When the treatment was more intense the benefit was more marked. Auto-conduction was, as a rule, less efficacious than the effleuve in moderate doses. The association of auto-conduction and effleuvation did not increase the effect of each separately. The influence of high frequency treat-

[1] Doumer, Oudin, Gandil, Reviere, etc.

[2] Lagriffoul and Dénoyès, Archives d'Electricité Médicale, June, 1900; Dénoyès, Les Courants de haute fréquence. Hamelin. Montpelier.

ment was even manifested, although in a less degree, when the treatment had been delayed until after the appearance of enlarged glands above the seat of inoculation. The effleuve in moderate doses seemed to attenuate the severity of the lesions. The treatment had no effect on the enlarged glands. Although the effleuve in these experiments seemed to exercise a beneficial influence on the evolution of the disease it did not prevent its generalisation.

In addition to these experimental results there are numerous reports of human tuberculosis relieved or cured. The effleuve applied to the thoracic region has given excellent results in the hands of *Oudin, Doumer, Glandil* and others.

I have not myself been so successful. In 1897 I treated nine cases under *Dr. Bouchard's* care at "la Charité." In some instances there was an aggravation of the symptoms, in others a diminution in weight, while still others left off the treatment as causing them too much fatigue.

Since then I have treated some cases with better success, but at present the result of electrical treatment is very problematical. It would seem that cases of neurasthenia in tuberculous patients, with feeble arterial pressure, are best suited for this treatment. The inhalation of ozone has also been employed in the treatment of tuberculosis, and favourable results have been reported. We should proceed with caution, as ozone is known to exert a very injurious action on the bronchi when a certain dose is exceeded. (353.)

524. **Non-tuberculous affections of the lungs.**—*Radio-diagnosis.*—Bronchitis does not alter the transparency of the pulmonary parenchyma. This is a valuable sign, enabling us to differentiate phthisis from bronchitis.

Bronchial stenosis shews itself by the slowness with which the pulmonary alveoli fill up on the affected side, and the small size of the corresponding lobe of the lung during the whole period of inspiration. This is accompanied by displacement of the mediastinum, which is drawn to the affected side.

Bronchial dilatation is not visible on the screen, unless large cavities are present.

When emphysema exists alone, it is revealed by an increased clearness of the image. When, however, it is associated with the congestive lesions which generally accompany it, the aspect of the image is very variable. The diaphragm is less raised and descends lower, while its movements are diminished in amplitude.

Pulmonary sclerosis is of very variable aspect. It is manifested by a diminution of the clearness and size of the image, and a decrease in the amplitude of the movement of the ribs and diaphragm. Occasionally there is displacement of the mediastinum during sustained inspiration.

In pneumonia well-defined opacities are visible, which may persist long after the termination of the disease. (*Le Noir.*)

In the treatment of sub-acute bronchitis and emphysema, hot air and light baths have been recommended by *Gautier* and *Larat,* and the arc light by *M. A. Cleaves*[1].

525. **Pleurisy.** — *Radio-diagnosis.* — Pleuritic effusion gives a well-marked shadow. The diagnosis of pleurisy by means of the X-rays was first made by *Bouchard* in 1896, and was the foundation of medical radiology.

When there is considerable effusion, the mediastinum may be seen to be pushed to one side. Displacement of the heart in pleurisy of the left side is also distinctly visible.

The surface of the liquid, instead of being horizontal, is frequently concave. According to *Bergonié* and *Carrière,* this is due to the depression of the surface of the liquid by the lung, which is more or less immersed in it. When the position of the patient is altered, the liquid obeys the

[1] Congress of the American Electro-therapeutic Association, Buffalo. Archives d'Electricité Médicale, Feb., 1899.

laws of hydrostatics, a circumstance which enables us to diagnose small collections of fluid, bound down or separated by adhesions.

If there is pneumothorax in addition to the pleurisy, there will be a lighter space about the dark shadows of the liquid. In that case, the line between the air and the liquid is very clearly marked, and it preserves its horizontal direction when the patient alters his position. It is, moreover, agitated by waves and undulations, which are plainly visible when the patient is shaken, and occasionally waves may be seen which are synchronous with the pulsations of the heart. (*Bouchard, Kienböck.*)

The level of the liquid is raised during inspiration. It is chiefly caused by the descent of the diaphragm on the healthy side, producing increased abdominal pressure, and a lifting of the inert portion of the diaphragm on the affected side.

Localised pleural effusions are early recognised by means of the X-rays.

Thickening of the pleura is characterised by opacity of the image. This opacity is not very visible when the thickened portion is irradiated at right angles to its plane. It is, on the contrary, very apparent when viewed sideways, as we should view a piece of glass through its edges. It is, therefore, important to be able to examine the thorax with different angles of incidence for the rays. This is particularly the case in dry inter-lobar pneumonia. (*Béclère.*)

526. **Diseases of the appendages of the respiratory tract—Goitre.** — Various kinds of electro-therapeutic treatment have been recommended in the different forms of goitre. *Dickson* of Toronto employs positive electro-puncture in the vascular variety and negative electro-puncture in the fibrous variety. He also uses bipolar electrolysis, and in slight cases he employs negative galvanisation. I have oc-

casionally had recourse to this mode of treatment, which has usually produced a notable diminution of the tumour. A cathode of 60 to 100 sq. cm. is applied to the front of the neck, and an anode of 200 to 300 sq. cm. to the nape. Seances every second day. Intensity of 30 to 40 milliamperes. In the treatment of cystic diseases of the thyroid, *Dickson* injects an electrolytic solution into the interior, and endeavours to obliterate the cyst, by setting up adhesive inflammation by the action of the negative pole[1].

527. **Whooping Cough.**—*Bordier* has obtained most excellent results by means of ozone inhalations. The patient is placed in a chamber into which is introduced the ozone produced by a high-frequency resonator or helix through which a current of oxygen is passing. (225.) As a rule, cylinders of oxygen may now be readily procured when required. The dose of ozone should not exceed .3 milligramme per litre of air.

The amount of ozone may be estimated by drawing off some of the air by an aspirator, and bubbling it through a standard solution of arsenic. (351.) Seances from 5 or 10 minutes for children, to 15 minutes for adults, and repeated every second day.

528. **Nervous Asthma.**—Admirable results have been obtained in this disease by faradisation of the vagi, one electrode being placed on the neck and the other on the epigastrium. (*Erb.*) *Rockwell* prefers galvanisation of the vagi. Where faradisation and galvanisation have failed, *Larat* has had good success by passing a shower of electric sparks from a static machine over the whole of the chest. The results are to all appearances permanent.

529. **Hiccough.**—This may be due to an affection of the digestive organs, or of the respiratory tract, or of the

[1] Congress of the American Electrical Association at Buffalo, in Archives d'Electricité Médicale, Jan. 15, 1899.

nervous system. Hiccough has the most varied pathogenesis, depending sometimes on irritation of the phrenic nerves, and sometimes on psychic causes. Our mode of intervention should vary according to the cause.

Usually galvanisation of the phrenic nerve should be adopted, one electrode being placed on the phrenic in the neck, and the other on the nape of the neck, or on the epigastrium. (*Capriati.*) Intensity, 10 to 20 miliamperes. —Duration, 10 to 15 minutes. In a case of hysterical hiccough, *Regis* and *Débédat* obtained good results by prolonged tetanizing faradisation of the œsophagus, a metallic sound with olive shaped tip being introduced into the œsophagus.

CHAPTER XI.

AFFECTIONS OF THE LOWER DIGESTIVE TRACT.

530. **Spasmodic Stricture of the Oesophagus.**—This may proceed from a nervous cause, such as hysteria, or it may depend on disease of neighbouring parts, the nature of which may often be determined by the aid of radio-diagnosis.

The treatment consists either in galvanisation of the vagi, or in direct faradisation or galvanisation of the œsophagus.

1. *Galvanisation of the vagi.*—An anode of 20 sq. cm. is placed on each side of the interval between the two heads of origin of the sterno-mastoid muscle. These should be joined up in parallel. An indifferent cathode of large size is placed on the epigastrium. The current should be increased very gradually up to 15 milliamperes and further to 40 to 50 milliamperes if possible. Seances 15 to 25 minutes. —Repeated every day or every other day.

2. *Intra-œsophageal method.*—A sound with olive shaped termination may be employed, or we may use a ring-shaped electrode as described for the treatment of organic stricture. The indifferent electrode may be placed in any convenient position.

Either the faradic or the galvanic current may be used. The faradic current most readily produces exhaustion of the irritability of the unstriped muscular fibres, for which purpose the stimulation should be continued for a quarter of an hour or more.

The contractions of the muscle around the olivary end of the instrument may be readily felt. The sound should be removed from time to time and reintroduced in order not to fatigue the patient too much. The intensity of the current should be pushed as far as the patient will bear. Seances at first every day, afterwards every second day.

Opinions are divided as to the best mode of applying the galvanic current in this disease. Some authorities treat spasmodic in the same way as organic stricture, applying intense currents by means of a bare olivary sound connected to the negative pole. Others, like *Bordier,* fearing the occurrence of post-electrolytic cicatrices, use a small olive-ended sound covered with cotton-wool and gauze, and do not exceed 8 milliamperes for a period of 10 or 15 minutes.

The following is the procedure for treating spasmodic stricture of the œsophagus:

1. Commence by galvanisation of the vagi.
2. If this fails, try faradisation of the œsophagus.
3. As a last resort, give intra-œsophageal galvanisation of feeble intensity, or if the symptoms warrant it, proceed to the electrolytic treatment used in organic stricture. *Larat* has had a brilliant success by this latter method.

531. **Organic Stricture of the Oesophagus.**—The remarks we have already made on stricture of the urethra are applicable to stricture of the œsophagus.

There are two modes of operating, by linear electrolysis and circular electrolysis.

Linear electrolysis should only be employed if other methods fail. It is practised by means of a special instrument like a urethrotome. This is connected to the negative pole.

The circular method has given most excellent results in the hands of many operators, *Harvey, Sletoff, Pastnikoff, Bergonié, Ravarit, Bordier* and others.

Harvey employs a sound with an olive shaped end.

We much prefer the bougie with ring shaped electrode, designed by *Bergonié*. The reasons for our preference we have already pointed out in the article on stricture of the urethra.

The technique is the same as for stricture of the urethra, the olive or ring being connected to the negative pole. The intensity varies between 10 and 40 milliamperes.

In some cases it may be necessary to apply cocaine to the pharynx.

532. **Nervous Vomiting.**—We have already described the treatment for the obstinate vomiting of pregnancy. Nervous vomiting in general may be treated in the same manner.

Semmola, Brenner, Tripier, de Watteville, Apostoli and others have obtained good results by various methods. *Gautier* and *Larat* follow *Semmola's* procedure, and their careful observations leave no doubt as to the value of the method.

The continuous current is employed, a small positive pole being applied on the right side, over the interval between the heads of the sterno-mastoid muscle and above the clavicle.

The negative electrode placed over the pit of the stomach should measure 13 cm. by 9 cm. Intensity, 8 to 10 milliamperes.—Duration, 10 to 30 minutes several times in the day.

After the first application the patient should be able to drink a cup of milk.

The technique differs but little from that which *Bordier* has laid down for the vomiting of pregnancy.

