A Short Textbook of RADIOTHERAPY

FOR TECHNICIANS AND STUDENTS

By

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and

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With a Foreword by

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F.R.C.S.Ed., F.F.R., D.M.R.E.

SECOND EDITION

J. & A. CHURCHILL LTD.

104 Gloucester Place, London, W.1

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Second Edition

WITH 303 ILLUSTRATIONS

LONDON

J. & A. CHURCHILL LTD.

104 GLOUCESTER PLACE W.1

1959

To Marianne
and to the Memory
of my Parents
(J. W.)

First Published 1950

Printed in Great Britain

A SHORT TEXTBOOK OF
RADIOTHERAPY

FOREWORD

by

J. L. A. GROUT, C.B.E.
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THE question is often raised, whether or not a book based on lectures can replace the lectures themselves. I do not think that it is Dr. Walter's or Dr. Miller's intention that it should, and with that I agree. However, as the answer to the question depends a great deal on the lecturer, it is obvious that a definite answer cannot be given. A book is static and a lecture dynamic, so that a book cannot include the day-to-day experiences of the lecturer, which occur for example in his out-patient clinics. Dr. Walter's and Dr. Miller's book may quite possibly contain much for the Student Radiographer to digest, but if supplemented by lectures of the right type no difficulty should be experienced in following the intricacies of radiation therapy.

Dr. Walter is as enthusiastic a teacher as he is an enthusiastic Radiotherapist and his book will do much to allay those fears which the very names Physics and Radiotechnics engender in the hearts of those preparing for examinations in Radiotherapy. On those grounds alone the book will be welcomed, but for the Student Radiographer, so ill provided in this respect, it will be a friend in need.

I am glad the authors decided not to include examination papers, for that would have implied that the book was solely for examination purposes. This would have detracted from the full appreciation of the work, which should be on all occasions the Radiographer's companion.

PREFACE

THE exhaustion of the first edition has given us the opportunity of revising the book, so as to take account of the many developments in equipment and technique that have taken place in the last ten years. We are grateful for the many comments, suggestions and criticisms offered by reviewers and others, and have done our best to meet them within the practicable limits of space.

The primary object of the book as a text for student technicians working for the examinations of the Society of Radiographers, especially in radiotherapy, has been maintained. We hope it may also serve as a bird's-eye-view for doctors (house officers, surgeons, etc.) and others, who would be repelled by a longer or more technical work. Since it appears that some parts of the book (dealing with subjects not always covered by standard textbooks) have been useful to trainee radiotherapists, we have added an occasional detail for their benefit in footnotes ; these can be ignored by the technician.

The principal changes are due to the increasing importance of supervoltage radiation and radioactive isotope techniques, and these, with some other alterations in radiotherapeutic techniques, are responsible for the main differences between this text and the first edition.

Some rearrangement of the descriptions of X-ray apparatus has been made and the subject has been enlarged to include recent equipment.

The new dosage units for ionizing radiations are used, since in many departments radiographers already meet these in practice. Methods of measurement of radiations have also changed somewhat since the first edition.

A large part of Chapter 7 and the whole of Chapter 15 on radioactive isotopes are new.

The old appendix containing recommendations of the British X-ray and Radium Protection Committee has been omitted and replaced by a more adequate treatment of radiation hazards in Chapter 8. This is based largely on the new code of practice for radiological departments now in use in British hospitals.

As examples of practical techniques the treatment of the following additional lesions has been described : cancer of bladder, antrum, testis, medulloblastoma, and considerable changes have been made in the treatment of cancer of breast, skin, cervix, larynx.

New sections include hormone therapy, chemotherapy, sieve therapy, moving field therapy, radiotherapy in children, and there are two new appendices (radiation hazards in peace and war, and an historical note).

Major changes have been made in the following sections : action of radiation on cancer tissue, and beam direction, including a description of the pin and arc.

The supplementary chapter for the dermatologist has been omitted and parts of it incorporated in the dermatological section. The original chapter may possibly continue to be of use to the dermatologist.

