EARLY YEARS OF RÖNTGEN'S DISCOVERY

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The physicist must start with certain resignation...that his work will be superseded by that of others... that his methods will be improved upon, more accurate results obtained and that the memory of his life and his work will gradually disappear.

William Conrad Röntgen (1845-1923)

INTRODUCTION

During the centuries following Newton's epoch-making discovery of motion laws of physics, three pillars were erected to firmly uphold the world of science: classical mechanics, electrodynamics and thermo-dynamics. No doubt, the greatest event of the late 19th century was the theory of electromagnetism with its field equations developed J.C. Maxwell (1831-1879), and later,on this basis by, in 1888, the discovery of electromagnetic waves by H. Hertz (1857-1894). Both events helped to strengthen the wide-spread conviction that the visible world of matter could be rationally described, and, together with the advancement in chemistry, all natural phenomena could be classified and described by the respective laws. Around 1890, it seemed obvious that the fundamentals of physics had been well implanted and thoroughly explored, so that what remained for physicists was to finish the job by supplying details to the existing facts and theories. This is best exemplified by the advice that M. Planck(1858-1947) received from Philipp vonJolly (1801-1884) when he was to start his physics studies: " *Strictly speaking, there is no point in undertaking such studies, since physics has no prospects ...* " It may also be worth quoting Max von Laue (1879-1960) who said on 10th December, 1950, on the occasion of the 50th anniversary of the Nobel foundation that: *"When, in 1901, it became known that the first Nobel Prizes went to Röntgen, van't Hoff and Behring (...) some knowlegeable people would question the ability of the Nobel Prize Committee to find enough candidates for the annually awarded prize in the future"...* [Derek and Solla, 1961]

However, one of the least important problems of the physics of that time, it seemed, was that of electrical discharge through gases. In 1853, an unknown French physicist, Antoine P. masson sent the first electric spark from a high-voltage induction tube through a partially evacuated glass tube and discovered that the tube was filled with a bright glow. Soon after that, Julius Plücker (1818-1868) also found 'faint blue light', and in his series of seven papers investigated this light which he called *"magnetische Licht"*. Later, Heinrich Geissler (1815-1879) developed gaseous discharge tubes which found many customers among physics lecturers who used them for demonstrations. The "Geissler tubes" can now be seen almost everywhere in the form of neon signs. Although the discharge in gases seemed to have been of minor importance at that time, it has not only given birth to modern physics , but it has also presented a most intricate physics problems due to the almost infinite number of variables involved. In 1869, Johann W. Hittorf (1824-1914) observed a dark region (detected as early as by M.Faraday in 1838), near one electrode in the tube with electrical discharge, that grew in size as the exhaustion was continued. This problem was later studied by Sir William Crook...es (1832-1919) who, while experimenting with electrical discharges through rarefied gases, discovered a second dark "space" that now bears his name. When the evacuation of the Geissler tube proceeded, the Crookes dark space widened and finally the whole glass tube glowed with a faint greenish light, which was soon found to be a fluorescence of the glass produced by invisible rays emanating from the cathode. These 'cathode rays' were first believed by Crookes to be a "fourth state of matter" consisting of charged atoms or molecules, and by Hittorf, as by many other German physicists, some kind of "disturbance in the ether". Hittorf, however, determined that the cathode rays travelled in straight lines, and Crookes was able to demonstrate in 1870 that they had momentum and energy, and held to the view, shared by other English physicists, that they were charged molecules something like the ions in electrolysis. Finally, Jean Perrin(1870-1942) found that they, in fact, were negatively charged particles.

The penetrating power of cathode rays was first demonstrated by Hertz and his assistant, Philipp Lenard (1862-1947), of whom we shall hear more in connection with Röntgen's discovery of X-rays , and who suggested that the cathode rays consisted of molecules of an attenuated space producing a turbidity in the ether. Here we have encountered the first serious controversy between the English and German physicists. It was only Sir Joseph John Thompson (1856-1940) who, entrusted with the task of solving the controversy, after several failures, was able to eliminate the controversy by determining the velocity of the rays and the ratio between the charge and mass of the particles making up the rays.