533. **Dilatation of the Stomach.—Neuro-motor Dyspepsia.**—Radio-diagnosis affords but little help in this disease. Occasionally when examining the thorax we may see below the cardiac shadow a more transparent area in-

dicating the position of the stomach distended with gas. *Leven* was able to measure the stomach by making the patient swallow a hard pill containing half a gramme or more of sub-nitrate of bismuth. Such a pill can be clearly seen on the screen. The patient is first placed in a vertical position, and the projection of the pill is marked on the skin. He is then placed on his left side and the projection of the pill, which has fallen to the lowest part of the stomach, is again marked. This process is repeated for the right side, and in this way an orthodiagraphic projection of the stomach may be made on the skin[1].

Béclère's iris-diaphragm may be used with the orthodiagraph described in par. 426. The patient should be placed on a narrow table interposed between the tube-holder and the screen.

Electro-therapeutics.—When there is well-marked dilatation of the stomach, complicated by symptoms of auto-intoxication, great improvement may be expected from stimulation of the unstriped muscular tissue of the stomach.

Two methods may be used:

1. *Intra-stomachic electrification* by *Max Einhorn's* method.

An olive made of ebonite and pierced with holes is introduced into the stomach. The cavity of the olive is provided with a metallic electrode in communication with a well-insulated flexible electrophore. A glass of water is given to the patient, fasting, and the olive is swallowed with a mouthful of the liquid. The stomach may then be faradised by connecting the olive to one pole of a coil and passing a rolling electrode over the epigastrium. Or it may be galvanised by joining the olive to the cathode and passing the anode over the epigastrium.

The electrode may be easily withdrawn by making the

[1]Leven. Société Biol., Oct. 25, 1903.

patient swallow at the moment when it passes the pylorus.

2. *The cutaneous method* is more frequently employed and often gives most excellent results.

We may commend the treatment by Morton's currents. I have often had occasion to witness the efficacy of this treatment, especially in the case of young patients.

The active electrode is a bare metallic ball. This is connected to the external armature of the condensor, which is suspended from the positive collector. The external armature of the condensor on the negative collector is earthed.

The patient, who need not be insulated, is placed on a couch, or lying well back in a chair. The metallic ball is applied to different points of the epigastric region, changing the position suddenly and not gliding it along the skin, which would cause unnecessary pain.

The intensity may be regulated by altering the spark gap. It should be pushed to a point which causes a painful sensation. The contraction of the abdominal muscles is then very obvious. Eructations are often produced during the seance. Duration, 15 to 20 minutes.—Seances every day or every two days. In default of *Morton's* apparatus, we may use the faradic current, the Watteville current, or the sinusoidal current. The indifferent electrode should be placed on the back, at the level of the 8th dorsal vertebra, while the active electrode is passed over the epigastric region by means of a large roller or pad.

A similar method may be adopted in the treatment of dyspepsia without dilatation, due to neurasthenia. In this affection the stomach is distended during digestion, but there is no "clapotement" in the early morning when the stomach is empty. In these cases we may apply the same treatment as in dilatation of the stomach, in addition to the general electrical treatment for neurasthenia.

534. **Constipation.**—One must distinguish between habitual constipation and that which is due to entero-colitis. Moreover, habitual constipation may itself be divided into two varieties, the one resulting from atony of the intestine and the other from spasm of the unstriped muscle.

The great error of medical electricians has been to treat all constipations as atony of the intestines.

535. **Constipation due to Atony of the Intestines.**—This form, which is principally met with in aged patients, is usually accompanied by relaxation of the abdominal walls.

The contents of the intestines form voluminous masses. There may be partial spasm in addition to atony of the intestines, in which case the spasm has probably preceded the atony, and it should, therefore, be treated in the same manner as the purely spasmodic variety and not as constipation due to atony.

In addition to general and alimentary hygienic treatment, the patient suffering from atonic constipation should be subjected to systematic gymnastic exercise of the intestines, in order to restore their tone. Massage, Swedish gymnastics and vibro-therapy are of less service than electrical treatment, which may be given under various forms.

a. *Faradic Current.*—The faradic, or, better still, the galvano-faradic current, may be given by employing two external electrodes as recommended by *Bénédikt,* or one electrode may be introduced into the rectum. The rectal electrode may be a metal olive as used by *Erb,* or a liquid enema as recommended by *Boudet.*

Bénédikt's procedure consists in placing a large anode on the lumbar region and passing a small cathode over the region of the cæcum and colon.

The intensity of the current is pushed as far as the patient will bear.

Intra-rectal faradisation by Erb's method consists in introducing an olive shaped electrode for a distance of 6 to 8 cm. into the rectum. The conducting bougie is connected to one end of the coil, while the other electrode is placed on the abdomen or lumbar region.

Boudet's method, by means of an enema, is described in the article on intestinal occlusion.

b. *Galvanic Current.*—For constipation the galvanic current should be used in its variable form, intermittances and reversals of the current being produced by means of a metronome. The intensity should be pushed to the limits of tolerance. Either the cutaneous or the rectal method may be employed. In the former, the passive electrode is placed on the lumbar region, and the active electrode is passed over the region of the cæcum and colon, and more especially over the left iliac fossa. In the intra-rectal method either an olive or an enema may be used in the same manner as for the faradic current.

c. *Hertzian Franklinisation.—Morton's currents.—The* treatment by Morton's currents tends to replace the preceding methods, as, owing to their powerful influence on the unstriped muscular tissue, the results are more rapid.

Patients with atonic constipation usually also suffer from dyspepsia and dilatation of the stomach. In these cases treatment by Hertzian franklinisation is particularly indicated.

Morton's currents should at first be applied by the cutaneous method. If this fails the intra-rectal method may be adopted. The cutaneous method is carried out in the manner described for dilatation of the stomach. The metal ball should be moved from place to place over the region of the cæcum and colon and the left iliac fossa. The balls of the spark gap should be gradually separated until we feel those well-marked, deep-seated massive contractions which characterise the action of the Morton currents.

The intra-rectal application is made by means of electrodes of various shapes. That of *Bordier* is very convenient. It consists of a metal rod covered by an ebonite sheath, and ending in a bare metal cylinder, which constitutes the electrode. A handle placed at an angle of 70° on this rod allows the patient to hold it in position himself. The electrode is provided with a hook which connects it by means of a chain to the positive condensor of *Morton's* machine. The chain of the negative condensor is earthed, and the patient is not insulated. The duration of the seance is 10 to 15 minutes.

536. **Spasmodic Constipation.**—This form of constipation, which is more frequent in young subjects suffering from neuropathy or neurasthenia, has been particularly studied by *Delherm,* who published an inaugural thesis on the subject in 1903. In these cases the fæces are in the form of a thin ribbon, or broken up in small hard nut-like masses.

Active treatment, which gives such good results in atonic constipation, is useless in the spasmodic form. These cases are best treated by soothing means, compresses, emollient baths, or copious enemata of olive oil. Even massage should not be used in these cases, or only in the form of effleurage. (*Mazeran, Froussard.*)

Delherm made experiments on guinea pigs, which were submitted to radioscopic examination after the introduction of bismuth sub-nitrate into the large intestines. He found that even cutaneous electric stimulation produced a temporary constriction of the intestine. Thus electric treatment can only augment the spasm in these cases. Still more are intra-rectal applications or electric enemas contra-indicated.

Clinical experience shews that after some apparent temporary improvement, the electric enema aggravates the condition of the patient suffering from spasmodic constipation.

The following is the technique prescribed by *Delherm* and *Laquerrière* in cases of spasmodic constipation:

1. The intestine is galvanised by currents of high intensity applied by means of two large electrodes of at least 200 sq. cm. applied one on the abdomen and the other on the lumbar region.

2. The faradic current may be combined with the galvanic current, using a fine wire coil and rapid interruptions. The best method is to use the Watteville current, which consists of the two currents applied simultaneously by the same electrodes.

The circuit is joined up so that the coil may be in series with the galvanic circuit, and the two currents in the same direction.

The rheostat or potential reducer in the galvanic circuit is adjusted so as to give 50 to 150 milliamperes, after which the faradic waves are gradually introduced, using a very fine-wired coil and as rapid a break as possible. The direction of the current is of no great importance. Duration, 10 to 15 minutes without reversal or intermission.

It may seem singular that the galvano-faradic current employed by *Erb* and *Broese* for atonic constipation is also found useful in spasmodic constipation.

For the treatment of intestinal atony we endeavour to provoke deep, slow contractions of the muscular coat, such as are produced by the Watteville currents with a coarse-wired coil and slow interruptions.

The Watteville current, however, acts in a perfectly different manner when a fine-wired coil and a rapid break is used. We get a fine tremulous action which does not stimulate the muscular coat to contract, but exhausts its irritability and diminishes its sensibility.

There are thus two distinct methods of using the Watteville current. In the first method we use a coarse-wired coil and slow interruptions. In the second we use a strong galvanic current, and a feeble faradic current from a fine-wired coil, with high frequency of interruption.

The first method is to be used in atony of the bowels and the second in the treatment of spasmodic constipation. There is a similar distinction in the treatment by massage. In the atonic form we use deep massage in order to provoke contraction of the bowels, whereas in the spasmodic form we make use of effleurage and light vibratory massage to diminish the irritability of the bowel. In a similar way a railway journey often arrests the diarrhœa of tuberculous patients. (*Trousseau.*)

In spasmodic constipation with neurasthenia we may employ the static breeze over the iliac fossa.

537. **Muco-membranous Colitis.**—*Doumer* and *Delherm* have both made a special study of muco-membranous colitis, a disease characterised by constipation, spasm of the intestines, pain, and the presence of a glairy or muco-membranous discharge in the stools. In some instances there are periodic crises of diarrhœa, and in rarer cases the diarrhœa is permanent.

The treatment should be of a soothing nature, as for spasmodic constipation.

1. The abdomen may be galvanised. Two plates of 60 to 80 sq. cm. are placed one in either iliac fossa, and connected to the two terminals of the battery. Or the two plates may be connected in parallel, while the indifferent electrode is placed on the loins. This method should be employed when the colitis is accompanied by diarrhœa or pain. (*Delherm.*) *Doumer* employs the same method, using two pads 6 centimetres in diameter placed in the iliac fossæ.

The direction of the current should be frequently charged by diminishing it gradually to zero and then increasing it slowly in the opposite direction.[1]

2. The intestine may be treated by *Delherm's* method, as in the treatment of spasmodic constipation.

In all cases of constipation, whatever the form, the previous treatment by laxatives or enemata should only be slowly abandoned. According to *Delherm* it requires over 30 seances to produce a durable result, beginning with daily seances and gradually reducing the number to one a week.

It is difficult to determine what is the exact mode of action of the currents on the intestines in cases of colitis. Experience shews that there is hypersecretion from the intestinal glands under the influence of the continuous currents. Galvano-faradic currents from a fine-wired coil with frequent interruptions also augment the secretion, probably in consequence of gentle massage of the walls of the bowels.

Probably also the current exercises a specific action on the solar plexus. In an interesting work published in 1904 *Truelle* endeavours to formulate the precise action of the different forms of the electrical current on the intestines. The question still remains in the debatable stage, and we have, therefore, only given the clinical results.

538. **Intestinal Occlusion.**—It is well known how difficult it is to diagnose the cause of the occlusion when we are called on to treat a patient who can pass neither fæces nor wind. This is occasionally the case even after an exploratory laparotomy. Before proceeding to a surgical operation, we should have recourse to the *electrical enema*, a mode of treatment which has often given most excellent results.

