THE PRINCIPLES AND PRACTICE OF DIATHERMY

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1957

WILLIAM HEINEMANN · MEDICAL BOOKS · LTD

LONDON

First Published, March, 1957

Printed in Great Britain by
The Whitefriars Press Ltd., London and Tonbridge

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PREFACE

This book is designed as a textbook for students of short-wave therapy. It deals with principles and practice of diathermy especially from the physical point of view. Physiotherapy teachers, students, and those entering Physical Medicine will, it is hoped, find the help that they need in what is sometimes regarded as a difficult subject. Some of the more difficult Physics and formulæ which are intended for Physiotherapy teachers and trainees in Physical Medicine are in appendices to some of the chapters.

An attempt has been made to simplify some of the problems which students are inclined to find difficult. This obtains particularly in the chapters on History, Physics, Generators and Indications for short-wave therapy. In the sections dealing with the regional application a different method of description has been adopted which may be helpful to students, and will be useful for quick reference when applying treatment in later years. Endeavour has been made to retain an ease of reading in a somewhat technical subject.

The writer would like to take this opportunity of acknowledging the help that has been received. I should like to thank Dr. William Tegner and Dr. Phillippe Bauwens, because without their training of a critical attitude in both the clinical and technical fields this book would never have been written. Moreover, I would like to thank Dr. Bauwens for his helpful criticism and advice.

I have drawn considerable assistance from the Admiralty Handbook of Wireless Telegraphy and from Dr. Derek Wyatt and Mr. Peter Styles, who both gave me unstinted help with the Physics. I should also like to mention Dr. Geoffrey Storey and Miss Vera Green, M.C.S.P., for reading the proofs and for their many helpful suggestions, and to Dr. E. F. Mason for his encouragement. I would like to thank Squadron-Leader C. B. Wynn-Parry for lending me some of his notes and references.

To Miss Margaret McLarty my thanks for her care and attention in producing the drawings and to my Publishers for their co-operation.

I should like to acknowledge Messrs. Stanley Cox, Sierex Ltd., The Medical Supply Association, Electro-Medical Supplies, A. F. Bulgin & Co. Ltd., Standard Telephones and Cables Ltd., Mullard Ltd., Dubilier Condenser Co. Ltd., Elstone Electronics Ltd., Whitely Electrical Radio Co. Ltd., Jackson Bros. Ltd., Brown Bros. Ltd., for all their help and kindness in lending blocks.

Lastly, but by no means least, I should like to praise the tireless patience and cheerfulness with which my secretary, Miss Madeleine Edmondson, typed the various manuscripts, and the forbearance and encouragement of my wife whilst the book was being written.

Oxford — Bryan O. Scott.

January, 1957.

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CHAPTER I

INTRODUCTION

THE application of physical agents in the treatment of disease has undergone many changes in recent years. Physicians and surgeons are rightly more critical of the techniques used and in the evaluation and assessment of the results achieved with these techniques. In consequence, many forms of treatment have been dropped altogether, whilst others have been modified and improved.

The application of short-wave therapy is no exception, and to-day many of the treatments given by short-wave diathermy are considered of little value. For example, hyperpyrexia was at one time regarded as a valuable treatment in cases of general paresis of the insane, but with the advent of chemotherapy and the antibiotics treatment by short-wave diathermy has naturally and rightly fallen into disuse. In this instance, this does not mean that short-wave diathermy will not raise the temperature of the patient and achieve the results obtained previously, but that there is a more efficient and scientific method of treating the patient.

The same criteria apply to treatment of patients with long-wave diathermy. This method, most valuable in its time, has been relegated to the past, and most modern departments use short-wave therapy as it is more efficient. The heating with short-wave diathermy is more uniform provided it is applied with good technique, and in general it is more convenient to apply. However, the fact that the technique is more convenient should not lead one to suppose that it is easier to apply. The reverse is often the case. Short-wave diathermy may appear easy to apply, but is not easy to **apply correctly.** For this reason great care and attention to detail is necessary when giving any treatment by short-wave diathermy.

