# RÖNTGEN RAYS, 1895-1945

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IT is fitting that on this occasion of the commemoration of their discovery half a century ago, we should refer to X-rays by the name of their discoverer, even though such a terminology is now obsolete. WILHELM KONRAD RÖNTGEN discovered X-rays while operating a discharge tube in his laboratory at Würtzburg in November 1895. For this discovery of fundamental importance in physics he was awarded the Rumford Medal of the Royal Society in 1896 and the first Nobel Prize in physics in 1901. This discovery opened the gates to a vast new field of fundamental scientific and industrial research and placed a new and powerful tool in the hands of the medical man for the alleviation of human suffering. The vastness of the field and the fundamental nature of the discovery may perhaps be best realised by the statement that during the fifty years following the discovery, as many as seven Nobel Prizes have been awarded for discoveries in X-ray physics. Eminent men of science have since worked in this field making outstanding discoveries of a fruitful character some of which have been of much use not only in physics but in other branches of science and industry. The discovery of X-rays was not a matter of chance. Röntgen was looking for invisible radiations emitted by a discharge tube. For this purpose, he had on his table a small screen of cardboard coated with crystals of barium platinocyanide such as those used at the time in Germany for revealing the invisible rays of the spectrum. Röntgen carefully covered up the discharge tube with black paper and excited it to find out whether all light was excluded. To his intense surprise he found the screen shining brightly. This led to further investigations and the ultimate discovery of invisible radiation from the tube, to which he gave the name X-rays "for brevity". These rays were found to be emitted by the spot on the discharge tube bombarded by the cathode rays. Röntgen conducted further experiments and discovered that X-rays traverse matter opaque to ordinary light and that they affect the photographic plate. He announced his discovery in a paper presented before the Physik-Medic. Gesellschaft of Würtzburg in December 1895. This paper was subsequently reprinted in *Annalen der Physik* (64, 1, 1898). In this very first paper he anticipated many of the different applications of X-rays which have developed during the past fifty years.

X-rays are emitted by any material bombarded by cathode particles. In X-ray tubes a metallic target, known as the anti-cathode, is provided for this purpose. In so-called gas tubes cathode-rays produced by the discharge are focussed on the anti-cathode by suitably shaping the cathode. In hot cathode tubes the electrons emitted by the hot filament of the cathode are accelerated by the applied tube voltage. They are also focussed on the anti-cathode by surrounding the filament by a concentric metal cylinder, one end of which projects a little beyond the filament. X-rays are emitted from the focal spot on the target. In gas tubes it is necessary to maintain a residual gas pressure of the order of about $10^{-3}$ mms. of mercury for running the discharge. The hot cathode type of tube is comletely evacuated, degassed and sealed off. The tube voltage was generated by an induction coil in the early days. The high tension transformer is universally employed nowadays. During the past fifty years the application of X-rays in medicine, industry and scientific research has advanced very rapidly. Advance in the design and manufacture of X-ray apparatus has kept pace with the rapid advance in the application of X-rays. The range of apparatus commercially available is considerable, each type serving a specific purpose. X-ray tubes employing voltages of the order of millions are in regular use particularly in America. One such was developed by the Massachusetts Institute of Technology and is installed at the Huntington Memorial Hospital of the Harvard Medical School. Another one, thirty feet long and weighing ten tons, is in use in the Mozelle Sasson High Voltage X-ray Therapy Department of St. Bartholowew's Hospital, London.

The use of X-rays for diagnostic purposes in medicine was the first to be realised. Within a very short time of their discovery, they were successfully employed for diagnosing a diseased thigh bone in Paris, for observing the reunion of a fractured bone in Berlin and for the location of a bullet lodged in the calf of a patient in America. For diagnostic purposes, the X-ray shadow of the subject is observed on a fluorescent screen or alternatively photographed for obtaining a permanent record. Such a photograph is known as a radiogram, the technique itself being known as radiography. Radiography is a routine in many medical institutions nowadays. Bone and such other dense material throws deeper shadows than surrounding tissue so that the radiologist can, as it were, look inside the body of the patient.

Radiography is also in general use in industry, particularly in Europe and America. The detection of flaws in weldings, pressings, forgings and castings and also the inspection of assembled articles like radio valves, fuses and so on by radiographic methods is a matter of routine in many factories. This method is invaluable in the aircraft industry. Radiograms are often of great help to fine art for scrutinising works of art reputed to be ancient.