Technique of the electrical enema.—It is due to the labours of *Boudet* of Paris that the technique of the treat-

[1] Doumer, Annales d'Electrobiology, May and June, 1901.

ment of occlusion has been perfected. The faradic current had been previously employed by *Leroy d'Etiolles* in 1825, and by *Duchenne,* of Boulogne, and *Bucquoy,* in 1878. The galvanic current had also been employed by *Leroy d'Etiolles* in 1876. It was in 1884 that *Boudet,* of Paris, published the results of his treatment, which has since become classic. His method guards against the accidents which were previously too common, the most formidable of which was the sloughing of the intestine when the current was passed into the rectum by means of metal electrodes.

Boudet's method consists in introducing a large quantity of saline solution into the rectum by means of a canula of his own design. The current is passed between this intra-intestinal liquid electrode and an abdominal electrode.

Boudet's sound or canula consists of a metallic tube of lead or flexible metal insulated by a sheath of hardened rubber.

The insulating tube is longer than the lead tube. It is perforated near the extremity by a lateral aperture and is connected by means of an india-rubber tube to a large irrigator holding 2 litres. The inner lead tube is connected to the electric source by means of an insulated wire. In June, 1901, *Lacaille* exhibited to the Société d'Electrothérapie a sound in which the leaden tube is replaced by a spiral brass spring.

The abdominal electrode should measure at least 200 sq. cm.

Each electrode is joined to one pole of the battery, and the current reverser is turned so as to connect the sound to the negative pole. The sound, well coated with vaseline, is then passed into the rectum. It may be difficult at first to introduce it for its whole length, but the difficulty may be overcome by allowing some of the saline solution to flow into the bowels. The sound will then be found to slip forward when a little gentle pressure is used.

When the sound is in place, about a litre of the saline solution is allowed to enter the bowel. The irrigator is then lowered and the tap turned so that a small quantity of water may continue to flow into the bowel during the operation. In this way we avoid all danger of producing a burn in consequence of a portion of the liquid becoming isolated in a fold of the bowel, thus reducing the volume of the liquid electrode. With too little water there is a sudden fall of intensity of the electric current, which immediately rises again when more water is introduced.

The current is turned on and gradually raised to 20, 30 or 40 milliamperes, maintained for 5 minutes, and then gradually reduced to zero. The current is then reversed so as to make the rectal electrode negative. A metronome with 5 seconds' interruption is now introduced into the circuit, and the interrupted current is gradually increased. In this way violent contractions of the abdominal muscles are produced which are easily felt by the hand.

When a metronome is not available we may employ an interruptor, or use the reverser as an interruptor, or we may make and break contact between the terminal and the sound.

This may be continued for 5 to 20 minutes, according to the effect produced and the condition of the patient. The liquid will be expelled in jerks, shewing the effect of the current on the intestinal pressure. An evacuation may occur immediately after the enema has been given, or more frequently in the course of two or three hours. If there is no result the operation may be repeated.

Indications and contra-indications for the electric enema.—*Painetvin* has shewn us how to distinguish between mechanical occlusions, mechano-dynamic occlusions and dynamic occlusions. Among mechancial occlusions are volvulus, torsions, invagination, abnormal flexion, bridles, rings, tumours, etc.

The utility of the electric enema has sometimes been contested in cases of mechanical occlusion. If the mechanical obstacle is not very strong, moderate contractions may overcome it. Moreover, there is a diminution of meteorism under the action of the current, as though there were some resorption of gas. It is essential to act promptly and prudently, so as not to interfere with surgical intervention if this should become necessary.

The electrical enema is more certain of success in the second form of occlusion, when there is a mechanical obstacle insufficient of itself to cause occlusion, with spasm of the gut around the obstacle, or atony of the intestine behind it. This form is found in patients suffering from biliary calculi, intestinal worms, or cancerous lesions which form an incomplete obstacle.

The electric enema is still more efficacious in the third form, where the occlusion is wholly dynamic. Thus the obstruction due to chronic constipation, whether due to spasm or atony of the bowel, is speedily relieved.

The only contra-indication to its use is the presence of ulceration or perforation of the intestines accompanied by severe peritonitis or collapse.

Peritonitis alone, unaccompanied by perforation, is no contra-indication to its use, since all cases of occlusion are accompanied by a certain amount of peritonitis.

A second contra-indication is suppuration and adhesions of neighbouring organs, since the electric enema might produce rupture of the adhesion. The use of the electric enema is contra-indicated when the patient is pregnant. The risk is, however, only comparative. There is, it is true, a risk of producing abortion, but this may be necessary in order to save the mother.

539. **Prolapsus of the Rectum.**—The galvanic current is very efficacious in this affection.

The prolapsus should be reduced in the usual manner. A cathode consisting of an olive-shaped electrode surrounded by cotton-wool is placed over the anus, while the anode is placed over the loins.

The current may be gradually raised to 20 or 30 milliamperes for 5 minutes, and the seances repeated every other day.

540. **Paralysis of the Sphincter Ani.**—In this affection electrical treatment is almost always successful, except where the paralysis is of spinal origin. The rhythmic faradic current is used, with 30 beats of the metronome per minute. (*Bordier*). An olive-shaped electrode is introduced into the anus, or the rectal manometric electrode designed by *Bergonié* may be used. This is a hollow ebonite cylinder with a metallic armature at its extremity. The cylinder is pierced by two windows and contains the ball of one of *Potain's* sphygmo-manometers, the thin walls of which are in contact with the windows in the cylinder. In this way the force of the contractions may be measured.

541. **Hæmorrhoids.**—*Doumer* was the first to employ high frequency currents in the treatment of hæmorrhoids. We may use *Oudin's* electrode with glass handle, or the cone-shaped metal electrode designed by *Doumer*. I prefer the latter, since by its means we may dilate the anus, taking advantage of the anæsthesia caused by the high frequency currents. It has the further advantage of being painless even with the full intensity of the current, and it is not liable to get broken. The electrode is joined up to some form of resonator, either helix, coil or spiral. The following is the method I adopt: I place the patient in the gynæcological position, taking care to have my movable table of distribution close to the patient.

I start the high frequency apparatus first of all and I take the electrode connected to the spinal in my hand to make sure that all is working well.

I turn off the current, and gently introduce the electrode, well covered with vaseline, into the anus. I then turn on the current. In this way I avoid the sparking which occurs on bringing the electrode near the patient. Seances of 5 to 10 minutes may be given three times a week.

It is very rare that one does not get some improvement by this treatment, although the results are much more rapid in acute cases than in chronic hæmorrhoids.

542. **Fissure of the Anus.**—*Doumer* was also the first to point out the excellent results obtained by high frequency treatment in fissure of the anus. He uses an electrode with a thick glass handle. This should be well lubricated with vaseline and passed well up into the rectum, so as to be in contact with the whole breadth of the sphincter. In nervous patients, when the introduction is too painful, it may be well to allow the electrode to rest on the margin of the anus until anæsthesia is produced. The intensity should be increased very gradually. We may also employ *Doumer's* conical electrode, which has the further advantage of dilating the sphincter. It seems, however, that the short sparks which come from the glass electrode have a beneficial influence in this affection.

A seance of 3 to 10 minutes may be given three times a week. The results are usually rapid.

543. **Pruritus Ani.**—Pruritus Ani may be treated according to the general principles laid down in par. 478. Very satisfactory results may be obtained by the use of high frequency currents applied by means of a condensing electrode introduced into the anus, as for cases of fissure. The seance may be terminated by effleuvation of the whole region.

CHAPTER XII.

DISEASES OF THE EYES.

544. **Trichiasis.**—This affection should be treated by epilation by means of electrolysis. The operation is the same as for general epilation. A steel needle is introduced into the follicle parallel to the eye-lash. A current of 2 milliamperes is passed for 20 or 30 seconds. Before the operation it is advisable to procure local anæsthesia by the use of cocaine.

545. **Trachoma.**—This affection may be treated by pricking each granulation with a steel electrolytic needle. The procedure is, however, very painful. Treatment by copper electrolysis may also be employed. A small copper electrode of special construction is connected to the positive pole. The indifferent cathode is placed on the nape of the neck. We may pass from 2 to 4 milliamperes for 1 to 3 minutes, moving the active electrode continually to obviate any adherence of the electrode to the tissues.

546. **Entropion.**—The best treatment of this affection is the electrical one. A steel needle should be introduced parallel to the free border of the lid, from one to three millimetres from the edge. This should be connected to the negative pole, the indifferent anode being placed on the nape of the neck. A current of 5 to 8 milliamperes is passed for 6 to 8 minutes. The cicatricial retraction following this operation raises the edge of the lids. This result is noticeable in about a fortnight. If this is not obtained the operation may be repeated.

547. **Xanthelasma.**—This affection may be treated ac-

cording to the method described for xanthoma (par. 490.) A negative needle is introduced into the patch, parallel to the skin, and this is connected to the negative pole. A current of 6 to 10 milliamperes is passed for 2 or 3 minutes. Several parallel punctures at a distance of 6 millimetres may be made during the same seance. The slough comes away in about ten days, and the operation may be repeated if necessary after a fortnight's interval.

548. **Blepharitis.**—*Freund* and *Schiff* obtained the cure of blepharitis, both of the squamous and ulcerative varieties, by means of a few radiotherapeutic seances with a hard focus tube. It is not, however, necessary to use a hard tube. As in all cases where we desire to act superficially, rays of penetration Nos. 4 and 5 are indicated. It should not be forgotten that the chemical rays of the spectrum and probably also the X-rays are capable of producing blepharitis. It is advisable, therefore, to act with prudence in the application of the treatment.

549. **Stricture of the Lachrymal Ducts.**—This affection may also be treated by electrolysis. It was first practised by *Tripier* and *Desmarres,* and has been modified by *Lagrange,* whose method is one to be followed.

He uses a *Bowman's* sound of silver, insulated up to a distance of 3 centimetres from its end by a coat of insulating varnish to protect the lachrymal canaliculi and the edge of the lid. The current is gradually raised to 5 milliamperes, maintained at this level for four minutes, and decreased gradually to zero. Seances may be repeated every 8 to 10 days, the duct being treated in the interval with antiseptic injections.

550. **Paralysis and Spasm of the Ocular muscles.**—It is impossible to test the ocular muscles for purposes of diagnosis. Contraction *en masse* may be induced by applying one electrode to the closed eye-lids and the other to the

nape of the neck. This method may be employed in peripheric paralysis *a frigore,* of rheumatic or traumatic origin.

The continuous current may also be used. The cathode should be applied to the eye-lids and a current of 3 to 5 milliamperes passed for 6 to 10 minutes. Or the rhythmic faradic current may be employed with a button-shaped cathode applied as near as possible to the paralysed muscle. The duration of the seance should be five minutes, and the intensity may be pushed till we get forcible contraction of the orbicularis palpebrarum.

Spasm of the ocular muscles may be treated by the continuous current, or in hysterical cases, by the electrical treatment appropriate to its cause.

551. **Keratitis—Leucoma—Corneal Opacity.**—Various observers have obtained excellent results in the treatment of parenchymatous keratitis accompanied by ulceration or pannus. The eye is submitted to the action of the continuous current with the cathode on the eye-lid. A current of 3 to 5 milliamperes may be used for 15 to 20 minutes.

Opacities, even of long standing, are amenable to this treatment. Two remarkable cases of success attained by *Gautier* and *Larat* are reported by *Arcoleo.*

Some authorities apply the current directly to the cornea by means of a small electrode of cotton-wool, a sponge, or a camel's hair brush. *Larat* and others prefer an active cathode of cotton-wool applied to the closed eye-lids, with a current of 6 to 8 milliamperes for 5 minutes.

