2nd edition
revised and enlarge

G. J. VAN DER PLAATS

# MEDICAL X-RAY TECHNIQUE

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## PRINCIPLES AND APPLICATIONS

G. J. VAN DER PLAATS M.D.

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# PREFACE

The days have gone for ever when hospital nurses and others trained themselves as X-ray assistants by a process of trial and error. With the increasing use of various types of radiation, which present much greater hazards to the operating personnel, and the increasing demands for greater technical experience in radiological procedures, it has become necessary to hold courses for the training of radiographers.

It was with such courses in mind that, when approached to write a text-book on Medical X-Ray Technique, I gladly accepted.

It was decided to base the book on not too low a level and to assume a certain amount of knowledge of mathematics and physics, so that the treatment of the elementary basic ideas could be omitted.

In view of the number of well written and plentifully illustrated books on radiographic positioning and centering, these subjects were intentionally passed over. The few radiographs which are included in this book serve only as examples of the techniques indicated in the text; there is and can be no question of a complete range of representative radiographs.

Though it does not directly come under the title of this work, I considered it imperative to include a chapter on radioactive isotopes, in view of the close relationship which exists between this subject and the radiological problems treated in the therapy section.

Certain points have been treated with extra thoroughness in order to ensure that the radiographer is in full possession of the knowledge necessary to carry out all types of procedures, which call for highly specialized experience. Such detailed information appears throughout the book in small print. In some instances the large print deals with the same subject matter as the smaller print; in the latter the treatment is more thorough or elaborate.

In some places, where matters of importance are concerned, I have not hesitated to resort to repetition. For the sake of greater clarity, diagrams rather than photographs have been chosen as illustrations. Many of the diagrams have been taken in whole or in part from existing works by Eggert, Schinz, Raver, Lamarque, Kepp, Barth, Wachsmann and Lenihan, to whom due acknowledgement is made.

For certain sections, physicists and X-ray engineers have been called upon to give their assistance in those parts where the medical man is no longer on his own ground. I can count myself most fortunate in having obtained the collaboration and suggestions of the Misses van Dijk and

Gorissen and Messrs. B. Combée, W. J. Oosterkamp, S. D. J. Overdijk, L. Penning, C. W. Schoorel, P. J. M. Botden and W. D. Scherhorn. It is to these people that my special thanks are due. I should also like to express my gratitude to Mr. W. G. Terry and Mr. A. C. Gunstone who gave their help in ensuring the accuracy of the technical terminology and to Miss Quadvlieg for her painstaking care in the execution of the correction work. Last but not least, I want to thank Mr. Vervoort whose enthusiasm was so stimulating.

May this work fulfil the aim of providing a text book for all radiographers and all those who are interested in medical radiology.

PROF DR. G. J. VAN DER PLAATS,
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June 1959

## PREFACE TO THE SECOND EDITION

Medical radiology is an ever expanding field of science and since the publication of the first edition, further developments and techniques have enabled me to add to the contents of this book. In the interest of greater clarity some things have been omitted, which in the light of new knowledge, might have proved a little confusing to the student.

In addition to this English edition, Spanish, French and German versions are in print. I would like to express my thanks to those whose interest in this book has made these additional editions necessary.

The translation of a technical book is always a matter of some difficulty and I am grateful to those who have indicated points, upon which misunderstanding could have been possible. I hope that these have been dealt with satisfactorily in this new edition.

Included in the appendix are references to some new advances, especially important being the introduction of television techniques into the field of medical radiology.

September 1960 The Author

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CHAPTER I

# ORIGIN OF X-RAYS
# STRUCTURE AND OPERATION OF THE X-RAY TUBE

## § 1 Discovery of X-rays

On the 8th of November 1895 Professor W. C. Röntgen discovered an unknown kind of rays, which he called X-rays.

While he was busy with experiments on the behaviour of cathode rays in Hittorf-Geissler-Crookes' tubes (glass bulbs in which the air has been evacuated to a very high degree) he happened to notice that some barium-platino-cyanide crystals lying near the tube had become strongly fluorescent. Röntgen studied this phenomenon and decided that it was caused by a hitherto unknown radiation.

