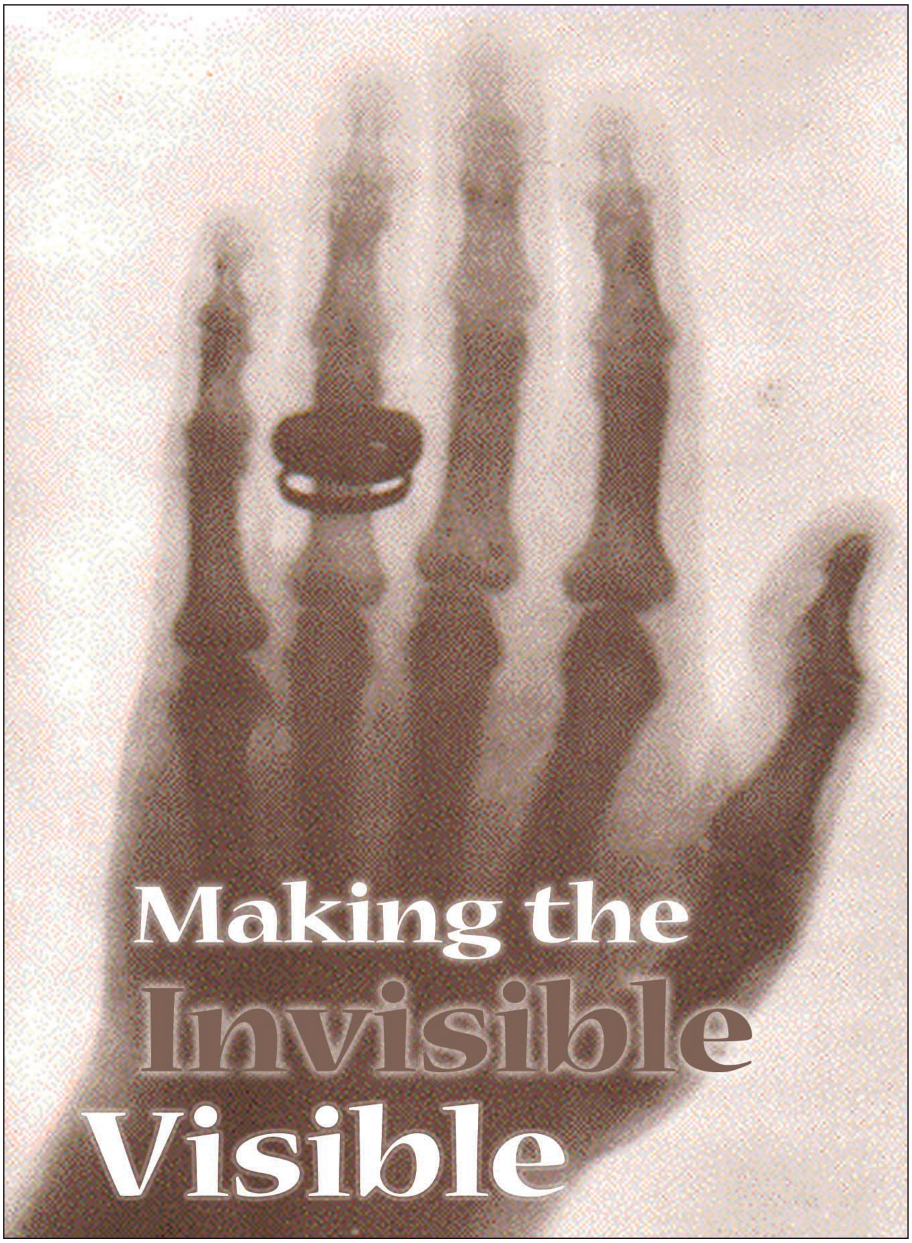


Röntgen's Mysterious X Rays

BRIAN S. BAIGRIE

Amateur scientists who traveled from town to town in the mid-nineteenth century delighted audiences by showing them the ancestor of the neon sign: the air was pumped out of a glass tube with platinum wires embedded in opposite ends, and the interior was made to glow in lively patterns when a high voltage was run across the wires. Transfixed by the fluorescence, the lecturers had however absolutely no idea what caused the electrical excitation in the vacuum tube.

By 1859, improved pumps were allowing physicists to suck out still more air and produce a green glow where the light from the cathode reached the glass. Many lines of research were pursued in the new laboratories created during the second half of the nineteenth century, but research related to the green glow generated in evacuated tubes came to dominate the others, culminating in an entirely new model of the atom.