Further, the fact that high-frequency energy can be made to bridge a gap between the apparatus and the patient suggests that there is something rather magical in short-wave diathermy. This belief is particularly so in the case of the patient, but unfortunately is often the case with those applying short-wave therapy.

It is hoped in this book therefore to show that, although not all the " peculiarities " of behaviour of high-frequency currents are known, at least the greater part of the phenomena that do occur can be explained on a purely physical basis.

To apply short-wave therapy in all its forms correctly demands a sound knowledge of the physical principles concerning high-frequency currents. Once these principles are understood, the application of therapy follows naturally and more easily.

The student often thinks that the learning of physics is an unnecessary burden when she is filled with a desire to treat and help her patients. However, with the application of short-wave therapy, as with anything else, the knowledge of the " why " makes the practise of the how, when and where much easier. Moreover, the details of treatment are remembered more easily when the rationale is understood. The student is advised not to pass on to the chapters on application until the chapters on physics and on the working of generators have been read and thoroughly understood. Time spent on these chapters will not be wasted either from the point of view of examinations or from the therapeutic application of diathermy in later years.

At the end of some of the chapters there are a few suggestions for additional reading, which will be found to be valuable and interesting, particularly for the more advanced student. These will enable workers to obtain a start if they should embark on further investigation into some of the still uncharted seas of the archipelago of diathermy.

CHAPTER II

HISTORICAL

THIS chapter [1] contains a brief survey only of the main events leading up to the modern use of short-wave therapy. A complete history has not been attempted as, although this is extremely interesting, it is not essential for the practice of short-wave therapy.

The main occurrences have been arranged in chronological order so that the student may form a broad picture of the important events. A few brief notes are included which will be of interest and may help the student to remember the salient features.

1746 Cuneus and Musschenbröek of Leyden devised the Leyden jar, which is the precursor of the modern condenser. A condenser is a device for storing electricity. The term " jar " is used as the name of a unit of electrical capacity and is 1/900th part of a microfarad, which is the modern practical unit of capacity.

1801 William Wollaston, an English Chemist and Physicist, discovered that the discharge of a Leyden jar was pulsatory in character.

Romagnosi is supposed to have discovered the magnetic effect of an electric current.

1820 Oersted, a Danish Physicist, stated the laws relating to the magnetic effect of an electric current. He gives his name to the practical unit of magnetizing field strength. A magnetic field of one oersted exerts a force of one dyne on a unit north pole placed in it.

1831 Faraday showed that an electromotive force (E.M.F.) was induced in a conductor when it was moved in a magnetic field and thus discovered another means of producing an electric current. Subsequent development of this discovery has led to the production of dynamos, electric motors, transformers, and other devices which are used in our everyday life.

Faraday subsequently studied electrolysis and found that the same quantity of electricity liberated the gramme-equivalent of any ion. This quantity, which is 96,500 coulombs, is called a faraday. The unit of electrical capacity, the farad, is also named after him.

1842 Joseph Henry deduced that the discharge of a Leyden jar might be of an alternating character, in which the direction of the current was first in one direction and then in the reverse.

[1] The use of some technical terms in this chapter is unavoidable. These are explained either in the Glossary or in Chapters III and IV. The young student is advised to read these chapters before reading this one.

1853 Professor William Thomson, who subsequently became Lord Kelvin, described the conditions in which the discharge would either be an alternating current or unidirectional.

1865 Clerk Maxwell, investigating the electric and magnetic field in the region of a discharging condenser, came to the conclusion that the oscillatory discharge of a condenser through a circuit containing inductance is accompanied by an electromagnetic radiation which is propagated through space at the speed of light.