Our grateful thanks go out to our many colleagues at the Centre—doctors, physicists, technicians and stenographers—whose help has made our work possible. In particular we would like to thank Mrs. M. Walter, Mrs. Ruth Martin and Mrs. A. Lynn for their secretarial assistance, Miss D. Wemm for preparation of diagrams, and Mr. D. J. Rees for advice on presentation of the physics sections.

J. W.
H. M.

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CHAPTER 1

THE STRUCTURE OF MATTER

INTRODUCTION : ATOMS : THE NATURE OF ELECTRICITY : CATHODE RAYS : X-RAYS : RADIOACTIVITY : ELECTRONS : THE STRUCTURE OF ATOMS : THE PERIODIC SYSTEM OF ELEMENTS : THE RUTHERFORD-BOHR ATOM : THE CHEMICAL PROPERTIES OF THE ELEMENTS : THE CONDUCTION OF ELECTRICITY : CONDUCTION OF ELECTRICITY IN IONIZED GASES : THE NUCLEUS.

X-RAYS and the radiations given off by radium have been used for half a century in the treatment of disease, though, for the most part, the action of these radiations has been understood only imperfectly. Some knowledge of the nature of the radiations—ionizing radiations as they are called—and of their method of application is, however, necessary for the radiographer whose duty it is to use them effectively. It is the purpose of this text to provide that necessary information.

The fifty years that have passed since the discovery of X-rays have seen a complete revolution in our ideas of the fundamental nature of matter. The attempt to understand the behaviour of X-rays and other similar radiations has contributed enormously to the development of this new and fascinating picture of material things. Before the behaviour of the radiations themselves can be adequately appreciated, it will be necessary to give an account of some modern ideas of the minute structure of the material universe in which we live.

Atoms

We are familiar with the fact that the material universe contains a large but not unlimited number of elementary materials chemically distinguishable from each other. Of these elements, as they are called, 92 are believed to exist in nature, though many are found only in extremely minute amounts, and of one or two the evidence that they exist at all is only indirect. All materials are either forms of one or other of these elements, or, more usually, combinations of two or more of them. Some of the elements occur much more commonly than others. About 99 per cent of the weight of the earth's crust, for instance, is formed of the elements oxygen, silicon, aluminium, iron, calcium, magnesium, sodium and potassium. All but a minute fraction of all organic material is composed of the elements carbon, oxygen, hydrogen and nitrogen.

The elements themselves are known to consist of a large number of simple particles or atoms, each atom being chemically identical with other atoms of the same element and being the smallest amount of the element that can retain the characteristic properties of that element. The combination of atoms of one element with those of another element leads to a compound, the unit of which is known as the molecule. It is this combination of atoms to form molecules which is responsible for the tremendous chemical complexity of the world around us.

The atomic hypothesis is very old but is now quite firmly established by a large amount of experimental evidence. This is so, in spite of the fact that the size of these ultimate particles is so small that singly they are quite beyond the reach of any known methods of observation. The diameters of the atoms are known to be about 10^{-8} cm., i.e. 100,000,000 atoms side by side would occupy a length of about 1 cm. though the actual diameter of a particular type of atom differs somewhat from the diameter of other types. The weights of the atoms are also known with some accuracy. The weight of a sulphur atom, for instance, is known to be 50×10^{-24} gm. The total number of atoms in 1 gm. of sulphur, therefore, is the enormous number 2×10^{22}. In practice it is usual to refer to atomic weights in terms of a unit other than the gram, and the weight of the lightest atom, hydrogen, is accepted as the unit. The atomic weight of sulphur is expressed as 32, meaning that it has a weight of 32 times the weight of the hydrogen atom. The atomic weights of the elements vary from unity for hydrogen to 238 for uranium, the heaviest of the naturally occurring elements.