After the discovery of diffraction of X-rays by crystals in 1912 by Max von Laue, great advances were made on the investigation of the nature of X-rays on the one hand and the fine structure of matter on the other. Röntgen was of opinion that X-rays are waves due to *longitudinal vibrations* in the so-called luminiferous ether. Some physicists, mainly British, thought that they were corpuscular like cathode-rays. But Laue's discovery definitely proved that X-rays are electromagnetic waves similar to light. Their wavelength lies in the range of about 0·06 to 500 Å. The work of Barkla, Mosley and others has shown that the X-rays emitted by the anti-cathode of an X-ray tube are of two types, *viz.*, the continuous radiation and the characteristic radiation. The continuous radiation consists of all wavelengths above a short-wave limit which itself is dependent on the voltage applied to the X-ray tube. The characteristic radiation consists of monochromatic radiation characteristic of the element of the anti-cathode. Every element has its own characteristic X-ray spectrum and X-ray spectroscopic methods have been developed for the analysis of any given material. Such methods led to the discovery of Hafnium by Hevesy and Coster in 1923. A systematic study of X-ray spectra has gone a long way towards the elucidation of atomic structure.

The diffraction of X-rays by crystals has led to the systematic study of the solid state of matter. The structures of a very large number of crystals have been determined resulting in the comprehension of many phenomena connected with the solid state of matter. Among outstanding workers in this field may be mentioned the late Sir William Bragg and his school.

X-ray crystallographic methods find a large number of applications in industry like the measurement of stress in castings, pressings and forgings. Many problems confronting the metallurgist like thermal equilibrium, internal stress and strain, crystal texture and phase identification may be solved by simple X-ray crystallographic methods. The development of these methods has advanced to such an extent as to warrant the organisation of Industrial X-ray Conferences by the Institute of Physics.

Systematic work on the biological effects of X-rays was stimulated by the discovery that continuous irradiation produces a disease known as X-ray dermatitis. X-ray irradiation in proper doses inhibits the growth of living cells in tumours. But prolonged exposures may produce proliferation of cells resulting in cancer. Some of the early X-ray workers became victims to such disastrous biological effects. Recommendations for adequate protection from such effects have been drawn up and published by the International Congress or Radiology. The biological effects are made use of in the treatment of certain types of tumours and skin diseases. X-ray irradiation is also known to produce mutations of chromosomes in certain cases.

Even from a casual survey of the past half a century of X-ray work, one cannot help finding that there are very few branches of human knowledge and experience which have not felt the impact of the developments of applications of X-rays. It is not too much to hope that their applications to the advancement of human knowledge and the alleviation of human suffering may multiply a thousand-fold.

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## A LARGE-SCALE YIELD SURVEY ON COTTON

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SINCE 1942-43 studies have been in progress on cotton for evolving a suitable method on a random sampling basis for forecasting and estimating the yield of the commercial crop. These have led to extensive developments, and not only has one large-scale survey on cotton been successfully carried out in the Central Provinces last year and another proceeding in the current season, but similar large-scale surveys on the principal food-crops, wheat and paddy, have been completed (Sukhatme, 1945) and are being conducted in different provinces by the Imperial Council of Agricultural Research. Within a short space of time, an efficient practical tool has thus been made available for measuring with precision the yield of crops covering millions of acres. The object of the present article is to describe the yield survey on cotton conducted during the season 1944-45 in Central Provinces and Berar. This survey, which has spread over 29,342 square miles and covered nearly three million acres of cotton, provided for the first time the means of estimating the average yield per acre and total production of cotton in the province by a scientific objective process.

For a proper appreciation of the sampling technique adopted, it will be useful to describe in broad terms the structure of a province in India. A revenue district is the major administrative unit in a province, and a province usually contains 20 to 25 districts. The geographical area of a district is about 3,000 sq. miles. A district is divided into four or five *tahsils* or *taluqs*, each with an area of 600 to 800 square miles and containing roughly 400 to 500 villages. A *tahsil* is further divided into three to five circles for the convenience of the revenue administration and a circle contains about a hundred villages. A Revenue Inspector is stationed in each circle. Communications between villages are poor. Good metal roads are few and far between and most of the villages are only accessible by a cart track. The revenue map of a *tahsil* with the village boundaries marked on it looks like a honey-comb with the villages forming the cells of this comb. The map of a single village reproduces the same pattern with individual fields forming the cells. Complete lists of villages in each *tahsil* or in each circle are available with the Land Records Department. The area of each field is accurately measured periodically and recorded in the villages. Except in provinces like Bengal and Bihar with a permanent land revenue settlement, there is a village accountant or *patwari* for each village or a group of villages and one of his principal

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