On December 28th, 1895 he made in Würzburg the first announcement of this radiation in a paper entitled:

"Über eine neue Art von Strahlen" (About a new kind of rays). His presentation of the facts was so convincing as to leave no doubt that a new kind of radiation had indeed been discovered. Moreover Röntgen had already thoroughly investigated—as appeared later—the most important properties of this new radiation.

The discovery of X-rays ranks as one of the greatest discoveries of the last century. They were later also termed Röntgen rays to commemorate his name. There are several biographies of W. C. Röntgen, which give particulars of his great discovery, interspersed with much humorous and interesting information of that period and of his private life.*

In order to understand what takes place in an X-ray tube it will be necessary to recapitulate some concepts of general physics.

* Röntgen was born in Remscheid-Lennep (near Wuppertal), a town which is worth visiting for its own intrinsic charm. A Röntgen-museum has been founded near the house of his birth and here it is possible to see many instruments and documents of his time. The museum is constantly kept up to date and demonstrates the development of X-ray technique throughout the years. A visit to the place may be warmly recommended.

See also Glasser O: Wilhelm Conrad Röntgen and the early history of the Röntgen rays, and Glasser O.: Dr. W. C. Röntgen (ed. Charles C. Thomas, Springfield, Illinois).

## § 2 Definitions and units

In every branch of science and technology the first essential is to establish basic definitions of the different quantities and the units employed to express them. Some units and definitions to be used in the following are given below.

The unit of length is the *metre*, from which are derived the centimetre, the millimetre etc.. Although useful enough for domestic purposes, they are very much too large to be used in the physics of X-radiation; the units here used are the *micron*, $\mu$, equalling $10^{-6}$ metre (0.000 001 metre, or 0.001 millimetre), the millimicron ($10^{-9}$ metre), the *Angström unit* (Å), equalling $10^{-10}$ metre, and the *X-unit*, $10^{-13}$ metre.

The unit of work or energy is the *joule*.

Power may be defined as the energy consumed per second, and is expressed in *joules/sec* (or *watts*).

Energy occurs in various forms, a different unit being used for each form of energy. A smaller unit of energy or work is the *erg*. One joule is $10^7$ erg (one erg is $10^{-7}$ joule).

Accordingly heat is equivalent to energy. The unit of heat is the *calorie*, which is the amount of heat required to raise the temperature of 1 gram of water from 14.5 to 15.5 degrees centigrade. One calorie equals 4.2 joules. The unit of electrical energy is the *watt-second*. 1 joule = 1 watt-second.

Large energies are expressed in kilowatt-hours, abbreviated to kWh (found with domestic electricity meters for example). 1 kWh = $3.6 \times 10^6$ watt-second.

Electrical power, i.e. electrical energy per unit time, is expressed in joules per second or watts (symbol $W$).

A widely used energy formula is $E = \frac{1}{2} mv^2$.

It expresses that a body of mass $m^{kg}$ and velocity $v^{m/sec}$ has an energy of motion (kinetic energy) of $E$ joules.

The practical unit of electric current is the *ampere* (symbol A). The practical unit of electrical tension is the *volt* (symbol V). When a current of 1 A passes through a wire between the ends of which there is a potential difference of 1 V, a power is produced of 1 W.

The practical unit of electrical resistance is the *ohm* (symbol $\Omega$ = omega). A wire has a resistance of 1 $\Omega$ when a current flows through it of 1 A at a voltage of 1 V. This relation between voltage, current and resistance is known as *Ohm's law*, which is expressed by the following relations:

$$V = I \times R \qquad \text{or} \qquad R = \frac{V}{I} \qquad \text{or} \qquad I = \frac{V}{R}$$

(where I is the current in amps, R is the resistance in ohms and V is the tension in volts).

