Part I

X-RAY PHYSICS AND FUNDAMENTALS

Chapter I

X-RAYS AND THE ELECTROMAGNETIC SPECTRUM

The discovery of the "x-ray" in November, 1895, by Wilhelm Conrad Roentgen, according to Christie, "was one of the dramatic concluding events of that tremendous Nineteenth Century which was more important in its contributions to scientific knowledge than the eighteen hundred years that preceded it. It will be known to future historians as the century in which scientific medicine had its birth."[1]

It is a matter of history that throughout most of the century preceding Roentgen's discovery, many physicists carried on experimental work of forcing high tension currents through partial vacuum tubes. According to MacKee,[2] investigation was probably started by Abbé Nollett, using a tube with a high degree of vacuum. His work was followed by that of many others, among whom Geisler, Hittorf, Crookes, Hertz, Lenard and Plucker used different types of tubes with varying degrees of vacuum. Early important observations and experiments were made by Abria, Faraday, Gassiot, Spottiswoode, Fernet, Goldstein and others.

Finally, in 1895, a Bavarian physicist, Roentgen (pronounced ren′-ken, according to Dam[3]), realized that the partial vacuum tube with which they had been experimenting was producing a ray which had never previously been recognized. As he did not know the exact character of this ray, he designated it the x-ray, allowing x to stand for the unknown, as in a mathematical formula.

One should not believe, however, that Roentgen was not fully aware of the character of these rays. As Haenisch stated: "Roentgen not only exhaustively set forth, in his first works, the physical properties of these rays, and even predicted their relations to light rays, but also he had the vision of the epochal development which his discovery would bring about in medical science."[4]

By the work of physicists in recent years, we know that the x-rays are rays which vary from a fraction of 1 to a few Angstrom units in length. Therefore they are located in the invisible portion of the electromagnetic spectrum.

The visible portion of the electromagnetic spectrum contains the seven primary colors. Radio involves that region of the same spectrum which has to do with longer wavelengths. The shorter wavelengths of higher frequency constitute the field of radiology in which radiologists are diligently working to learn methods of producing and controlling new types of rays for application in many problems of health preservation and restoration.

Bardeen a few years ago discussed the spectrum as follows:

> Midway between the region of the electromagnetic waves in which the radio-fan takes interest and the region of those in which the radiologist takes interest comes the region of the electromagnetic waves which convey energy from the sun to the earth and upon which all life depends. In the center of this region come the rays which, falling upon the retina, give us vision, the rays of light.
>
> On one side of the visible spectrum we have the infra-red region, with longer waves and lower frequency; on the other side, the ultraviolet region, with shorter waves and higher frequency. Thus, we have in the spectrum of electromagnetic waves three main regions, that of the radio, that of the sunlight, and that of the x-rays and gamma rays.[5]

Bardeen continued his discussion from the long wavelengths used in radio down through the visible spectrum, ultraviolet, Grenz rays, long x-rays, short x-rays and radium radiation to Millikan's discovery of the cosmic rays, which are shorter than the gamma rays of radium.

Since the discovery of cosmic rays, physicists have proceeded with their exploration of the atom, but still the gamma rays of radium remain the shortest rays customarily put to clinical use. They have been found to have a wavelength of from 0.02 to 0.1 Angstroms.[6] Next, there is a section on the spectrum between the longest x-rays and the shortest ultraviolet rays as yet almost entirely neglected. Grenz rays fall in this area; Bucky[7] is probably the leader in their clinical application in this country. The shortest ultraviolet rays measure about 300 and the longest about 4,000 Angstrom units.

Beyond the red rays, the longest in the visible spectrum, come the longer wavelengths of the ultra-red or infra-red heat waves, then the high frequency currents for diathermy, autocondensation, and so on, up to the hertzian waves used in radio work.

These vary in length from a few centimeters to hundreds and thousands of meters. Bardeen remarked, concerning hertzian waves: "From the biological aspect, there are at present no known direct effects on the body of the rays of the radio region of the electromagnetic spectrum. The tissues of the body appear to be not at all attuned to electromagnetic disturbances of the frequency commonly used in wireless communication."[5] This is not so, however, in the shorter wavelength fields, where the cells of the body are definitely affected by exposure.