In commenting on some successful cases by this method *Larat* says: "It is probable that the vitality of the cornea is increased, and that the cellular exchanges, usually so slow in the cornea, are stimulated so as to produce absorption of the cells which have been infiltrated by previous inflammatory action."

552. **Iritis and irido-choroiditis.**—Galvanisation should be used in this disease according to the method advocated by *Dr. Pansier,* of Avignon. An anode is placed on the mastoid process and a cathode on the closed eye-lids. A current of 2 to 4 milliamperes may be given with a duration of 20 to 25 minutes. A drop of atropine should previously be instilled into the eye. The treatment results in an immediate cessation of pain. In cases of old iritis with synechiæ there is a partial or total breaking down of the adhesions.

553. **Opacity of the Vitreous body.**—*Giraud-Teulon, Onimus, Baucheron, Abadie* and *Terson* have obtained undoubted good results in the treatment of opacities of the vitreous body. *Giraud-Teulon* applies an anode on the eyelids and a cathode on the mastoid process.

Onimus, on the contrary, places the cathode on the lids and an anode on the superior cervical ganglion of the sympathetic.

It does not appear that the direction of the current is of any great importance, so long as the transparent media of the eye are situated in the field through which the lines of electric flux pass. A current of 3 to 4 milliamperes should be given for 3 to 5 minutes. *Bordier* recommends 3 to 5 milliamperes for 3 to 5 minutes, repeated three times a week. *Abadie* and *Terson* have obtained surprising results by electrolysis practised by means of a needle thrust into the vitreous body for a depth of 8 millimetres.

554. **Glaucoma.**—*Allard* galvanises the sympathetic in the neck. He places the anode along the whole length of the cervical sympathetic, the cathode being placed on the back of the neck of the opposite side. Intensity, 15 to 20 milliamperes.

The results are often remarkable. In all the cases treated by *Allard* the pain has rapidly diminished, and in some instances the vision has been improved. In two cases normal acuity of vision returned.

Other operators galvanise the eye-ball directly by means of an anode applied on the eye-lids. Intensity, 4 to 6 milliamperes; seances, 10 to 15 minutes, repeated daily.

555. **Detachment of the Retina.**—The detachment of the retina is due to the presence of liquid between the retina and the choroid. Treatment should be directed so as to cause the absorption of this liquid. Electrolysis occupies the foremost place in this respect, and when the detachment is recent it offers a good chance of success.

Gillet and *Grandmont* published an interesting case. *Terson* especially has demonstrated the good results obtained by positive electrolysis in this affection. A platinum needle is passed into the eye so as to reach the locality of detachment. This is a delicate operation and, it is needless to say, can only be performed by a specialist. In consequence of the difficulty of piercing the sclerotic, which is depressed by the pressure of the needle, *Gayet* and *Bordier* mount the needle on the corneal drill designed by *Mathieu.* This gives it a rapid movement of rotation and enables it to pierce the sclerotic easily. When the needle is in position a current of 5 milliamperes is passed for one minute. The first effect of this is to coagulate the liquid. According to *Terson's* report, there is in most cases a temporary, and in recent cases a permanent improvement.

556. **Optic Neuritis—Atrophy of the Optic Papilla.**—The failure of all other modes of treatment warrants us in trying electricity in optic neuritis, although the intervention is not often crowned with success. Nevertheless, good results have been published by *Dor, Erb, Pflüger, Rumpft* and *Bénédikt.* The continuous current is to be employed. The active cathode, of moistened cotton-wool, is placed on the

closed eye-lids, the indifferent electrode being placed on the neck. Intensity, 3 to 5 milliamperes. Duration, 7 to 8 minutes. Seances every day.

The application may be terminated by a few interruptions of the current by means of the metronome. *Erb* recommends, in addition, traverse galvanisation of the head, with an electrode on either temple.

There have been some reports from America of satisfactory results from treatment with X-rays, but these have not been confirmed.

557. **Foreign Bodies in the Eye.**—A long chapter would be needed to fully discuss the diagnosis and treatment of foreign bodies in the eye. We can only give a few indications here.

Diagnosis.—The X-rays are of great use in enabling us to determine the presence of foreign bodies in the orbit. When the foreign body is in the eye itself the examination should be made with the patient in the sagittal position. The focus tube should be placed so that the normal ray may fall just behind the temporal region, and the screen should be placed at an angle of 30° with the sagittal plane of the patient's head. On page 982 of *Bouchard's* Traité de Radiologie Médicale will be found *Guilloz's* article on the localisation of a foreign body in the eye, by observing its parallax during rotation of the eye-ball.

Radiography enables us to localise a foreign body with even greater precision. We may use the stereoscopic method of *Marie,* the procedure of *Contremoulins,* or the method of *Guilloz* or *Massiot's* compass. A description of these may be found in *Guilloz's* article.[1]

Extraction.—The extraction of a foreign body from the eye belongs to the domain of the oculist. When it consists of fragments of iron and steel we may have recourse to the electro-magnet. Either the large magnet of *Haab* may be

[1] See also the thesis of Braunberger, Paris, 1903.

used, or the smaller magnet of *Hirschberg*. According to *Turk's* experiments, both of these instruments have an equal action when placed at a distance of 1 millimetre from the foreign body. At a longer distance the smaller magnet rapidly loses power. The larger magnet should then be used, but should not be approached suddenly to the eye, so as to avoid any tearing of the wound by the too rapid attraction of the steel particles.

In the long standing lesions, if the foreign body is in the posterior chamber it is wiser to abstain from all intervention. (*Holmström*). The extraction may cause still further traumatism.

In two instances *Holmström* has seen atrophy of the eye follow exhaustion. He has also met with a case of detachment of the retina occurring after sclerotomy and the introduction of *Hirschberg's* magnet into the vitreous humour. He prefers to draw the foreign body towards the iris or the anterior chamber by means of *Haab's* magnet, extracting afterwards by a keratotomy and the use of *Hirschberg's* magnet.[1]

[1] Archives d' Electricité Médicale, 1901, p. 637.

CHAPTER XIII.

MALIGNANT TUMOURS.

558. **Sarcoma.**—Sarcoma, as is well known, is a tumour composed of embryonic cells—that is, cells which are non-differentiated or are only commencing differentiation. This fact gives to sarcoma an appearance like connective tissue (fasciculated sarcoma), or myeloid, or osseous (ossifying sarcoma, epulis), or like neuroglia (glioma). Sarcoma is the more malignant the nearer the cells approach to the embryonic type.

Encephaloid sarcoma, which is the most malignant type, consists of cells which are entirely embryonic in character.

This variety in the nature of sarcoma in a measure explains the divergent opinions held as to the efficacy of the X-rays in its treatment. While some authors deny that sarcoma is influenced by the X-rays, others, like *Kienböck, Morton, Brocq, Sabouraud, Béclère, Bisserié* and *Belot,* have adduced positive evidence as to its value, and *Holzknecht* goes so far as to assert that sarcoma is even more amenable to treatment than epithelioma.

Opinions also differ as to the mode of application. *Belot,* basing his experience on the technique used in *Brocq's* clinique, recommends massive doses of 7 H to 10 H, given in one or two seances. He found that a sarcomatous tumour, which had been treated in vain by a long series of small doses at short intervals, was speedily diminished by a few massive doses.

To determine once for all this question of dose some such experiment as the following should be made: One series of cases should be treated during two months by 15 exposures of 1 H or 2 H, while a similar series should be treated with massive doses of 10 H, followed, after an interval of six weeks, by another of 5 H.

This question of dose can only be settled by a comparison of results. A massive dose, *i.e.,* the maximum quantity which is compatible with the integrity of the superjacent tissues, produces withering and arrest of development of embryonic tissue. The withering action on the primary cells is shown by swelling of the nucleus, difficulty of staining and granular degeneration of the protoplasm. We have already seen that a massive dose produces destruction of the hair papilla without injury to the epidermis (496, 497), and that it can produce azoospermia without injury to the integuments of the scrotum. In consequence of the greater susceptibility of rapidly growing cells, it is conceivable that we may be able to arrest their evolution by irradiation without injury to the normal cells. On the other hand, it has not been proved that the dose must necessarily be given at a single sitting. Theoretically, the method by successive doses is just as likely to succeed.

Experience proves that the effect of a quantity 10 H of No. 5 rays is exactly the same whether it be given in a single dose or in a series of doses at short intervals. This assertion is subject to some limitation. There is no doubt a process of repair between each exposure—a repair which is useful in preventing injury to the healthy tissues, but may also diminish the destructive effect on abnormal tissue. If then we decide to act by means of successive fractional doses, we have to take into consideration this reparative action.

A priori we should expect that the reparation of the normal cells would be more rapid than that of the abnormal cells. Abnormal cells develop in spite of the resistance of their neighbours, and in spite of the ordinary defence of the organism, that "vis medicatrix naturæ" which opposes itself to all deviation from the normal type. This vis medicatrix has been vanquished in its opposition to the growth of the tumour. It will now play a double rôle; it will aid the reparation of the healthy cells, and it will at the same time oppose itself to the reparation of the abnormal cells.

Treatment by successive doses has a double action, depending on the inequality of the destructive action of the rays on healthy and diseased tissue, but also on the inequality of their reparation under continued irradiation. The treatment by massive doses depends only on the inequality of the destructive action of the rays on healthy and unhealthy tissue. In the case of deep-seated tumours the superficial tissues will absorb the more active rays, and thus the differential action on normal and abnormal structures will be partially compensated.

In the treatment of deep-seated tumours, therefore, it is better to proceed by repeated fractional doses, thus calling to our aid the inequality of the reparatory processes.

Morton, of New York, has devised a special procedure, which appears to have given good results in the treatment of sarcoma. It consists in the injection into the tumour of a solution of bichloride of quinine, which becomes phosphorescent under the action of the X-rays. The tumour is thus exposed simultaneously to the action of the X-rays and to the violet and ultra-violet rays emitted by the fluorescent salt.

Von Tappeiner noticed that certain fluorescent substances after exposure to the sun's rays become toxic to the lower organisms. They are also destructive to the ciliary motion of the epithelium (*Jakobson, Jodlbauer*). A 5 per cent aqueous solution of eosine is very efficacious in this respect. By its use *Jakobson* and *Jodlbauer* have sucessfully treated certain infectious dermatoses, such as lupus, cancer and syphilis. During the day the affected part was exposed to the sun under a bandage impregnated with fluorescent solution, while during the night it was covered with a plaster of oxide of zinc.[1]

559. **Epithelioma—Carcinoma.**—If we may rely on the very complete bibliography given by *Belot,* it would appear that the first experiments for the radiotherapeutic treatment of cancer were made by *Despeignes,* of Lyon, in 1896, some three or four years before the appearance of the earliest reports in foreign journals. We must refer the reader to *Belot's* monograph for further details on this subject[2].

It is only quite recently, in 1904, that observations based on precise methods of measurement have appeared, with records of the quality of the rays defined in degrees on *Benoist's* radiochromometric scale, and the quantity in *Holzknecht* units.

In France the labours of *Brocq, Bissérié, Belot, Tuffier, Haret* and *Desfosses* and *Béclère* have furnished us with accurate data for intervention. Previous observations were not without value, although lacking in the all-important data of measurement.