1888 Heinrich Hertz demonstrated the existence of these radiations, which subsequently became known as Hertzian waves. He used the spark caused by an induction coil as an "oscillator" and received and detected the waves by means of a "resonator." In this case the resonator was a simple coil of wire with a narrow gap across which sparks passed when it was placed in the path of the waves. He showed later that these waves could pass through stone walls and wooden floors.

1890 Professor Arsène d'Arsonval, at the Collège de France, Paris, who might be called the father of diathermy treatment, showed that a decrease in the threshold to stimulation of muscle fibres occurred when using an alternating current with a frequency of greater than 5,000 cycles per second (5 Kc./sec.), and that when the frequency was increased to 10,000 (10 Kc./sec.) the stimulation ceased altogether. This work was the first communicated to the Société de Biologie in 1891.

1891 Nicola Tesla observed the heating action of high-frequency currents.

1892 D'Arsonval demonstrated that a high-frequency current of 1 amp. could be passed through an assistant (Cornu), himself and a filament lamp. The only sensation which they noticed was a warmth in the wrists through which the current was passing. Previously low-frequency currents of this magnitude passing through the human body had usually resulted in death.

D'Arsonval continued to perform a series of biological experiments which demonstrated that changes took place in the human body when subjected to high-frequency currents. (These changes could all be explained by the heating which took place, but the importance of heating was not at that time realized.)

The currents were believed to pass on the surface only and not to traverse the tissue.

In England at this time many people were sceptical of the effects of these high-frequency currents. D'Arsonval continued his experiments until 1898.

1896 Marconi first produced electrical high-frequency oscillations and picked them up again at a distance. This, of course, was the forerunner of the modern wireless transmitter and receiver.

1899 To Van Zeynek, who published his findings in the *Gottinger Annälen*, goes the honour of being the first to observe tissue heating by high-frequency currents. It is for the tissue heating effect that we now use short-wave therapy, and it is interesting to remember that some fifty-seven years had passed between the time that the oscillating current was demonstrated before its main therapeutic effect became apparent.

1907 Nagelschmidt at a congress in Dresden, when discussing high-frequency currents, spoke of thermopenetration and demonstrated heating in the arms and chest of a man.

1908 Berndt, Preiss and Zeynek published the results of four years' work in a paper on the treatment of diseases of joints by high-frequency currents.

Interest in the subject appears to have declined or to have been interrupted by the 1914–18 war, for there was a gap of eighteen years before—

1926 Schereschewsky investigated the action of short-wave currents on animals.

1928 Schliephake during the past three years had been practising the treatment of patients with short-waves with the help of his two assistants, Esau and Pätzold, both of whom were physicists.

1929 Heinrich reported on the effects of short-wave diathermy on animals.

1930 Carpenter and Page described the use of short-wave diathermy for the production of fever. This method was used especially in the treatment of the specific diseases and was considered to be of great value. (The advent of the antibiotics, however, has naturally resulted in its relegation to the past.)

Many other workers reported favourably on this method and, though important, are too numerous to mention.

1937 An International Congress was held on short-wave diathermy in Vienna. This provided considerable stimulus and a great number of the leaders in the subject were enabled to exchange knowledge. It was at this meeting that Liebesny produced photographic evidence that pearl chains of fat globules were formed in an emulsion of fat when it was subjected to a high-frequency field. He did not claim any specific therapeutic effect as a result of this phenomenon.

1938 William Bierman published his book on the medical applications of the short-wave current, which contained a comprehensive review of the literature, and many valuable original contributions to the knowledge of the subject, especially in the clinical field.

1938 Philippe Bauwens, who is an acknowledged expert on the subject, especially in England, introduced the cross-fire technique of applying short-wave diathermy. Theoretically this technique is the one of choice when deep heating is required in localized parts of the body.

1950 Bauwens and Peter Styles designed and built a crystal-controlled short-wave generator which was fitted with an automatic tuning unit and also with a wattmeter. This apparatus gave a constant power input into the load and also measured accurately the total load input. Investigations showed that the automatic tuning unit was of greater clinical advantage than the wattmeter. Some commercial short-wave diathermy generators are now made incorporating this type of unit.