RÖNTGEN'S EXPERIMENT

In 1893-1894 the mysterious cathode rays and their properties became so popular in the physics world that some researchers from other, better known fields began to study them. Among them, was Wilhem Conrad Röntgen, the professor of physics at the Royal University of Würzburg, of local fame only, who is now known the world over for his discovery of X-rays. The best account of that discovery was presented by H.J. W. Dam in an American monthly *McClure's Magazine* of April 1896.

"Now, Professor," said I,"will you tell me the history of the discovery?"

"There is no history," he said."I have been for a long time interested in the problem of the cathode rays from a vacuum tube as studied by Hertz and Lenard. I had followed theirs and other researches with great interest, and determined as soon as I had the time, to make some researches of my own. This time I found at the close of last October ['95]. I had been at work for some days when I discovered something new.

"What was the date?"

"The eight of November.

"And what was the discovery?"

"I was working with a Crookes tube covered by a shield of black cardboard. A piece of barium platino-cyanide paper lay on the bench there. I had been passing a current through the tube, and I noticed a peculiar black line across the paper."

"What was that?"

"The effect was one which could only be produced, in ordinary parlance, by the passage of light. No light could come from the tube, because the shield which covered it was impervious to any light known, even that of the electric arc."

"And what did you think?"

***"I did not think; I investigated** [bold O.A.C.]. I assumed that the effect must have come from the tube, since its character indicated that it could come from nowhere else. I tested it. In a few minutes there wasno doubt about it. Rays were coming from the tube which had a luminescent effect upon the paper. I tried it successfully at greater and greater distances, even at two metres. It seemed at first a new kind of invisible light. It was clearly something new, something unrecorded."* [Jauncey, 1945]

Before this famous discovery, Röntgen had already acquired a reputation of a thorough investigator, having been able to combine his talents as a theorist with that of an experimenter. In his discovery he made use of the physics equipment available to his contemporarties , Lenard, Hittorf or Crookes. There is little doubt that they had also been producing x-rays, though had not been aware of them. William Crookes used to find darkened photographic plates in his laboratory and he even once claimed refund from his supplier, Ilford Photographic Company.

RÖNTGEN'S LIFE

Wilhelm Conrad Röntgen was born on March 27, 1845 in a small town Lennep in Germany. He was the only child of Friedrich Conrad Röntgen, a textile merchant, and his Dutch wife, Charlotte Constance Frowein. When Wilhelm was three years old, his parents moved to Apeldoorn in Holland and became Dutch citizens. Because of a practical joke that somebody played, Wilhelm was expelled from his secondary school in Utrecht and failed the entrance examination to the University. Happily, he was admitted to the Zürich Politechnikum, from which he graduated in mechanical engineering at the age of 23. With his dissertation *"Studien Über Gase"* he received *Doctoris Philosopiae* degree from the University of Zürich. In subsequent years, he became August E.E.Kundt's (1839-1894) assistant, first at Würzburg, and then in Strassburg, where he became *Privat Dozent.* In 1879, he was appointed Professor of physics at the Hessian University of Giessen, where he lived for 10 years. Then, in 1888, he returned to the Königliche University of Würzburg as Professor and Director of the new *Physikalische Institut.* In 1893 he was also elected Rector.