The essentials to know are that in addition to the visible portion of the electromagnetic spectrum, with its seven primary colors, there are some rays too short and some too long to be seen by the unaided eye. X-rays fall in the shorter class.

With the foregoing brief review, one should have no trouble remembering the relative position of the x-rays in the electromagnetic spectrum (Fig. 1) and also that not all the rays in the spectrum are biologically active, or at least not to any degree of clinical significance.

Roentgen's early report on his newly found rays was thorough. He explored their possibilities as only a true scientist could, familiarizing himself with practically all their major characteristics. When he presented these facts to the scientific world in December, 1895, he announced a discovery which led to many advances in the sciences of physics, chemistry, medicine and surgery. The discovery was not accidental. It was due to the keen observation of Roentgen in a field where much research work had been done by many scientists over a long period.

It would be impossible to overestimate the full value of Roentgen's work. He will go down in history with Pasteur, Lister, Koch and many others who lived in the same century, whose achievements in medicine, surgery and the allied sciences form the foundation blocks on which present-day scientific medicine rests. Roentgen's discovery has changed considerably our conception of certain anatomic facts and physiologic phenomena as well as aided in the correlation of clinical aspects of dentistry, surgery and medicine. It is used daily in all parts of the world as an aid in the diagnosis, the prevention and the treatment of disease.

In the field of therapy, Roentgen opened the electromagnetic spectrum to further scientific and clinical exploration. Much