The author was fortunate in being associated with the experimental work on this apparatus, and also had the opportunity of working with Bauwens, who as a scientist and teacher is a great inspiration to those around him.

1956 Styles designed a short-wave generator incorporating a device called a " pot resonator " which had the effect of reducing the power of the harmonic radiations. This reduced considerably the amount of radio and television interference which is caused by the usual short-wave generators. The strength of the harmonic radiations with this generator are well below limits proposed by the G.P.O. at the time of publication. This innovation will probably affect the design of all future short-wave therapy apparatus. At least one manufacturer is making an apparatus incorporating this device. The great advantage in using the pot resonator is the reduction in radio and television interference. This is no small consideration when the magnetic spectrum is becoming so crowded.

CHAPTER III

BASIC PHYSICS

CONSTITUTION OF MATTER

In general, matter may be described as anything which occupies space and is subject to the gravitational attraction of the earth. Therefore it has weight or mass. This is measured in grammes, pounds or other similar units. Matter exists in three states :—

1. **Solid matter** has a definite size and shape. It preserves its original shape and does not take up that of the vessel which contains it.

2. **Liquids** have a definite volume and take on the shape of the vessel into which they are placed, but they do not necessarily fill it. Water is the obvious example. Pitch is less obvious, although if lumps of pitch are placed in a funnel they will eventually flow through it.

3. **Gaseous matter** has no definite volume or shape, but takes on the shape of the containing vessel. Gases have the property of adapting their volume so that they fill and are distributed evenly within the container.

Matter can change from one state into another. Thus water is solid below 0° C., liquid between 0°–100° C., and gaseous above 100° C. when the atmospheric pressure is 760 mm. of mercury. Alteration of the atmospheric pressure results in these changes taking place at different temperatures. An increase of atmospheric pressure results in the melting temperature of ice and the formation of steam occurring at a higher temperature. Similarly, a decrease of pressure lowers these temperatures. Thus a kettle boils at a much lower temperature on the top of a high mountain.

The Molecule

If a Dundee cake is cut into small pieces, there comes a point at which the pieces cannot be reduced in size without altering their consistency. That is, the small piece is either all cherry or all currant. At this point, the piece although actually part of a Dundee cake would not be recognizable as such. The same is true of matter. The smallest portion of any substance which cannot be further divided without altering its original properties is called a molecule. If a molecule is divided, the properties of the substance are altered.

In all states of matter the molecules are in a continuous state of rapid motion. The amount of motion depends on the state of the matter.

In a gas the molecules are very free and are travelling at great speeds. A gas completely fills the vessel and exerts a pressure on the containing vessel. The molecules collide with each other and also with the walls of the container. It is as if we took a hundred men and let them run about freely on an aerodrome. They would collide with each other and also with the fences surrounding the aerodrome. Collisions would be relatively infrequent, since the space containing the men would be large compared with the number of men.

If a gas is compressed sufficiently it will become a liquid.

A liquid has the molecules much closer and they are not moving so fast because of the more frequent collisions that occur as they are more crowded. Returning to our simile of the men and the aerodrome, if we take the hundred men and put them (i.e. compress them) in a small field they are still able to wander about in the field, but their average speed is not so great because of the more frequent collisions. Moreover, the molecules tend to stick to each other. If we compress a liquid still further or lower the temperature it becomes a solid.

A solid takes up less space than a liquid and is like putting our hundred men into a room where they would be close together. Similarly the molecules can now hardly move about at all because of the overcrowding, but they can turn round and vibrate from side to side, still keeping about their mean position.

An Atom

An atom is a subdivision of a molecule, just as a cherry or currant is a subdivision of the Dundee cake, and has different properties from the molecule, of which it may become a part. Water consists of two atoms of hydrogen and one of oxygen; (H_2O) being the symbol for a molecule of water. Both of these atoms behave in an entirely different way from the molecule which they go to form.