EARLY EFFECTS OF RÖNTGEN'S DISCOVERY

At the beginning of that year, as we know from the interview above, Röntgen, like many other researchers, became interested in Lenard's work on cathode rays. He corresponded with Lenard and bought the necessary tubes, photographic plates, and fluorescent materials. He started experiments in March 1894, but it was in the Autumn of 1895 that he was able to continue with his work, this time with a set-up suggested by Nicola Tesla (1856-1943), consisting of a condenser and transformer between the coil and the tube . Then, as we learned earlier, after his first experiment and much additional experimentation and careful observation, on December 28, 1895 he delivered to the Secretary of the Würzburg Physical and Medical Society, a note entitled, *"Über eine neue Art von Strahlen" (On the new nature of rays).* In a footnote, he explained that "*to differentiate them from others*" he wanted to give them a name of X-rays. On New Year's day, he sent copies of his article and prints of his radiographs to: Jules Henri Poincaré (1854-1912) of Paris, Lord William Thomson Kelvin (1824-1907)of Glasgow, Sir Arthur Schuster (1851-1934) of Manchester, Hendrick Antoon Loretz (1853-1928) of Leiden, Otto Lummer (1860-1925) of Berlin, August Voller (1842-1920) of Hamburg, Fredrich Wilhelm Kohlrausch (1840-1910) of Strassburg, Ludwig Louis Albert Zehnder (1854-1949)of Freiburg, and Franz Serafin Exner (1849-1926) of Vienna [Juan, 1985]0. Sir Arthur Schuster , as he describes it himself in the book *The Progress of Physics (1911),* came to know the contents of Röntgen's letter when he was returning from a short Christmas holiday in late December 1895. On his way home, he called at his laboratory and found an envelope containing photographs, which, without the accompanying text, were unintelligible. Among the photographs was one of an outline of a hand, with bones clearly marked inside. The accompanying text was in fact a few pages of Röntgen's article. Schuster read and reread the text, keeping his family waiting in the cold outside. He became convinced and started making his own experiments with X-rays. The news of the discovery was quickly picked up by the press. As early as Sunday, January 5, 1896 the Vienna *Freie Presse* published the news on its front page. Thus the whole world learned about Röntgen's discovery. The sensation caused by the new rays can be compared with that caused by the first atom bomb in 1945. For weeks and months people learned about the fantastic properties of X-rays. In one of the newspapers we read that

It is suggested that... there will no longer be any privacy in a man's home, as anyone armed with a vacuum tube outfit can obtain a full view of any interior through a brick wall.

No wonder that some elderly ladies would take their baths completely dressed since they were afraid of being exposed to the inquisitive eyes of physicists, modern Peeping Toms, armed with X-ray apparatus. Therefore, in England, newspapers carried advertisements of "X-ray proof undergarments for ladies! In New Jersey, USA, legislation was introduced to make it illegal to use X-ray opera glasses (*sic)*.The harmful properties of the new rays were not yet fully understood, but stories on lethal weapons began circulating in popular journals and magazines. It was suggested in the newspapers that X-rays could bring back life and that cathode rays (with the confusion between the X-rays and cathode rays) could be used for resuscitating electrocuted persons. A prominent electrical engineer in the USA claimed that X-rays or cathode rays were sound waves and that he had...heard them. Toothache was thought to be dispelled with X-rays. It was also claimed that these rays could be reflected from a sunbeam.

In a Polish newspaper "*Gazeta Warszawska"* information on the discovery appeared as early as January 10, 1896. It was a very reliable account, entitled "Science News":

"In Vienna's scientific circles news has been circulating about the remarkable discovery made by Professor Röntgen of Würzburg. If true, this discovery will make a great revolution in physics, and particularly in medicine. Here is the news:

Professor Röntgen takes the Crookes glass tube, and passes induction current through it. Then, using rays that are emitted by the tube, takes photographs on ordinary photographic plates".

These rays, which so far have not been known to exist, are totally invisible to the naked eye but they penetrate wood, organic matter and other impenetrable bodies. It is only metals and bones that can stop these rays. That is why, some objects locked up in a wooden box can be photographed in daylight. It means that these luminous rays penetrate the box's walls. For example, Professor Röntgen takes photographs of weights locked up in a box without opening the box...

These rays are also supposed to be able to penetrate the human body. In this way, a human hand, on a photograph, shows only the bones, whereas the flesh cannot be seen. The above attempts have caused extraordinary sensation.

Another example of a quick response to Roentgen's discovery in Poland is the translation of his small book " On the New Type of Rays" (*O nowym rodzaju promieni)*, by S. Srebrny and published by Teodor Paprocki Publishers in Warsaw as early as 1896 .

By the end of April 1896, X-rays were accepted by general public as part of natural phenomena. In serious journals in the single year of 1896, more than 1,000 papers were published, and some 50 books were written on X-rays.

