Chapter III

November 1895

WITH WINDOWS overlooking the garden of the physics institute toward the east, two laboratories at the end of a long hallway on the first floor were selected by Röntgen for the cathode ray experiments. Into the larger of the laboratories was moved a Ruhmkorff induction coil of the type manufactured by Reiniger-Gebbert and Schall in Erlangen. This was equipped with a Deprez interrupter and produced sparks from four to six inches in length. Several Hittorf-Crookes tubes, or discharge apparatus as Röntgen preferred to call them, were arranged on a shelf, together with some Lenard tubes, including the one he had obtained the year before from Müller-Unkel. Other equipment, notably a Raps vacuum pump, was then reassembled to make and evacuate additional Hittorf-Crookes and Lenard tubes.

The particular apparatus that Röntgen proposed to use in the cathode ray experiments was based not only upon the production of high tension electric charges but upon their conduction through highly evacuated vessels. The knowledge of electricity had had its origin almost three centuries before in *Gilbert's* studies of magnetism and static electricity. Subsequently simple demonstrations of electrical phenomena had had wide public appeal, particularly those of the effects of static electricity upon evacuated spaces and living organisms. Eventually, largely through the efforts of scientists such as *Franklin, Galvani, Volta, Am-*

père, *Ohm*, *Faraday*, and *Henry*, the knowledge of electricity had been systematized.

The barometric vacuum had been discovered by the Italian *Torricelli* in 1643, and about the same time *Otto von Guericke*, a German burgomaster, had built an air pump with which he could slowly evacuate air from enclosed vessels. Vacuum pumps and simple electrostatic machines had been further developed by the English scientists *Robert Hooke* and *Robert Boyle* in 1660 and by *Francis Hauksbee* in 1705. The precursor of Röntgen's own tubes for the cathode ray experiments was doubtless that developed by *Heinrich Geissler*. About 1855 Geissler, a glassblower at the University of Bonn, had built a practical mercury vacuum pump with which he had evacuated his famous tubes. These tubes filled with various gases showed beautiful colored effects when high tension discharges from an induction coil were passed through them. *Plücker*, professor of physics at the University of Bonn and Geissler's chief, had helped in the refinement of the tubes, and his historic observation of an emanation from the cathode end of the tubes, when a high tension discharge was passed through them, had been among the earliest to be made of the so-called cathode rays.

To *William Crookes* these "cathodic" rays had represented a new "fourth state of matter," and one by one their real properties had been explored by workers such as *Hittorf*, *Hertz*, *Goldstein*, and *Lenard*. In order to study the properties of these mysterious cathode rays outside the tube in free air, Hittorf and later Lenard had equipped ordinary glass cathode ray tubes with extremely thin aluminum windows, through which the cathode rays could penetrate to the outside. In a series of classical experiments Lenard had found that the rays made the air electrically conductive, but that they were easily absorbed in a few centimeters of free air. He had also discovered that they produced luminescent effects upon certain fluorescent salts and darkened the photographic plate.

Many of these experiments had been repeated by Röntgen, and now in initiating further researches he suspected that the theoretical speculations of *Maxwell* and *von Helmholtz* on electric and magnetic disturbances within the so-called ether might also be of significance in the interpretation of some of the observed phenomena.

In repeating Lenard's experiments, Röntgen, according to the inventor's suggestion, enclosed the Lenard tube in a tightly fitting cardboard coat covered with tinfoil, which evidently had been supplied for the purpose of protecting the thin aluminum window of the tube from possible damage in the strong electrostatic field, but which at the same time prevented any visible light from the tube from penetrating to the outside. He again was able to confirm by his own observations that invisible cathode rays emanated from the tube and did produce a fluorescent effect on a small cardboard screen painted with barium platinocyanide, but only when this screen was placed fairly close to the window. Now it occurred to him that in similar experiments with heavier-walled Hittorf-Crookes tubes fluorescence of such a screen might also be caused by cathode rays, but that it might possibly be obscured by the strong luminescence of the excited tube.

This idea fascinated Röntgen. Late one afternoon when, as was his custom and preference, he was working alone in the laboratory, he determined to test the ability of a Hittorf-Crookes tube, that is, an all glass tube without a thin window, to produce fluorescence on the barium platinocyanide screen. Selecting a pear-shaped tube from the rack, he covered it with pieces of black cardboard, carefully cut and pasted together to make a jacket similar to the one used previously on the Lenard tube, and then hooked the tube onto the electrodes of the Ruhmkorff coil. After darkening the room in order to test the opacity of the black paper cover, he started the induction coil and passed a high tension discharge through the tube. To his satisfaction no light penetrated the cardboard cover.

He was prepared to interrupt the current to set up the screen for the crucial experiment when suddenly, about a yard from the tube, he saw a weak light that shimmered on a little bench he knew was located nearby. It was as though a ray of light or a faint spark from the induction coil had been reflected by a mirror. Not believing this possible, he passed another series of discharges through the tube, and again the same fluorescence appeared, this time looking like faint green clouds moving in unison with the fluctuating discharges of the coil. Highly excited, Röntgen lit a match and to his great surprise discovered that the source of the mysterious light was the little barium platinocyanide screen lying on the bench. He repeated the experiment again and again, each time moving the little screen farther away from the tube and each time getting the same result. There seemed to be only one explanation for the phenomenon. Evidently something emanated from the Hittorf-Crookes tube that produced an effect upon the fluorescent screen at a much greater distance than he had ever observed in his cathode ray experiments, even when he had used Lenard tubes with the thin aluminum windows.