The atom is the smallest particle that can enter into chemical combination. All the atoms of a substance like hydrogen are exactly alike ; a molecule consists of one or more atoms. The carbon molecule consists of one atom of carbon, whereas the molecule of oxygen has two atoms (O_2). The number of different kinds of atoms is limited, and is believed to be ninety-two, but since molecules are made up of different kinds and numbers of atoms the number of molecules is almost limitless, and accounts for all the substances that we know.

ATOMIC STRUCTURES

It is possible to subdivide an atom in the same way that our currant out of the cake has a centre with pips in it and a skin around. Atoms are made up of a centre or nucleus which is composed of one or more protons, which is the smallest quantity of positive electricity. Around the nucleus rotates one or more electron which is the smallest quantity of negative electricity. For example, the hydrogen atom consists of a nucleus in which is one proton, and round this nucleus one electron revolves in a rotatory orbit.

The radius of an electron is of the order of 10^{-13} cm. The distance between the electron on its orbit and the proton is comparatively very great (about 100,000 times the diameter of the proton). If, for example, the proton was the size of a tennis ball, then the electron would be rotating around it at a distance of nearly four miles.

THE ELECTRON THEORY OF ELECTRICITY

Normally the atom is electrically neutral—that is, the negative electrons rotating around the nucleus exactly neutralize the positive charge of the proton. In certain substances, however, it is possible to either remove an electron from its orbit or to add another electron to it. This does not alter the nature of the atom, but it does alter its **electrical** state. Since electrons are negative electricity, a deficiency of electrons will mean that the atom is positively charged, and if there is a surplus then it will be negatively charged. An atom which is in either of these states is called an " ion " and is said to be " ionized."

A positive ion (short of electrons) will naturally attract electrons, and a negative ion (surplus electrons) will repel other electrons and will readily give up the surplus electrons that it has acquired. From this it will be seen that the amount of electrification depends on the number of ionized atoms. Normally an atom will only gain or lose one electron.

An accumulator is a device which stores electricity by chemical action, and the terminals are marked " Positive " and " Negative." This means that there is a deficiency of electrons at the positive pole and a surplus at the negative pole. Therefore, if the two poles are connected together by a conductor of electricity, there will be a flow of electrons from the negative pole to the positive in order to equalize the distribution of the electrons. It is to be noted that the **flow** of the **electrons** is from **negative** to **positive,** although **a current** is spoken of as flowing from **positive** to **negative.**

Conductors and Insulators

Speaking electrically, substances are divided into two classes : (*a*) conductors and (*b*) insulators.

Conductors are those which will readily conduct a flow of electrons under the influence of electrical pressure, and insulators are substances in which there is a negligible flow of electrons under the same circumstances. It is not possible, however, to draw a rigid line between these two classes of substances because a substance may be an insulator at one voltage and a conductor at another. For example, wood behaves as an insulator when subjected to an electrical pressure of only about 200 volts, whereas it would conduct electricity if subjected to a pressure of 200,000 volts. The presence of dampness in the wood, however, increases its conductivity. The reason a substance will or will not conduct a flow of electrons is readily explained by the Electron Theory. Copper is an excellent conductor. In the molecule of copper there is an electron which is rotating in an orbit which is relatively a long way from the nucleus, and it is easy to imagine that the electron on this orbit could easily come under the influence of the nucleus of another molecule which is adjacent ; thus the electron will readily " hop " from one molecule to the adjacent one. In other words, the electron in copper is not very closely bound to its own molecule and will readily change places and will rotate around the nucleus of another molecule in much the same way as is represented in Fig. 1.