On the Sunday afternoon of January 12, 1896 Röntgen made a demonstration before the audience that included the Emperor Wilhelm, and then on January 23rd he made a formal presentation of his discovery before the *Physikalisch-Medizinische Geselschaft* when he took a radiograph of Albert von Köhllicker, Professor of Anatomy. As the developed plate was shown, the audience broke into applause and Professor Köhllicker suggested that the rays should be called *Röntgen's rays.*

Röntgen always refused to make a profit from his discovery. In his own words: "*I believe that...discoveries and inventions belong to humanity*". This attitude made him not only unpopolar with manufacturers, but also contributed to his image of an intolerant and gruff researcher.

THE NATURE OF X-RAYS

The physicists in 1895-6 were absolutely not clear about the nature of X-rays. First ,they were astonished and even incredulous, next those who had the technical possibilities (an induction coil, and a vacuum tube) tried successfully to repeat Röntgen's experiment. There were also those who believed that there was not much to add except make the measurements more accurate. But there were others who felt that Röntgen's discovery was only a gate opening to some unexplored territories.

Two different approaches were taken as to the nature of X-rays. Some physicists contended that X-rays were transverse vibrations in the ether and were of the same nature as light. But there others who held that X-rays were cathode rays and, that, following Plücker, Hittorf, Hertz and Lenard they were longitudinal vibrations in ether. Röntgen did not elaborate much on the nature of his rays, he only said that X-rays could not be deflected even by the strong magnetic field and, consequently, were of a different nature from cathode rays, although in his first paper he propounded the idea of longitudinal waves in the ether.

Salvioni suggested that X-rays could be a highly rarefied form of matter projected from the Crookes tube, whereas Goldhammer believe that X-rays were ultraviolet waves. Lodge stated that X-rays are transverse waves and that wavelength is not greater than the size of atoms. De Heen calculated from the mean velocity of molecules in a Crookes tube, as found by J.J.Thomson, of 3.3×10^7 cm/s, that this corresponds to a temperature of 4.8×10^{7} °C!

Henri Becquerel (1852-1908), who reported on the existence of peculiar rays from uranium salts added to the confusion. The nature of the *Becquerel rays* seemed to be similar to that of X-rays. All in all, the year 1896 ended with the still unsolved puzzle concerning X-rays and cathode rays.

FIRST X-RAY UNITS FOR DIAGNOSIS AND THERAPY

Now, we shall return to the fundamental experiments with X-rays, in which a simple Crookes tube was used, later to be modified in such a way that the cathode formed a dish to focus the electrons and the anode was mounted opposite the cathode. Even those modified tubes were difficult to use. They had to be properly seasoned. It was only in 1913 when the Coolidge tube was introduced, i.e. the glass bulb was completely evacuated and the electrons were liberated from the heated spiral, that, with the voltage and current regulated independently, the results became uniform. In the early tubes, high tension cables were attached to the ends of the tube producing a considerable risk of electrolocution!

X-ray machines used to be located in poorly ventilated and damp cellars and basements. These conditions often made the operation of the tube difficult: the preliminary effort went into... drying the apparatus. In hospitals, at that time, electricity was not common and the tube would be supplied by Groves cells. The whole apparatus was usually mounted on a trolley, together with the electric cells and induction coil and contact breaker. The tube was held in a wooden clamp and there was no protection for the operator from the X-rays. The harmful effects of the new radiation were not understood and the cases of dermatitis found among the personnel were attributed to the effect of the film developer or high tension. This problem became quite serious as the common practice was to fluoroscope the operator's hands to test the tube.

The X-ray pictures were first made on glass photographic plates coated with emulsion on one side only (however Röntgen also used films), which would often slip off during developing, and the job of a junior was to wax the edges of the plates to keep the emulsion in place. The first professional film for X-rays (perhaps double-sided) was introduced by Eastman in 1918. However, the quality of the X-ray images on glass plates were for quite a long time superior to that of Eastman films.

The X-ray staff included professional photographers, general practitioners and even medical students., and the X-ray departments usually joined the electro-therapeutic departments. X-ray operators had no specific training and had to learn on the job .In Britain, the Society of Radiographers was established as late as 1920.