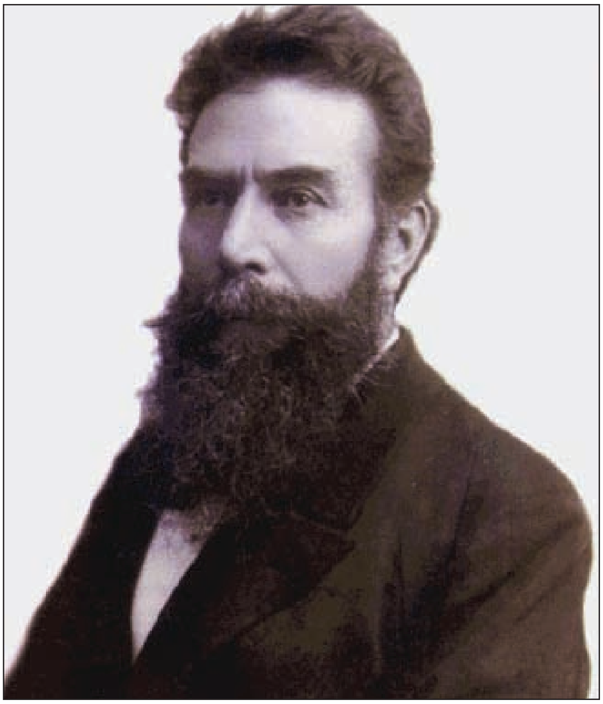
The German physicist Eugen Goldstein (1850-1930) set events in motion in 1871 when he suggested that rays coming from

1047-6938/02/01/0040/4-$0015.00 © Optical Society of America

the negative electrode and striking the glass caused the luminescence. Because the negative electrode was commonly known as the cathode, Goldstein called these emanations cathode rays. During the course of intense experimentation, he found that the path of the rays could be altered if they were subjected to the influence of a magnet. The action of an electric field, however, seemed to have no effect on the rays. Goldstein argued that a wave interpretation of matter seemed to be the best explanation for these results.

The same year, Cromwell Varley (1828-1883) advanced a completely different interpretation based on his belief that cathode radiation was caused by the collisions of particles. Since it had been shown that the path of the rays was deflected in the presence of a magnet, these particles had to be considered carriers of a negative electrical charge. If, as Varley believed, the rays really were made of charged particles, one would expect that they would be deflected by the presence of an electrical field as well. But despite his best efforts, Varley was unable to orchestrate any such deflection.

William Crookes (1832-1919) is associated with a number of developments concerning instrumentation. Crookes glass, for example, is a type of glass invented to protect the eyes of industrial workers from intense radiation. Crookes designed a string-and-sealing-wax arrangement, known as a Crookes tube, to examine the behavior of cathode rays at various gas pressures, and to subject them to a magnetic field. He developed great ability in controlling the path of the rays. He found that when a bar magnet was brought near the tube, the cathode ray beam was directed into a spiral, and that a horseshoe magnet bent the path into a curve. These findings gave experimental support to Varley's particulate theory of the cathode ray: the direction of the deflection was that which could be expected if the cathode rays consisted of a stream of negatively charged particles. In the glow of his tubes, Crookes identified a phenomenon worthy of serious investigation. He pronounced the cathode rays "a fourth state of matter," an addition to the already accepted group of solid, liquid, and gaseous states.



Wilhelm Conrad Röntgen

Wilhelm Conrad Röntgen (1845-1923) was born in the German town of Lennep. After earning his doctorate in mechanical engineering from the University of Zurich, he held various academic positions throughout Germany. In 1888, he accepted a position as chair of the Physics Department at Würzburg University; later he was elected rector. Despite his mounting academic responsibilities, Röntgen's passion for experimental research never flagged. In 1895, he discovered x rays. Although the discovery made him instantly famous, Röntgen chose not to patent his discovery, seeking no monetary gain or personal recognition. In 1901, he received the first Nobel Prize for physics and donated the cash award which accompanied the prize to Würzburg University.