Realizing that this conclusion was certainly in contradiction to general knowledge about cathode rays and especially his own experience that cathode rays never penetrated more than a few centimeters of air, he became deeply absorbed in attempting to explain the strange phenomenon. His concentration was so intense that he was completely unaware of the passage of time and of his surroundings. Marstaller, the diener of the institute, knocked at the door, entered the laboratory to look for a piece of apparatus, and left without being noticed. As the evening hours wore on, Röntgen's excitement in the peculiar and inexplicable observation increased. Several times Mrs. Röntgen sent a servant to call him to dinner, and when he finally sat down to the table, he ate little and in almost complete silence. The meal was hardly finished before he returned to the laboratory. He had made no reply when Mrs. Röntgen had asked him what was the matter, and his return to the laboratory in a state of suppressed excitement she ascribed to a fit of bad humor.

Although these first observations of an unidentified emanation from an excited Hittorf-Crookes tube were made on Friday, November 8, 1895, the first notes on the new phenomenon were not recorded until a few days later. Over the weekend in the absence of students there was little activity in the institute, and taking advantage of the opportunity for uninterrupted work, Röntgen returned to the laboratory early Saturday morning to repeat the experiments of the previous evening. Systematically in the next few days he made notes on the experimental set-up and his observations. Then in succeeding weeks of feverish activity he devoted himself exclusively to identifying more properties of the emanation—weeks in which he ate and even slept in his laboratory.

If the emanation could penetrate air to a hitherto unobserved degree, it was possible that it could also penetrate other substances. The inspiration came to him because of a peculiar shadow on the green fluorescent screen, apparently caused by a wire running across the tube from the induction coil. To test the truth of the conjecture he held a piece of paper, then a playing card, and then a book between the tube and the screen and closed the switch to the inductor. Simultaneously with the passage of the current through the tube the little screen behind the papers and the book lit up; the fluorescence for the book was not quite so bright as before, but it was certainly distinctly visible. He then collected some other materials, sheets of various metals, and placing them between the tube and the screen, he found that a thin aluminum sheet affected the fluorescence to approximately the same degree as had the book, but that a thin sheet of lead seemed to stop the rays completely. Already he was thinking of the new agent in terms of rays, since it had a few properties in common with known radiation, such as traveling in straight lines from the focus and throwing regular shadows. To test further the ability of lead to stop the rays, he selected a small lead piece, and in bringing it into position observed to his amazement not only that the round dark shadow of the disk appeared on the screen, but that he suddenly could distinguish the outline of his thumb and finger, within which appeared darker shadows—the bones of his hand.

One can only imagine how this first ghostly shadow picture of the human skeleton within living tissue affected the observer: Doubt must have been followed by wonder and perhaps by a reluctance to continue experiments that promised to bring him disrepute in the eyes of his colleagues. At that point he determined to continue his experiments in secrecy until such time as he himself was certain of the validity of his observations. Thus during the closing weeks of 1895 Röntgen worked in seclusion in order to prove to himself that his chance observation was a fact, and then to build up sufficient faith in his findings to hand them over to other scientists for confirmation or refutation. Even his good friend Boveri was kept in the dark, and once to Boveri's impatient question of what was going on, Röntgen replied, "I have discovered something interesting, but I do not know whether or not my observations are correct."

Knowing that cathode rays darkened a photographic plate, Röntgen set out to determine whether the peculiar radiation from the Hittorf-Crookes tube, which might or might not have been due to cathode rays, could produce a similar effect. After finding that the rays did possess this property, he extended the experiment by placing a piece of platinum on the plate before the exposure. On the developed plate a light area appeared where the platinum had absorbed the rays.

Correlating these observations with the shadow picture of the bones of his hand upon the fluorescent screen, he conceived another experiment for which one evening he persuaded Mrs. Röntgen to be the subject. At his instruction she placed her hand on a cassette loaded with a photographic plate, upon which he directed rays from his tube for fifteen minues. On the developed plate the bones of the hand appeared light within the darker shadow of the surrounding flesh; two rings on her finger had almost completely stopped the rays and were clearly visible. When he showed the picture to her, she could hardly believe that this bony hand was her own and shuddered at the thought that she was seeing her skeleton. To Mrs. Röntgen, as to many others later, this experience gave a vague premonition of death.

Once convinced that his observations were based upon sound experimentation, Röntgen realized that early publication of his findings was essential. He spent the last days of December assembling his notes, and several days after Christmas he handed to the secretary of the Würzburg Physical Medical Society the manuscript of his paper, *On a New Kind of Rays, a Preliminary Communication,* with the unusual request that it be published in the *Sitzungsberichte* of the society, although it had not been presented at one of the meetings. The title of the paper attracted the attention of the secretary, and sensing the fundamental importance of its content, he slated it for publication in the forthcoming issue of the *Sitzungsberichte der Physikalisch-Medizinischen Gesellschaft zu Würzburg*, a journal, edited by Professor Schultze, Professor Reubold, and Dr. Geigel, which was a supplement to the *Verhandlungen* of the same society.