As for *roentgentherapy*, it first occured to Gillman of Chicago in the same month of January 1896 that X-rays could be used to treat various diseases, when he learned that Emil Hermann Grubbe (1875-1960), a tube manufacturer and a student instructor, suffered from dermatitis of his hands as an effect of exposure to the rays in vacuum tubes he produced. Gillman sent a patient with the carcinoma of the breast to Grubbe, who on January 29,1896 started fractionated irradiation of the patient for over three weeks. It is worth noting, that this was only four days after Röntgen's formal presentation in Würzburg. Practical application of a fundamental physics discovery did not take much time! In July, 1896, Despeignes of Lyon, France, reported treatment of a case of carcinoma of the stomach. As a result of treatment, patient's condition improved. However, the long exposures necessary and the close placement of the tubes often caused skin reaction. John Daniel (1863-?), Professor of physics at Vanderbild University,USA, reported that on April 10, 1896, when he "*photographed with X-rays*"the skull of a friend his hair fell out some days later. In 1897, N.S.Scott of Cleveland reported 69 cases of skin damage as result of X-ray irradiation. L.Freund(1868-1950) of Vienna, Austria, even employed X-rays for epilation and he was first to use the new rays scientifically. He tried to describe the various parameters of the new radiation such as its quality and quantity, the target-to-skin distance and even farctionation of dosage.

A large number of other researchers began exploiting Röntgen's discovery in medicine. Hermann Heineke (1873-1922), Jean Alban Bergonié (1867-1926) and Claudius Regaud (1870-1940) were first to study *radiobiological* aspects of X-rays. Antoine Louis Gustave Beclére (1856-1939), Francis Henry Williams (1852-1936), Guido Holzknecht (1872-1931), Gösta Forsell (1868-1943) and many others investigated the use of X-rays in *radiodiagnosis*. In *roentgentherapy*, the first contributions were made by Leopold Freund , William Allen Pusey (1863-1940), Robert Kienbök (1871-1954),an d George Clemens Perthes (1869-1927).

In the final years of his life, Röntgen was accused by some distinguished physicists of not being the only and genuine discoverer of X-rays. Those accusations were made mainly by the disgruntled Lenard who felt that the honour bequested on Röntgen was partly owed to him. No doubt, since Lenard was first to study cathode rays outside the Crookes tube, he could have made the discovery of X-rays before Röntgen did. In his Nobel Lecture delivered in 1905 he mentioned Röntgen in passing saying that "*it seems to me that the discovery [of X-rays] at this stage appeared to follow automatically*". In his books, he called Röntgen an opportunist and compared his discovery to that of a mid-wife. Happily enough, in some Röntgen's posthumous papers (most of his papers and correspondence were burned) a letter was found, dated May 27,1897, in which Lenard wrote that

" *Because of your great discovery caused such swift attention in the farthest circles, my modest work also came into limelight, which was of particular luck for me, and I am doubly glad to have had your friendly participation...especially through the presence of the ray discovered by you...* "

In 1945, when questioned by Lewis Elmer Etter (1901-1979) he confessed that he had expected Röntgen to share with him the merit of the discovery.

THE PRESENT AND FUTURE OF X-RAYS

A hundred years have elapsed since Röntgen made his discovery. Over that time, developments in the field of X-ray technology have brought us the introduction of the image intensifier and television (1950s), Hounsfield in 1970, and the novel idea of *Magnetic Resonance Imagining* in the late 1970s.

What will the future hold for us in medical imaging? In the words of Peter Dawson, President of the British Institute of Radiologists,

...*CT will become even faster and more versatile with further development of "spiral" technology; MRI will continue to develop in speed, resolution and rangew of applications; MR Spectroscopy will play some clinically useful role; a new generation of "smart" contrast agents will be developed for all imaging modalities with organ and disease specificity; and interventional "key-hole" technology* which improved the quality of the conventional radiograph and protected the doctor from direct viewing a simple fluorescent screen, as well as a variety of other techniques such as catheterisation, use of contrast media, etc. Then came a dramatic breakthrough in X-ray diagnosis with the invention of *CT scanning* by Godfrey *and techniques will expand in range with MRI and/or real time CT playing part.*.[RAD, 1985].

Let's hope that all these new developments will not only contribute to the well-being of man, but will be equally shared by the people the world over."

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