When one is in the habit of using the same installation and similar focus tubes it may be possible to give approximately the same exposure without the use of any measuring instrument, simply by noticing the time of exposure, and the appearance of the focus tube. Practise and daily routine may enable an operator to repeat a given dose with some approach to exactitude, but even then the "personal equation" of the observer comes into question. The great advantage of measurement is that it renders possible the comparison

[1] Münchener Medicinische Wochenschrift, Nov. 24, 1903.
[2] Belot. Radiotherapy in Skin Diseases. Rebman, 1905.

of the observations of different operators. In consequence of the adoption of *Benoist's* and *Holzknecht's* instruments the rules of procedure are more or less established, and the technique has been formulated and may be understood and repeated by practitioners all over the world.

We may now proceed to pass in review the method of procedure for each variety of cancer.

a. *Cancer of the skin.*—First as to the indications for radiotherapeutic treatment.

Where there is a well-defined cancerous nodule with no infection of the glands, we should advise the total ablation of the lesion by means of a surgical operation.

Where there is an affection of the glands this may possibly be non-cancerous and merely inflammatory. Such an adenopathy may frequently be cured by irradiation of the tumour or of the glands themselves. When the glands are already affected X-rays should be used, since one is never sure of getting rid of the whole of the disease by surgical means.

Radiotherapy should be preferred whenever the result of an operation is doubtful.

Where there is a central ulceration, with a hard ring-like margin, the "epithelioma adulta" of *Leredde* and *Hallopeau,* radiotherapy is more especially indicated on account of the very satisfactory results of the treatment.[1]

We should also have recourse to the X-rays in the treatment of widespread cancerous ulceration of the face, since it is surgically inoperable. If there is much redundant growth a previous scraping by means of the curette may be of service (*Belot*).

In epithelioma with pearl-like growths, which, as is well known, is a comparatively benignant form, the pearl-like

[1] This central ulcer with hard margin is apparently the "Rodent ulcer" of English text-books.

excrescenses may be removed by scraping, and the case afterwards treated by radiotherapy.

Carcinomatous nodosities of the skin, such as are frequently seen in cancer of the breast, are best treated by the X-rays.

We may also treat by means of radiotherapy the early forms, such as cancer of the face, while we are still doubtful as to the nature of the case, and are keeping the patient under observation before operation. Cancer of the lower lip is very rebellious to the action of the X-rays, so that it should be operated upon at once whenever possible.

The indications for surgical interference are thus somewhat restricted, and they will become more so as radiotherapeutic treatment improves.

In all cases it may be laid down as a general rule that, after operation we should not wait till the wound is completely healed before commencing X-ray treatment in order to prevent recurrence.

In the treatment of cancer some authorities, such as *Brocq* and *Belot,* give in a single seance the full dose compatible with the integrity of the superjacent tissue, while others, following the example of *Schiff* and *Freund,* use short exposures repeated two or three times a week. I have already given the reasons why I prefer the latter method.

The following is the method of procedure in the Hôpital Broca:[1]

(1) In cases of epithelioma with raised edges, which we may take as a type, 10 H to 11 H is given in one or two seances, taking care to irradiate the sound skin for a distance of at least five millimetres beyond the margin of the lesion. If the disease has attacked a sensitive region, such as the nose, the dose should not exceed 8 H to 9 H. At the end of three weeks another exposure may be given, and this may be repeated every fortnight or three weeks with doses of

[1] Belot. Radiotherapy in Skin Diseases.

5 H to 10 H, according to the degree of reaction and the state of the tumour. The total dose required for a complete cure is from 20 H to 45 H, with rays corresponding to Nos. 5 and 6 on *Benoist's* scale.

The method of fractional doses consists in giving a short exposure two or three times a week, taking care not to set up any reaction above a slight degree of erythema. During the first seance 4 H to 5 H may be given, and this should be followed by still shorter exposures.

In the treatment of cancerous glands rays of penetration Nos. 6 and 7 may be used.

After the first applications the pain diminishes or disappears entirely, the offensive smell is diminished, and there is a temporary increase of the discharge. The raised edge is flattened and the wound diminishes in size.

The mode of operation for the treatment of other varieties of cancer differs but little from the above.

Histological modification in cancerous tissues caused by irradiation with X-rays.—The researches of various authors, and especially those of *Pusey,* have enabled us to observe the action of the X-rays on the evolution of cancerous tumours. At the beginning of the treatment only those cells are affected which are at the periphery of the cancerous islands. Their nuclei are broken up, becoming of a blue tint when stained with hæmatoxylin. The vessels in contact with the new growth become affected with endarteritis obliterans. In section, the subepidermal connective tissue presents bands of fibrous tissue which stain pale blue with hæmatoxylin, showing that the degenerative process, which was at first confined to the periphery of the cancerous islands, is extending through the whole mass of the tumour. It is the cancer cells themselves which are attacked by the X-rays, and take on a special form of degeneration, being ultimately replaced by healthy connective tissue.[1]

[1] Belot. Radiotherapy in Skin Diseases.

b. *Cancer of the Tongue and Mouth.*—The results of radiotherapy in this disease are not so brilliant as those in skin disease. It is better to have recourse to surgical intervention whenever possible, and to treat the patient with the X-rays immediately after operation in order to obviate recurrence. In inoperable cases we may have recourse to radiotherapy, which in certain forms, not at present well defined, gives most excellent results. At all events the X-rays will calm the pain, which is often intolerable in this affection.

The application of the rays is often very difficult in consequence of the position of the tumour. We may use *Oudin's* tube designed for this purpose, or *Belot's* localiser. For those who do not possess these adjuncts I will describe the method which I use myself. A wooden case lined with lead is supported at either end on a suitable stand, so that it can be placed in any position. The focus tube is suspended in the centre of this case, and is separated from the lead lining by plates of glass and oil-silk so as to avoid sparking. A window in the rear enables one to watch the action of the tube. There is an orifice in the side directed towards the patient. The orifice is furnished with a deep rim of lead. When called on to treat cancer in a difficult region I fix a cylinder or cone of lead on this rim and cut it to fit the place of application. In other cases, as in the tip of the tongue, for instance, I fix a metal plate on the patient's skin by means of plaster. An orifice is cut in the plate corresponding to the area to be irradiated, care being taken to keep this area within the limits of the field of irradiation defined by the opening of the tube carrier.

In irradiating cancer of the tongue No. 5 rays should be used.

c. *Cancer of the Breast.*—In 1900 *Gilmann* reported to the Clinical Society of Chicago the first series of cases of cancer of the breast treated by radiotherapy. In the twenty-five cases reported there were only two failures. *Beck, Clark, Hopkins, Mikulicz* and *Fitting, Schiff, Morton* and others have obtained more or less encouraging results. On the other hand, *Coley,* in 1903, declared that in 26 cases, two-thirds of which were round-celled cancers, he only obtained a temporary improvement in four cases. There are no doubt well authenticated cases of cancer of the breast cured by radiotherapy, but there are also many cases of failure.

We may say that the X-rays will almost certainly cure the cancerous ulceration, diminish the pain, and decrease the tumour, and even in certain cases cause its complete disappearance.

According to *Morton,* after operation for cancer the wound should be systematically irradiated so as to obviate any danger of recurrence.

The following are the rules I observe in the treatment of cancer of the breast:—

1. If the tumour is operable, not ulcerated, and the glands of the axilla are not affected, I advise operation. The case to be treated afterwards with X-rays so as to prevent recurrence.

2. If the cancer is ulcerated I commence radiotherapeutic treatment at once, with the certainty of healing the ulceration, but not of avoiding recurrence. At the commencement I employ No. 4 or No. 5 rays, with two seances a week, and when the ulcer has healed, I continue with more penetrating rays, Nos. 7 to 9, in hopes of diminishing the tumour itself.

3. If the case is one of recurrence after operation and

non-operable, with cancerous growths around the cicatrix, cancerous glands, and a tendency to metastasis, I treat with radiations Nos. 7 to 9. In such cases there is not much hope of success. Occasionally, however, one meets with surprising results, and having regard to the inutility of all other modes of treatment, it is the duty of the surgeon to try the X-rays even in the most unfavourable cases.

d. *Deep-seated cancer of the œsophagus, stomach, intestines, kidneys, bladder, etc.*—We have no precise information as to the action of the X-rays in these cases. It should be a general rule to treat all inoperable cases of cancer with penetrating rays, Nos. 7 to 9. In cancer of the uterus we may use *Oudin's* tubes (450), or *Belot's* localiser introduced into the vagina, employing rays of penetration No. 5 or No. 6, and ending up with irradiations of the abdomen, with rays Nos. 7 to 9. One of the most remarkable cases of uterine cancer cured by the X-rays was reported by *M. A. Cleaves,* in 1902. It was an inoperable case of cancer of the neck of the womb, involving the vaginal walls and the broad ligament, the patient being in an advanced stage of cachexia. She was treated by means of an ordinary focus tube placed in front of a *Ferguson's* speculum. Cure resulted after 110 seances distributed over a period of four months, radiotherapeutic and phototherapeutic treatment being used simultaneously.

CHAPTER XIV.

FOREIGN BODIES.

560. **Presence of foreign bodies.**—When the presence of a foreign body is suspected it may be only necessary to decide if such a body be present or not, without determining its exact position. This is the case with a foreign body in the digestive track or the urinary passages, or a calculus of the kidney, or a sequestrum of bone. A screen examination or an ordinary radiograph will be sufficient for this. The fluorescent screen is in some ways more convenient, since by its means we can tell the position of the body with respect to a bone or an organ whose shadow is visible. If the focus tube is moved behind the region to be observed the displacement of the shadow is greater the nearer the opaque body is to the focus tube. By a similar means we may judge of the position of a foreign body in the orbit (557).

In other cases we need to know the exact position of the foreign body in order to extract it.

Two cases occur.

1. *The foreign body is in an accessible position,* the hand or foot, or a limb. It is usually sufficient to examine the region by means of the fluorescent screen, and to note its position with regard to some bone or other anatomical point of reference. Then if we examine it in different positions, with different incidences of the rays, we may judge the position of the body and its depth from the surface. It may be advisable to mark points of reference on the skin. In operating on thicker regions, such as the thigh, it is bet-

ter to have recourse to the more accurate methods of localisation described further on. It may be that we are unable to find the foreign body after we have made the necessary incision. We may then search for it further by means of the screen. In small operations which may be done in the dark room, it is easy to darken the room, replace the patient on the couch, and seek for the object with the assistance of the shadow of the forceps in the wound.

By this procedure I have often been able to remove a needle from the hands or fingers. We must, however, be on guard not to overexpose the patient. It is easy to underestimate the lapse of time when one is seeking for a needle which eludes one's grasp. Moreover, one is liable to bring the limb too near to the focus tube. On one occasion I was more than 40 minutes seeking a needle embedded in the fleshy part of the hand, and produced a dermatitis both on myself and on the patient, the latter passing through all the phases of a lesion of the third degree.

2. *The foreign body may be embedded in an inaccessible region,* the head, the trunk, or the thigh. We must then use measures of greater precision. These may be found described at length in *Bouchard's* treatise. We may employ the stereoscopic method by means of *Marie's* stereometer. Or we may use one of the procedures due to *Mackenzie Davidson* and *Hedley,* to *Rémy* and *Contremoulins,* or those of *Guilloz, Mergier, Londe, Leduc,* or *Massiot.* The method we most commonly employ depends on the principle of the three-legged compass used by sculptors.

This three-legged compass is placed on three points of reference marked on the skin, while a fourth branch gives the direction and position of the foreign body.