It was convenient for a long time to treat atoms as though they were merely hard indivisible spheres of which 92 different kinds existed. At the same time certain evidence did suggest the possibility that these 92 species of atom were in fact structures composed of a few simple particles combined together in different ways. The unravelling of this atomic structure, however, began only with the discovery of one of these fundamental particles in the last decade of the nineteenth century—this was the electron. It was the discovery of the electron by Sir J. J. Thomson and the important discoveries in the period 1895 to 1900 by Roentgen, Becquerel and others which laid the foundations of our knowledge of the fundamental particles from which the whole of the material universe is built. These discoveries also led to a deeper understanding of the nature of that other important phenomenon of our world, radiation.

The Nature of Electricity

Frictional electricity had been produced by the Greeks. In the eighteenth century two kinds of electrification were recognized, vitreous and resinous, and it was supposed that two electrical fluids existed. These were in equal quantities in an unelectrified body and so neutralized each other. The possibility of the transfer of the electrical fluid from one point to another was investigated. Thus arose the distinction between conductors and insulators. Metals like copper conduct electricity very readily, materials like sulphur do not conduct at all and are classed as insulators, while substances in an intermediate class exist which may be considered as poor conductors. Examples of these are cotton, water and the human body. The precise nature of these electrical fluids, however, remained in doubt, though the development of electrical science and technology went on.

From the point of view of understanding the real nature of the electrical fluid, the most important investigations have been those concerning the way in which an electric current is carried through gases. Under normal conditions a gas is an exceedingly good insulator. This simple fact is illustrated by the way in which a charged gold leaf electroscope will retain its charge for long periods if care is taken to use the best possible insulator to support the gold leaf system. The air surrounding the leaf is responsible for only a very small part of the leak from the ordinary electroscope.

It is possible to cause the passage of electric current through air if the potential difference between two neighbouring points is made high enough. The current does not pass steadily in these circumstances but in the form of a sudden spark, sometimes a violent one. Very high potentials are needed to cause current to flow in this manner. For example, to cause a spark between two spheres of 1·0 cm. radius, in air, at 1 cm. apart, a potential difference of 32,000 volts is required.

Quite different behaviour, however, is observed if an attempt is made to pass current through a gas when the gas pressure is reduced to a small fraction of the atmospheric pressure. The experiments are normally made in a glass tube in which the gas pressure can be varied. Two electrodes are sealed into the tube, and between these suitable potentials of perhaps a few hundred volts can be applied. The effects produced vary with the pressure of the gas but at a suitable pressure the electricity passes smoothly and is accompanied by emission of light which has a colour characteristic of the gas through which the charge is passing. An example of such a tube is the familiar neon sign.

The emission of light from a gas at reduced pressure, through which an electric charge is passing is a complicated phenomenon which we need not describe in detail. By reduction of the gas pressure to a lower value (about 0·1 mm. of mercury), however, the emission of light ceases, though charge continues to flow across the tube if a suitable potential is applied. It is known that the charge is then carried by streams of particles which originate near the negative electrode or cathode. These are the *cathode rays*, the discovery and investigation of which, in the years following 1890, revealed the nature of electricity and led on to the realization that atoms themselves have a complicated electrical structure.

Cathode Rays

Although cathode rays produced in a tube containing gas at sufficiently low pressure are themselves invisible they produce a faint glow when they strike the walls of the tube. This glow is greatly enhanced if they strike a layer of fluorescent material[1] (such as zinc sulphide) spread either on the glass wall of the tube or on structures inside the tube. Using this device a great deal of information can be found out about the properties of cathode rays.

The fact that the rays travel in straight lines can be demonstrated by introducing an opaque body in the path of the rays. A shadow is formed on the tube wall as shown in Fig. 1.1. In this tube the anode is placed on one side of the tube out of the way of the cathode ray stream.