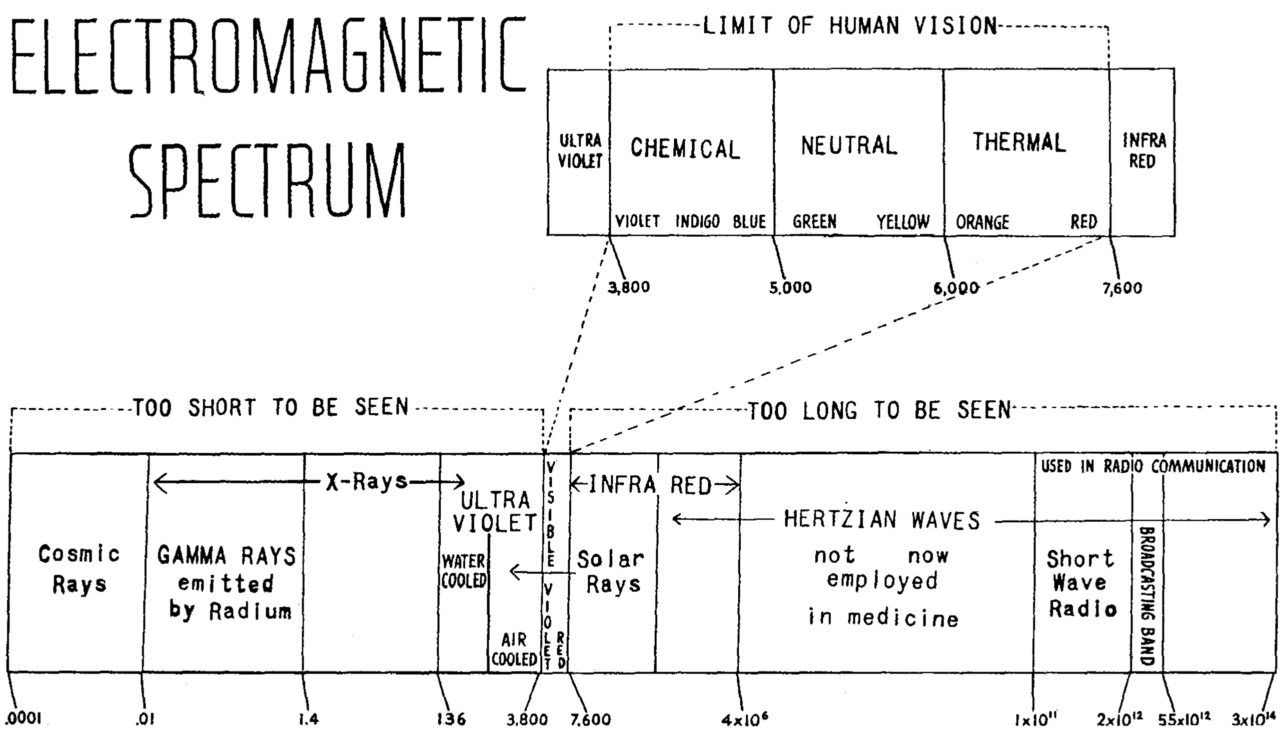

FIG. 1.—The diagram of the spectrum shows in its lower section the entire electromagnetic range with the visible spectrum centrally located set out above to the right, enlarged. The general tendency of the wavelength to the left is to initiate chemical changes while those to the right give rise to heat; the central band is neutral. The invisible rays to the left are used for radiation therapy. To the right are the wavelengths for the various types of heat-generating apparatus used in physical therapy.

has already been accomplished within less than 50 years since his discovery. During the present century, 10 or more years have been added to the span of life. X-ray diagnosis and therapy have played no small part in this advance of medicine. Nevertheless x-ray therapy is still in its infancy.

The latest advances of substantial clinical significance are undoubtedly going to be the result of the investigations made possible by Lawrence's cyclotron. With the cyclotron, Lawrence has provided a means of applying a new type of radiation to the ills of man. Stone, Lawrence and others of the group are intelligently and conservatively using these rays to determine what can be done with them. Radiologists the world over are anxiously awaiting their reports.

Properties of X-rays

As originally described by Roentgen, and as understood today, the most important properties of the x-rays, when directed toward material bodies for clinical purposes, are the following:

1. They are capable of penetrating objects opaque to ordinary light. The ability to penetrate is in inverse proportion to the density of the object (physical action).
2. They are capable of causing a chemical change in the emulsion of an unreduced photographic plate or film (chemical action).
3. They are capable of causing fluorescence (excitation of light) by striking certain crystals (physical action).
4. They are capable of exerting a stimulating or destructive action on living cells, depending on the amount of radiation received (biologic action).
5. By their action, gases can be made to conduct electricity (ionization-physical action).

Of these five properties, the first three are of special importance in diagnosis, while all five are probably of importance in therapy. Until all of them are more thoroughly understood, however, any attempt to divide them into groups would be useless. Consequently, all five properties must be thoroughly studied by anyone aspiring to do any type of radiologic work.

SIGNIFICANCE OF VARIOUS PROPERTIES OF X-RAYS IN TREATMENT OF INFECTIONS

Little is actually known and nothing has been proved regarding the specific or exact reason for the favorable therapeutic action of the x-rays in the treatment of infections.

The first property, the power of the rays to penetrate opaque substances such as tissues, is of value in therapy in reaching living, deep seated pathogenic organisms or their toxins and in aiding defensive cells or fluids beneath the surface of the body.

When the second property, the power of the rays to cause chemical changes, is added to that of penetration, it is possible to produce changes at the site of the disease even when the disease is deep within the tissues.

The third property, the power to cause certain crystals to fluoresce after the rays have passed through a more or less opaque substance, is seen daily wherever fluoroscopy is used. Like the chemical action exerted on the emulsion of the x-ray film, it is such a commonplace incident that it gives rise to little thought. Nevertheless it provides a simple means of proving to the most skeptical that rays penetrate and are still active after penetrating masses of tissue.

The fourth property, the power to cause biologic action when rays are directed on living cells, and the fifth property, the power to ionize or split gases, are mentioned only to insure their consideration when any attempt is made to explain the effects of radiation in the treatment of infections.

Despite our lack of indisputable experimental data, the most conservative clinician will be impressed, and even convinced, if he observes the results obtained after use of small safe doses of roentgen rays in the treatment of gas gangrene, acute spreading peritonitis and other similar fulminating infections.