The following is the mode of procedure:—

a. Two radiographic projections of the foreign body are made, the compasses having been previously placed on three marked points on the patient's body which enclose the probable position of the object. The patient is then removed and the plates replaced in position.

b. Since we know the position of the centre of emission in each case we can reconstruct the cone of incidence by means of threads. The intersection will give the position of the foreign body in space.

c. After the patient is removed, by means of special apparatus, the three-legged compass may be replaced exactly in the position it occupied when previously placed on the marked points of the patient's skin.

The fourth branch of the compass is brought to touch the intersection of the thread cones and is fixed then in position.

d. On replacing the legs of the compass on the patient's skin the sound will shew the direction and depth of the foreign body.

By this means the surgeon can make use of the compasses in exactly the same way as the sculptor would do.

The above is the mode of using *Massiot's* compasses, which I have already described.[1] It is given as an example of the principle of the various anterior and posterior detectors now manufactured.

[1]Radioscopie et Radiographie clinique de précision. Guilleminot, 1900.

three marked points on the patient's body which enclose the probable position of the object. The patient is then removed and the plates replaced in position.

b. Since we know the position of the centre of emission in each case, we can reconstruct the cone of incidence by means of threads. The intersection will give the position of the foreign body in space.

c. After the patient is removed, by means of special apparatus, the three-legged compass may be replaced exactly in the position it occupied when previously placed on the marked points of the patient's skin.

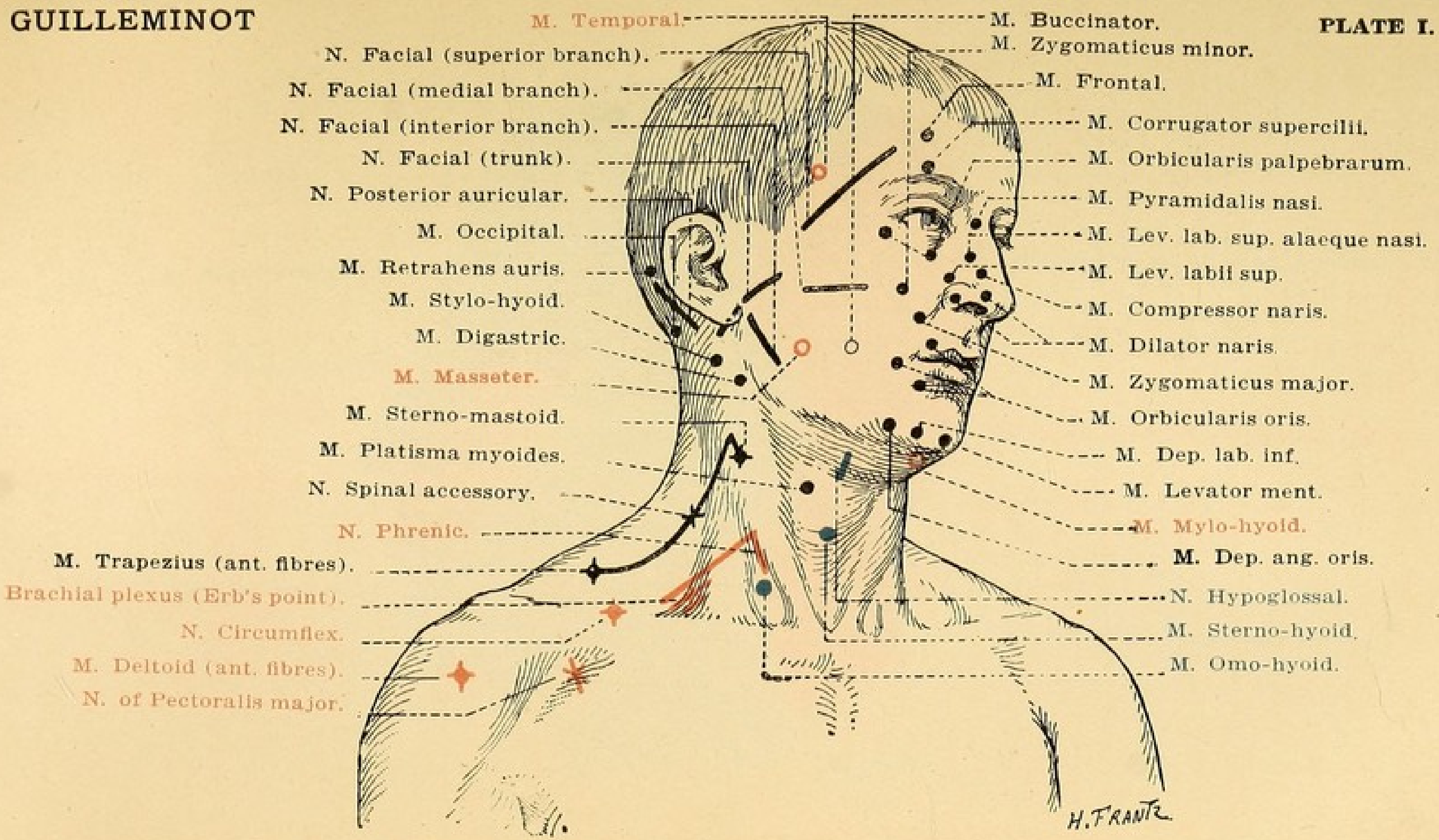
The fourth branch of the compass is brought to touch the intersection of the thread cones and is fixed then in position.

d. On replacing the legs of the compass on the patient's skin the sound will shew the direction and depth of the foreign body.

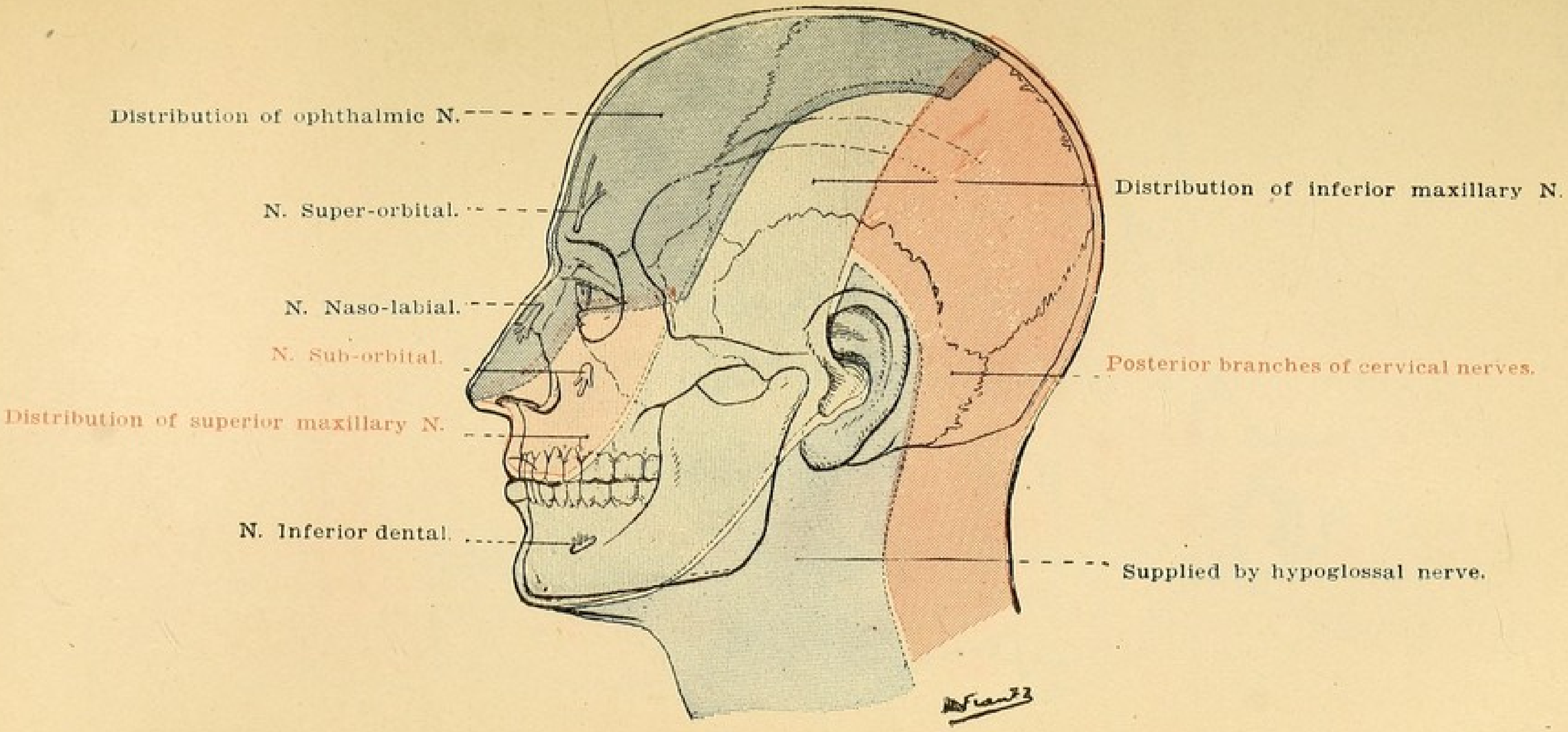
By this means the surgeon can make use of the compasses in exactly the same way as the sculptor would do.

The above is the mode of using *Marion's* compasses, which I have already described.[1] It is given as an example of the principle of the various anterior and posterior detectors now manufactured.

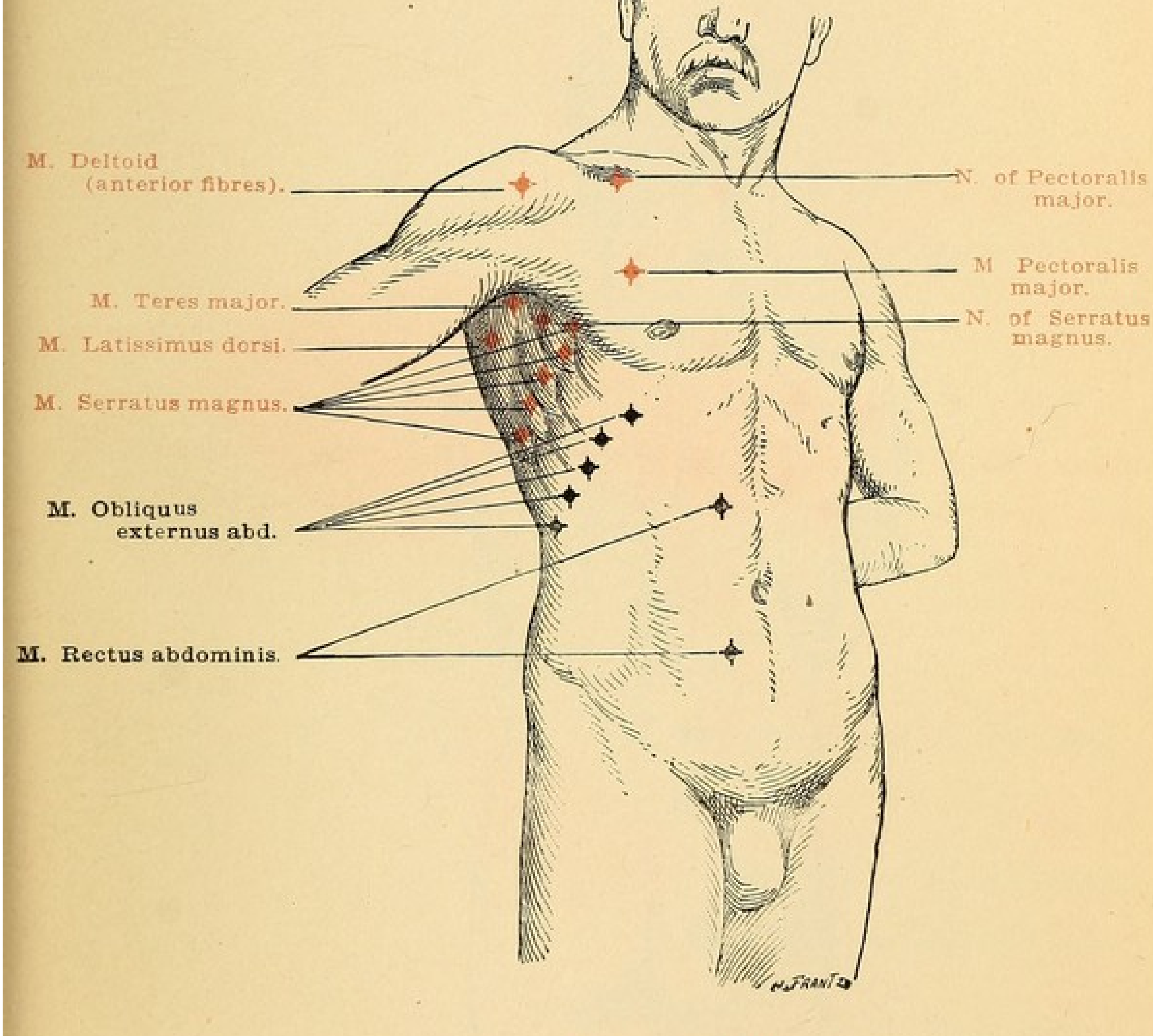
[1] Radioscopie et Radiographie clinique de précision. Guilleminot, 1909.