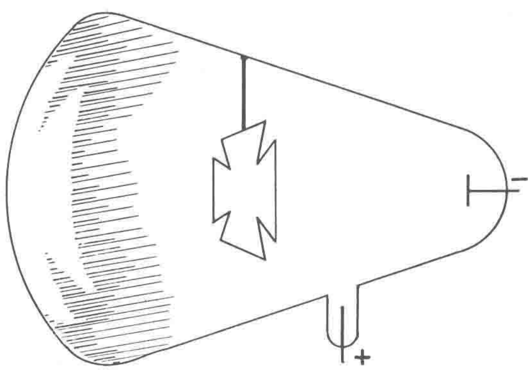

FIG. 1.1. Shadow of an opaque body formed by cathode rays.

By making the cathode concave, it is possible to cause the rays to converge to some point at the distant end of the tube. If the rays fall on to a small area of a suitable thin foil, the foil can become intensely heated. An interesting experiment can be done in a tube such as is shown in Fig. 1.2, in which a little paddle wheel with extremely light vanes is built to run along glass rails. This paddle wheel can be made to turn by the impact of the rays on the paddle vanes when the tube is suitably exhausted and the cathode rays excited. Evidently the rays carry both energy and momentum.

Some very important properties of the cathode ray stream may be deduced from the behaviour of cathode rays in magnetic and electric

[1] A fluorescent material is one which emits light of a characteristic colour either after absorbing radiation of a shorter wavelength, or under bombardment by charged particles.

fields. For this purpose the cathode ray stream is focused by its concave cathode so that it falls on a small spot of the fluorescent powder on the distant tube wall. If two additional metallic plates are placed in the tube, one on each side of the stream, and if a potential difference is placed between them, the stream is deflected towards the positive plate, as can be seen by the motion of the fluorescent spot on the end of the tube. This suggests that the stream consists of charged particles carrying a negative charge. Confirmation of this supposition can be obtained by allowing the stream to fall into a metallic cylinder and measuring the charge collected. The cathode ray stream is also easily deflected in a magnetic field as can be demonstrated by the movement of the fluorescent spot when a magnet is near to the tube. The deflection in this case is in a plane perpendicular both to the beam direction

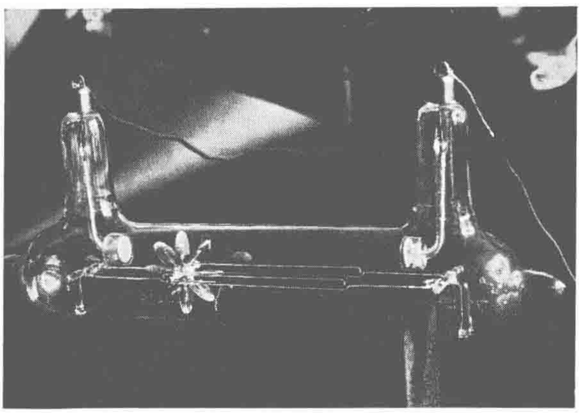

FIG. 1.2. Cathode rays driving a light mica paddle wheel along glass rails. [*By kind permission of Messrs. George Newnes Ltd.*]

and the direction of the magnetic field. This is behaviour very similar to the motion of a wire carrying a current in a magnetic field. In fact the direction of the deflection is given by Fleming's left-hand rule, if the cathode ray stream is assumed to be represented by a current flowing towards the cathode. The appearance of a tube in which the cathode ray stream is being deflected by a magnetic field is illustrated in Fig. 1.3.

The evidence of such experiments indicates that the cathode rays are streams of fast-moving negatively-charged particles. They are now known as *electrons*. By accurate measurement of the deflections produced in a magnetic and an electrostatic field, it is possible to deduce the velocity with which the particles are moving. It is also possible to deduce the ratio between the charge carried by the particle and the mass of the particle. A convenient way, for instance, to calculate the velocity of the particles is to arrange that the electrostatic and magnetic deflections are equal but in the opposite direction. A zero resultant deflection is then obtained and the velocity is simply calculated from the ratio of the two fields so applied.