Multiples of thousand are denoted by the prefix "kilo" (k). We shall be concerned most with the kilovolt, symbolized as kV (1 kV = 1000 V). Multiples of a million are denoted by the prefix "mega" (M), e.g.

$$1 \text{ megavolt} = 1 \text{ MV} = 1000 \text{ kV} = 1\,000\,000 \text{ V}.$$

Thousandths are denoted by the prefix "milli" (m). We shall be most concerned with the milliampere (1 mA = 0,001 A). Millionths are denoted by the prefix "micro" ($\mu$), e.g.

$$1 \text{ microampere} = 1\ \mu\text{A} = 0.001 \text{ mA} = 0.000\,001 \text{ A}.$$

A point of importance is the heat caused by the electric current; from the above equations it can be derived that this heat is equal to 0.24 VIt cal. (*Joule's law*), where V is the voltage, I the current and t the time during which the current flows.

Another term frequently encountered is *capacitance*. This is the power of, as it were, storing electricity as it is done in a capacitor. The larger the capacitance the more electricity can be added to it before a certain increase in the voltage is reached. The capacitance of a capacitor is thus expressed by the quotient $\frac{\text{charge}}{\text{voltage}}$. The practical unit of capacitance is the *farad* (F). Generally however, millionths of the unit are used, i.e. microfarad ($\mu$F).

It would be going too far to discuss such terms as electrical field-strength, self-inductance etc.

Electrons are extremely small, negatively charged particles. They have a mass of $9.11 \times 10^{-28}$ g, which is approximately equal to $\frac{1}{1835}$ of the mass of a hydrogen atom. The charge they carry is the smallest negative charge known. When an electron is subjected to a positive potential difference of 1 V and thereby accelerated, the resultant increase in energy is called 1 *electron volt* (1 eV). This extremely minute quantity of energy is widely used in atomic physics as the unit of small energies. The energy of one electron volt is equal to $1.6 \times 10^{-12}$ ergs. The units of large electrical energies are the kilo-electron volt (keV) and the mega-electron volt (MeV). 1 MeV = 1 million eV. For example, if the potential difference between the anode and cathode of an X-ray therapy tube is 6 million volts (= 6000 kV = 6 MV) the energy with which the electrons strike the anode is 6 MeV. The term MV is often used side by side with the term MeV.

## § 3 Direct current and alternating current

A distinction is made between direct voltage or direct current and alternating voltage or alternating current.

With direct current (D.C.) there is a constant potential difference between the two poles and the current passing through a constant resistance has a constant value and direction. An example of a constant voltage source is the accumulator, each cell of which supplies approx. 2 V. Direct current is not of any great use in X-ray technique. The voltage producing it cannot be raised sufficiently, it causes no induction and is therefore seldom used nowadays in radiology.

With alternating current (A.C.) the poles become alternately positive and negative with respect to each other and the voltage changes its value every instant, thereby also changing the strength and the direction of the current.

The peak value ($V_p$) of the voltage is the maximum value of the voltage. Apart from this we have the root mean square value or effective value ($V_{eff}$) of the voltage.

The effective value may be defined as the D.C. voltage required to generate the same amount of heat as the A.C. voltage in a given resistance.

Alternating current values are defined in the same way as A.C. voltage values, i.e. peak value ($I_p$) and effective value ($I_{eff}$).

Wide use is made of what is known as *rectification*, particularly at high tensions. For this process the negative half of each alternating current cycle, in which the current flows in the opposite direction, is either suppressed or reversed (see also chapter II).

In the first case a current is produced which flows only in every second half-cycle (half-wave rectification); in the second case (full-wave rectification) current flows uninterruptedly in both half-cycles of the alternating voltage. In both cases the current is a pulsating direct current which is sometimes wrongly referred to as direct current, because of its constant direction.

True direct current changes neither in tension nor in intensity. The devices used for converting an alternating current into a current of constant direction are called *rectifiers*, and are used both in low-tension technique (e.g. in radio sets and for charging accumulators) and in high-tension technique. In X-ray apparatus they are also known as *valves*.

The alternating voltage supplied by most national electricity networks has a frequency of 40, 50 or 60 cycles per second, i.e. each pole becomes positive and negative 40, 50 or 60 times per second.

In America the frequency of the mains voltage is, as a rule, 60 c/s. In Italy, Egypt and some other countries it is 40 c/s. An apparatus designed to operate at a frequency of 50 c/s cannot in general immediately be used on other mains frequencies without modification.