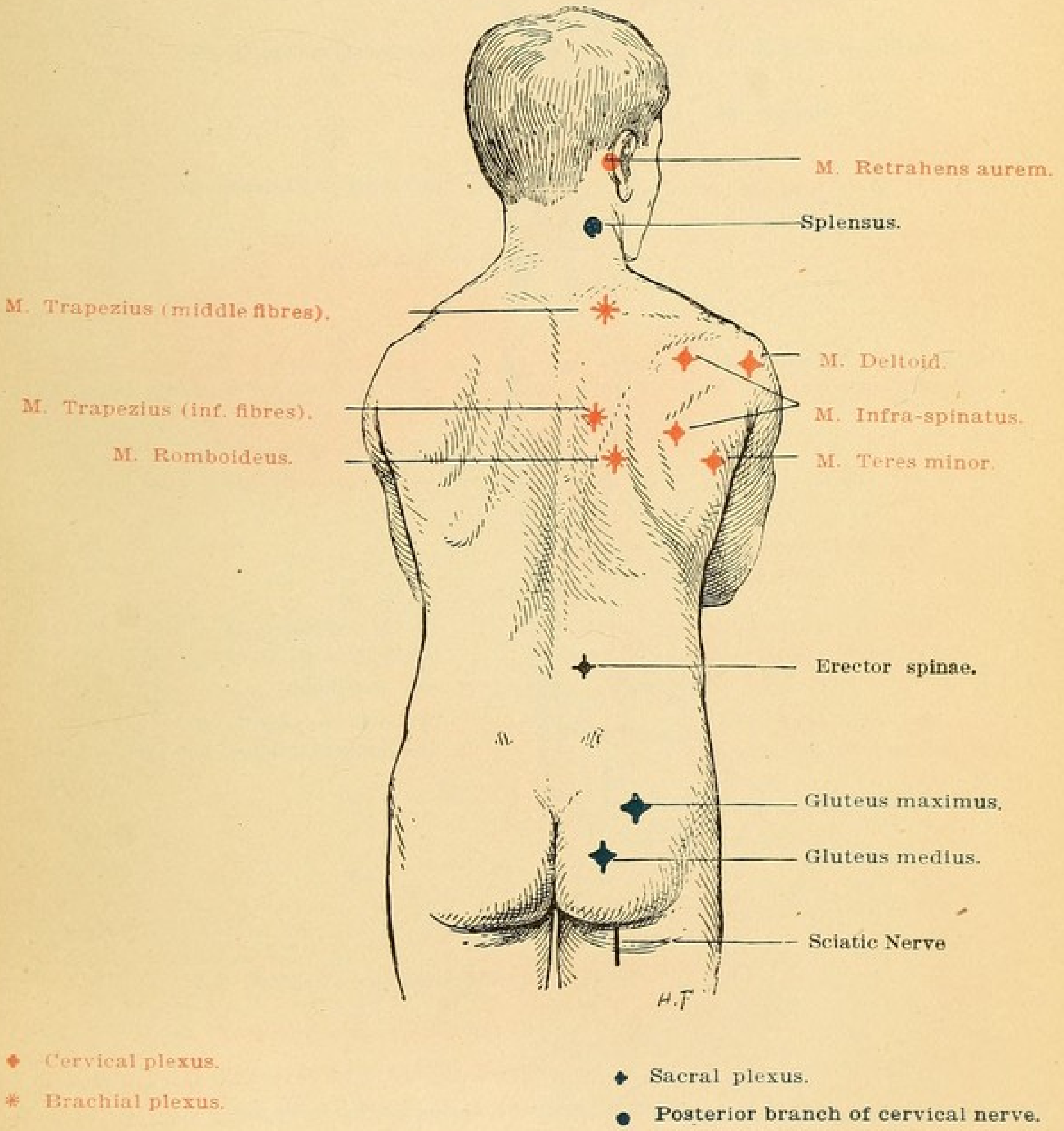
- Supplied by hypoglossal nerve.
- Motor branch of trigeminal.
- Brachial plexus, cervical and phrenic nerve.
- Supplied by facial nerve.
- Supplied by spinal accessory nerve.

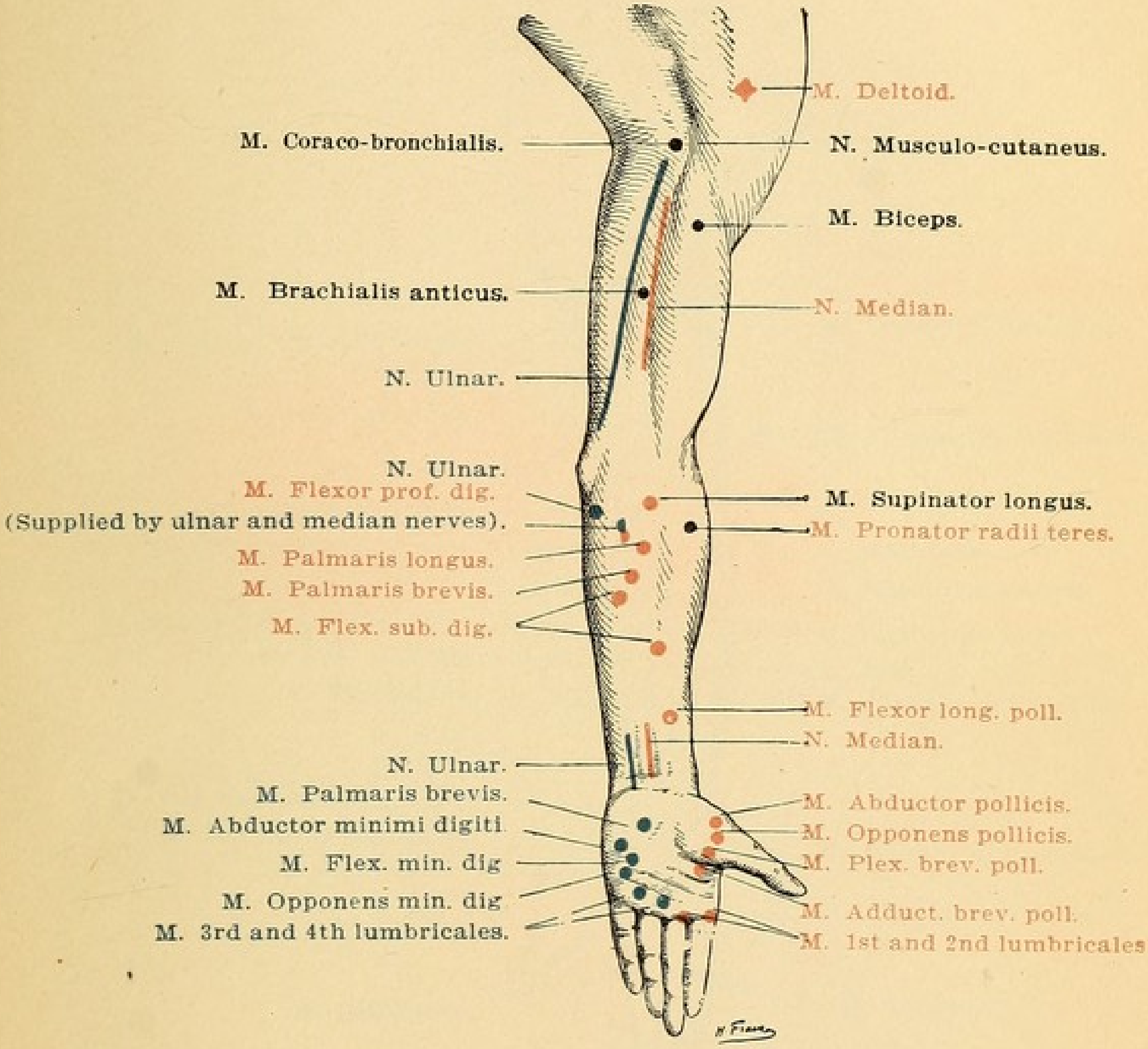


(After Testut.)



◆ Cervical plexus.
∗ Brachial plexus.


M. Retrahens aurem.
Splensus.
M. Trapezius (middle fibres).
M. Deltoid.
M. Trapezius (inf. fibres).
M. Infra-spinatus.
M. Romboideus.
M. Teres minor.
Erector spinae.
Gluteus maximus.
Gluteus medius.
Sciatic Nerve
H.F.
✦ Cervical plexus.
✳ Brachial plexus.
✦ Sacral plexus.
● Posterior branch of cervical nerve.