The velocity of the particles is found to be very large and to increase as the voltage across the tube increases. For a voltage of 4,000, for example, the velocity of the electron stream is $3{\cdot}7 \times 10^9$ cm./sec. The velocity of the particles is proportional to the square root of the voltage; that is, the energy of the particles is proportional to the potential difference applied to the tube. This is the behaviour we

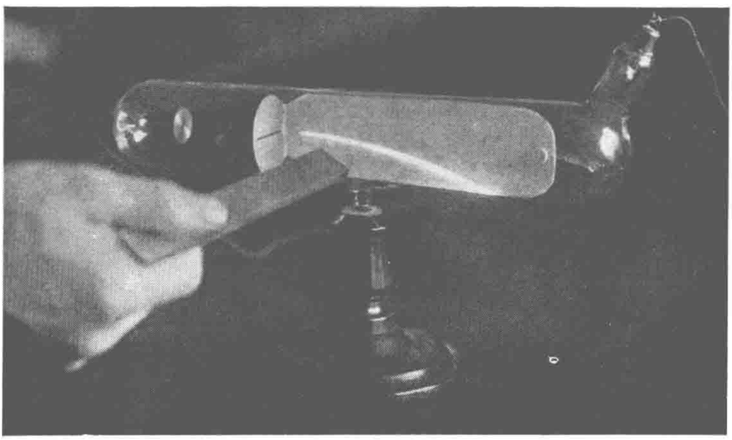

Fig. 1.3. Deflection of cathode rays by the N. pole of a bar magnet. The rays are made visible by a fluorescent screen. [*By kind permission of Messrs. George Newnes Ltd.*]

would expect for a charged particle moving through an electrostatic field.

If the charge e carried by the electron is known, the mass m can be deduced, since deflection experiments give the value of the ratio $\frac{e}{m}$. Before the discovery of the electron some knowledge of the size of the smallest negative charge that exists in nature had been obtained from experiments on the passage of current through electrolytic solutions such as copper sulphate solution. This process involves the passage of charged atoms (known as *ions*) towards the electrodes under the influence of the potential difference existing between them. The ratio $\frac{e}{m}$ observed for the electron stream is found to be some thousands of times greater than the ratio of charge to mass of the ions moving through the solution during electrolysis. If the smallest charge carried by the ions in solution is the same as the charge on one of these particles in the cathode ray stream, this fact would indicate that the mass of the electron must be very much smaller than the mass of the atom.

A direct measurement of the charge on the electron—the elementary unit of negative charge—was made by Millikan in the year 1910. This confirmed, and indeed gave a much more accurate value of the size of this unit negative charge already estimated from electrolytic phenomena. The outcome of these and other experiments was to demonstrate that the electron has a mass very much smaller than the mass of even the lightest atom, being, in fact, 1/1,800 times the mass of the hydrogen atom. Its charge, the elementary unit of negative electricity, as measured by Millikan, is $4{\cdot}77 \times 10^{-10}$ electrostatic units of charge.

X-rays

The experiments to investigate the way in which electric currents could pass across gases at low pressures led directly to the discovery of X-rays by Roentgen in 1895. When current is passing through the tube under conditions most favourable to the production of cathode ray beams, a new type of radiation (*X-radiation* or *Roentgen-radiation*) is found to spread out from those points on the glass wall that are being bombarded by the cathode rays. This radiation has some very special properties. It is able to penetrate materials opaque to light, even metal foils being at least partially transparent to it. It produces a glow of fluorescent light on a screen of suitable material, such as the fluorescent materials barium platinocyanide or zinc sulphide. The radiation may also be detected by its property of conferring electrical conductivity on gases through which it passes. For example, it causes the ready discharge of a gold leaf electroscope in the vicinity of the tube. The radiation is also found to have the same effect as light on a photographic plate—that is, it makes the photographic grains developable and, on development, blackening of the photographic emulsion is produced.

The story of the discovery of the radiation and the very rapid exploitation of the X-rays, especially for the purposes of medical diagnosis, is well known. In later chapters we shall deal in some detail with both the physical aspects of these radiations and with their use in the cure of disease.

Radioactivity

Following shortly after the discovery of X-rays and closely connected with it, was the discovery made by the Frenchman, Becquerel, the developments of which had very profound influence on the know-