PHYSICAL NATURE OF RADIATIONS USED IN INDUSTRY *

BY

G. D. ROCHESTER

From the Physical Laboratories, Manchester University

The principal radiations may be divided into two types, corpuscular and electro-magnetic radiations. Corpuscular radiations are those having the properties of particles, as, for example, alpha rays, beta rays and neutrons, while electro-magnetic radiations are those with wave-like properties. Examples of electro-magnetic radiations are gamma rays, x-rays, ultra-violet and actinic rays, visible radiation, infra-red rays and radio waves. Though this division is justified by experiment it should be pointed out that recent experiments have demonstrated that particles show wave-like properties and waves particle-like properties.

Corpuscular Radiations

These radiations are emitted in the natural or artificial disintegration of atomic nuclei.

Alpha particles are the nuclei of the gas helium; they carry positive charges and have four times the mass of the hydrogen atom. They are copiously and continuously emitted by naturally radio-active substances like radium and occur with well-defined

energies, usually about 5 million electron volts. On the average they travel with one-twentieth of the speed of light. In spite of their high energies and great speeds alpha particles have little penetration because they dissipate energy rapidly by the formation of ions. An alpha particle with a range of 4 cm. in air at atmospheric pressure (equivalent to a thin sheet of paper), produces as many as 275,000 ions along its track. The tracks left by alpha particles can be made visible by the Wilson cloud chamber. A photograph of alpha particles tracks is reproduced in fig. 1. The intense ionization and the straightness of the tracks may be noted.

Beta particles are high speed electrons ejected from radio-active nuclei or from the outer shells of electrons by gamma rays. Their energies range up to 10 million electron volts and they have velocities approaching the velocity of light. The ranges of beta particles are much greater than alpha particles because the ionization loss along their paths is much less. The small ionization loss is shown by the thinness of the track left in the Wilson cloud chamber. A high-speed beta particle has a range of about 1000 cm. in air or 1 cm. in water. Beta particles are highly scattered. If a beam of beta particles falls normally on a thin sheet of metal of high atomic number, 50 per cent. of the beam is scattered through more than 90 degrees.

Neutrons are not yet used in industry. They are neutral particles of mass equal to the hydrogen atom and are emitted in large numbers when certain elements, e.g. beryllium, are bombarded with the alpha particles from radium. They may be produced artificially by the Lawrence cyclotron. Their ranges are very great because their ionization loss in matter is extremely small. They are very difficult to absorb. The best absorbers known are water and paraffin.

Electro-magnetic Radiations

Electro-magnetic radiations have wave-like properties, that is they show the phenomena of reflection, refraction, dispersion, interference and diffraction. The only difference between the different types of radiation is a progressive change in wavelength from the shortest electro-magnetic radiation known, gamma radiation, to the longest, radio waves. They all travel with the velocity of light.

FIG. 1.—Tracks left by alpha particles in the Wilson cloud chamber. (After Blackett and Lees.)

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Many of the properties of these waves can be illustrated by water waves. Thus if two sets of water waves of the same wavelength cross, interference effects are observed in the region of crossing. At some places in this region much higher waves are observed while at other places there is still water because the 'humps' of one set of waves overlap the 'hollows' of the other set. Exactly the same effect is observed in the case of light and x-rays (see fig. 2) and, in fact, for all electro-magnetic radiations.

FIG. 2.—Interference fringes taken with (a) x-rays of wavelength 8.33 A.U. (after Kellstrom), and (b) visible light of wavelength 4358 A.U. (after White),

tions. The dark lines in the figure correspond to regions of destructive interference, i.e. no light, and the bright lines to regions of constructive interference. By this and many other experiments it has been proved that all the radiations classified as electro-magnetic have similar properties.

Gamma rays are electro-magnetic radiations of wavelengths from 0.005 to 1.3 A.U. emitted by radio-active nuclei. Their penetration is very great, the intensity being reduced only 50 per cent. by 2 inches of iron. Energy is lost by the production of beta particles (photo-electrons ejected from the outer shells of atoms), scattering and, for very short waves, the creation of pairs of electrons.

X-rays are electro-magnetic radiations of wavelengths from 0.01 to 10 A.U. A thickness of 3.5 cm. lead is needed to protect the body from 600 Kv. x-rays. Wilson cloud chamber photographs show that x-rays lose energy by the production of photo-electrons (see fig. 3), and by

FIG. 3.—Tracks left by electrons in the Wilson cloud chamber; tracks are from low energy photo-electrons (produced by a beam of x-rays) which are identical with slow beta particles. (After Nuttall.)

scattering. The medical effects are due to photo-electrons. The total length of track of all the photo-electrons produced in a small volume of the body by a comparatively short irradiation with x-rays may be of the order of thousands of miles.

Ultra-violet and actinic rays (wavelength range,

2500–4500 A.U.), *visible radiation* (4000–8000 A.U.), and *infra-red rays*, correspond to energies of from 5 volts and 0.1 volts. Medical effects may be physiological, photo-chemical or thermal. These radiations may be emitted or absorbed by matter in the form of line, band or continuous spectra. Line spectra are associated with electronic energy changes in atoms while band spectra are associated with electronic, vibrational and rotational energy changes in molecules. Continuous spectra may be produced by atoms or molecules in the gaseous, liquid or solid states. The continuous spectra produced by liquids and solids may be due to line or band absorption broadened to continua by the intense atomic and molecular fields. Examples of line and band emission spectra are shown in fig. 4. An

FIG. 4.—Examples of line and band emission spectra. The line spectrum, marked (a), is part of the spectrum emitted by the iron arc; and the band spectrum, marked (b), is emitted by the diatomic molecule antimony fluoride (SbF). The line spectrum is superimposed on the band spectrum.

example of line absorption spectrum is the Fraunhofer spectrum of the sun which is due to the absorption by the cool gases in the outer layers of the sun of the continuous spectrum emitted by the white-hot interior. A good example of very important continuous absorption is the narrow absorption band of chlorophyll in the near infra-red. By this absorption band vegetation absorbs energy from the sun and life on the earth is made possible.

Summary

A description is given of the physical nature of the principal radiations used in medicine. The radiations are divided into two main types, corpuscular and electro-magnetic radiations. The corpuscular radiations include alpha particles, beta particles and neutrons; while the electro-magnetic radiations include gamma rays, x-rays, ultra-violet radiation, visible radiation and infra-red rays. The medical effects are for the most part due to the production of photo-electrons but they may also be physiological, photo-chemical or thermal.

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