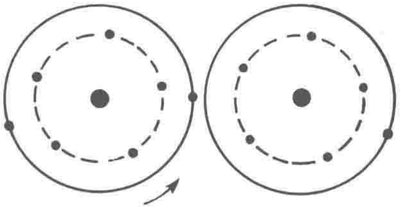

FIG. 1. The right-hand electron on the left orbit could easily "hop" to the orbit on the right.

Suppose the terminals of a battery are joined by a length of copper wire. Since there is a deficiency of electrons at the positive pole of the battery the electrons in the wire will flow towards the positive pole. This will cause a deficiency of electrons at the negative ends of the wire, but this deficiency will be made good by the excess of electrons at the negative pole of the battery. Fig. 2 shows diagrammatically what happens in the wire.

With an insulator, however, the state of affairs is somewhat

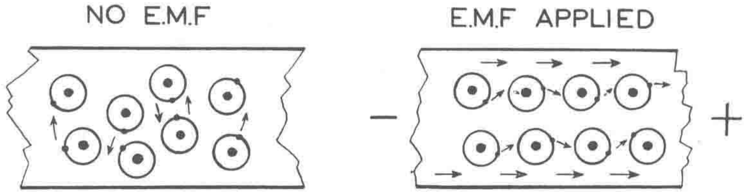

FIG. 2.

different. An insulator is made up of molecules in which the electrons are firmly bound to the nucleus and, unless considerable electrical pressure is enforced on them, the only effect of applied electrical

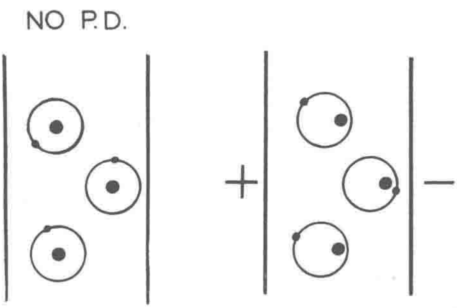

FIG. 3. The electrons are pulled towards the positive terminal.

pressure is a drawing of the entire orbit, in which the electrons rotate, towards the positive terminal, where there is a deficiency of electrons. This is represented in Fig. 3. Obviously, if the electrical pressure is sufficient, the orbit will be pulled so far that the nucleus no longer lies within it ; then there will be a flow of electrons. A current will flow and the insulator is said to have broken down.

Types of Electrical Current

The explanation by the Electron Theory of the reason why a current can flow in different substances makes it possible to classify currents into three well-defined types :

(1) Conduction Currents.
(2) Displacement Currents.
(3) Ionic Currents.

Conduction Current

This is the type of current that flows in a copper wire when the two ends are connected to the terminals of a battery. The nature of the current has been discussed previously and explained on the basis of the Electron Theory.

Displacement Current

This is the type of current which flows in an insulator. The number of free electrons in an insulator is very small and the electrons are firmly bound to their own nuclei. When a voltage is applied across the insulator or di-electric it only strains the orbit, so that the nucleus lies eccentrically within the orbit in which the electron revolves (see Fig. 3). The orbit has in fact been displaced. This type of current occurs in the dielectric (substance between the plates) of a condenser. It is therefore called a **dielectric displacement current.**

As has been stated before, if the applied voltage is increased sufficiently the orbit in which the electron is rotating is strained until it becomes eccentric in relation to the nucleus ; the electron moves to another orbit and a current is set up. If this current is sufficient, a breakdown occurs in the dielectric. This happens when a condenser breaks down. When a large current flows great heat is generated and the condenser or transformer is burnt out.

Ionic Current

This type of current is due to a movement of electrons, either positive or negative ions, in a gas or a liquid, and can occur even in a perfect vacuum. It is accompanied by a process of ionization, except in the case of a complete vacuum, when it is just the movement of electrons proceeding between the filament and grid of a valve or between the filament and anode of a valve. More will be said of this later when discussing the thermionic valve.

UNITS

Effects of an Electric Current

The flow of an electric current has certain effects ; the most important of these are three in number.

1. **The Heating Effect.** When an electric current flows through a