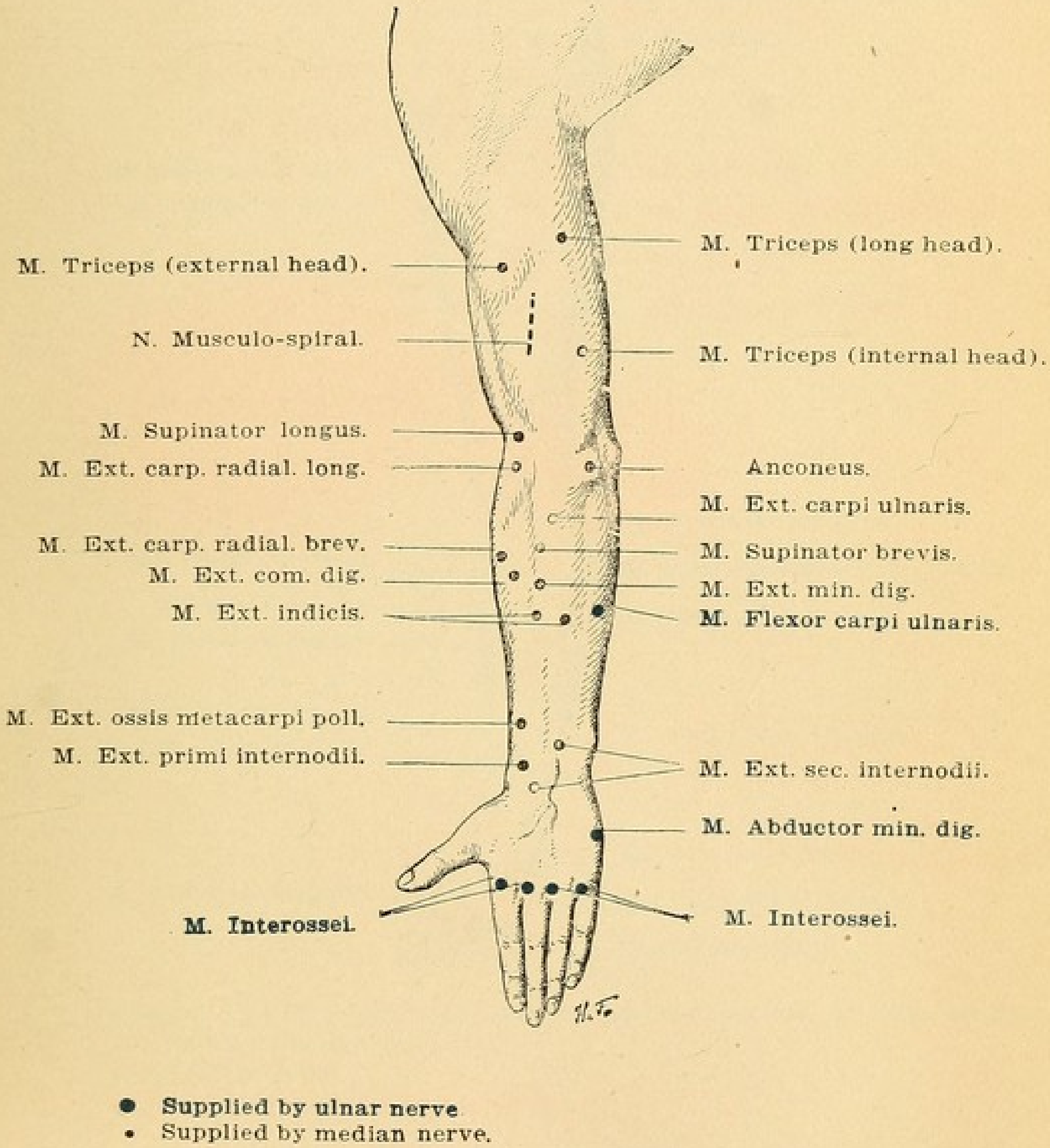


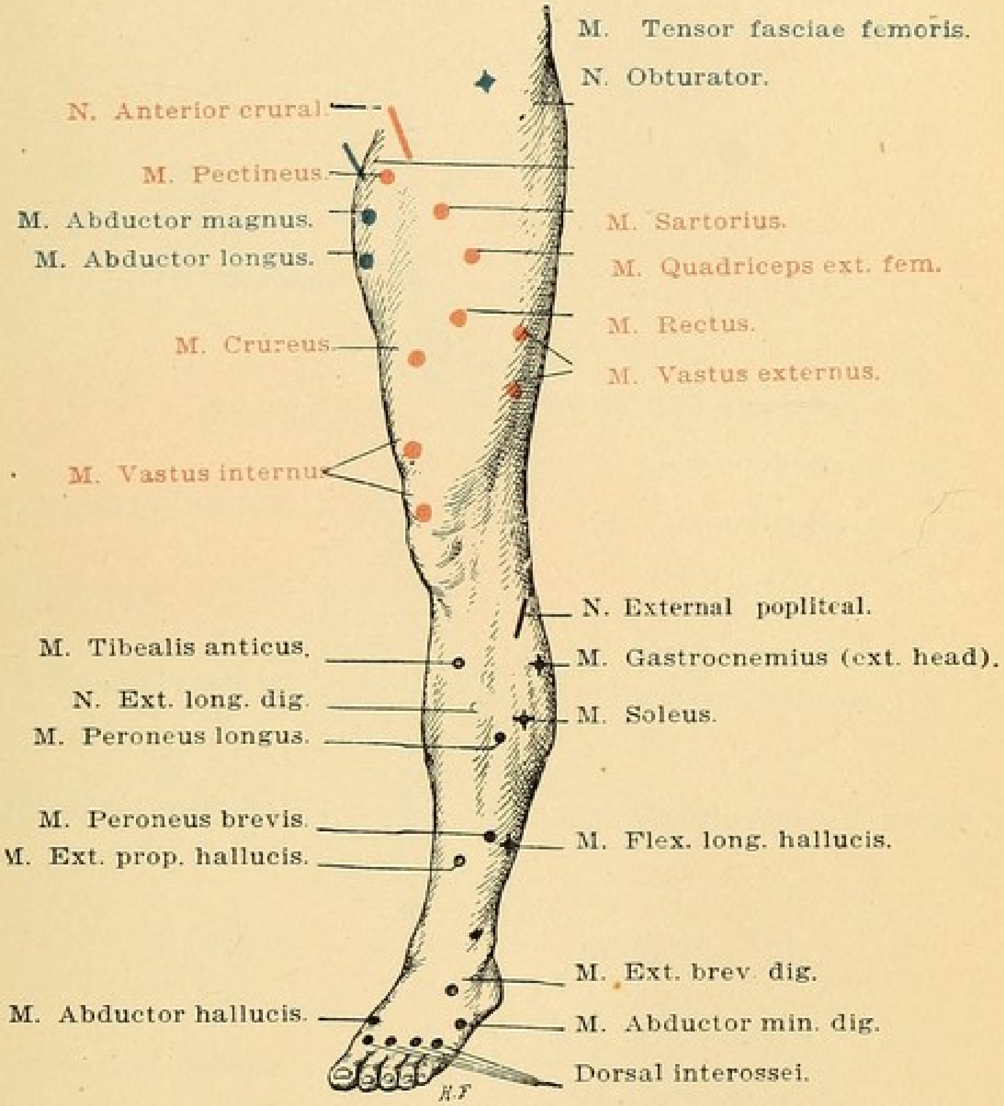
● Supplied by ulnar nerve.

• Supplied by median nerve.

✦ Supplied by brachial plexus.

• Supplied by musculo-cutaneous nerve.


M. Triceps (external head).
N. Musculo-spiral.
M. Supinator longus.
M. Ext. carp. radial. long.
M. Ext. carp. radial. brev.
M. Ext. com. dig.
M. Ext. indicis.
M. Ext. ossis metacarpi poll.
M. Ext. primi internodii.
M. Interossei.
M. Triceps (long head).
M. Triceps (internal head).
Anconeus.
M. Ext. carpi ulnaris.
M. Supinator brevis.
M. Ext. min. dig.
M. Flexor carpi ulnaris.
M. Ext. sec. internodii.
M. Abductor min. dig.
M. Interossei.
● Supplied by ulnar nerve
• Supplied by median nerve.



✦ Sacral plexus; comprising tensor fasciae, femoris, gluteus medius and gluteus maximus.

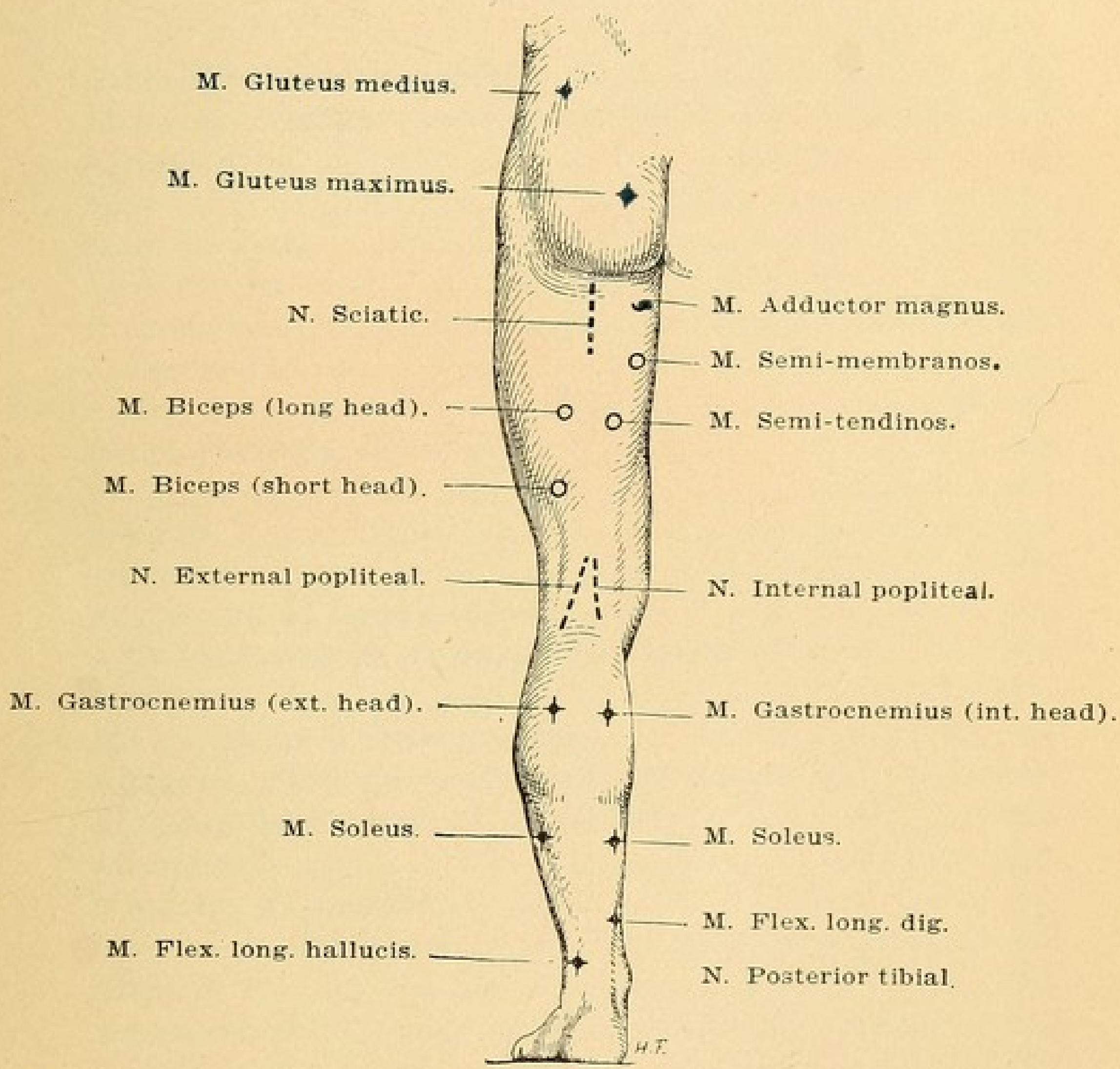
● Obturator nerve.

● Supplied by anterior crural nerve.

o Supplied by sciatic nerve before its division into external and internal popliteal.

✚ Internal popliteal passing into posterior tibial.

• External popliteal passing into anterior tibial and musculo-cutaneous.



◆ Sacral plexus.
• Obturator nerve.
o Supplied by sciatic nerve before its division into external and internal popliteal.
✦ Internal popliteal passing into posterior tibial.
• External popliteal passing into anterior tibial and musculo-cutaneous.

INDEX

(The numbers refer to the paragraphs.)

A

B

C

E

F

H

I

J

K

L

M

N

O

P

S

U

V

W

Table of Contents on Page XI.

1094