The controversy over the nature of cathode rays took a startling and unexpected turn in December 1895 with the discovery of a new type of ray by Wilhelm Conrad Röntgen (1845-1923), professor of physics at Würzburg in Bavaria. Röntgen was fifty years old when he made the discovery that would garner him, in 1901, the first Nobel Prize in physics. His lifelong interest was the physics of solids, not gas discharge phenomena; indeed, a review of his forty-nine published papers reveals that none addressed the subject of gas discharges. Röntgen called his discovery "x rays" because of their mysterious nature.

The discovery of x rays was not, as one might expect, the culmination of a long-standing research program but instead the result of a fortuitous accident involving a Crookes tube. One of the electrodes in Röntgen's apparatus, the cathode, gave off an electric discharge when heated by the current, and a stream of cathode rays passed to the anode. Although the rays themselves were invisible, the greenish glow of the glass tube indicated their existence.

Crookes had performed an experiment, repeated by Röntgen, that consisted of placing a mica shield in the form of a maltese cross in the middle of the tube, between the two electrodes, to see if it would cast a shadow (Fig. 1). It did indeed. The shadow of the star appeared on the wall of the glass tube. But this did not explain the nature of the cathode rays. Perhaps they were ultraviolet rays? A screen coated with a fluorescent material, potassium platinocyanide, happened to be lying nearby on a laboratory table. It lit up. Röntgen then put the tube in a box made of thin black cardboard. To make sure that no light came through the box, he switched on the current to his tube. No light came through the box but, to his surprise, he noticed a strange glow in the far corner of his laboratory bench. Thinking that the glow was a figment of his imagination, he turned the switch again. He saw the glow again. Drawing back the curtains of his laboratory window, he found that the glow had come from the small fluorescent screen that had been placed at the far end of the table.

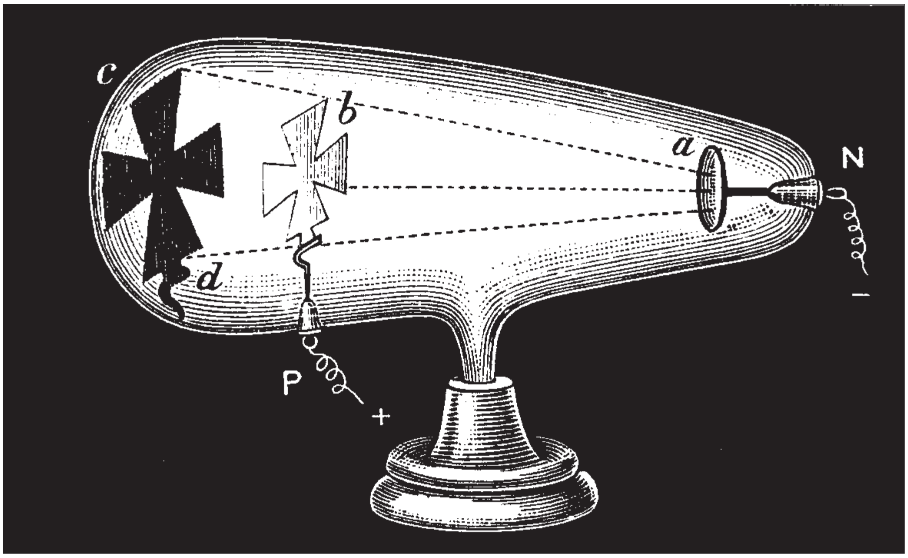


Figure 1. Cathode-ray shadows. Crookes placed a maltese cross (b) of mica inside a vacuum tube (c) facing a silver cathode (a). When energized by an induction coil, the bulb or tube glowed with a phosphorescent light that cast a dark shadow (d) of the cross on the tube wall. (*Source: W. Crookes, "Radiant Matter," (1879).*)

Röntgen knew that the cathode rays would make the screen glow but he also knew that they could not penetrate cardboard. Even in the case of a minute leak in the cardboard box, he knew that they could not penetrate more than an inch or two of air. The fluorescent screen indicated that the mysterious rays could travel through the glass of the tube, the cardboard box, and air. He reckoned that they must consist of some unknown kind of invisible light. If so, they must cast a shadow. Following a sudden impulse, he placed his hand in front of the screen. He received the shock of his life. What he saw was not the shadow of his hand but a skeleton of a hand. He could see his own bones, with the flesh and skin forming a faint, grayish fringe around them.

By this fortuitous chain of events, a form of light invisible to the naked eye, which never before had been observed or recorded, was revealed to Röntgen. He soon found that the rays could penetrate human flesh, wood and cardboard, metal foil and fabric, but they could not penetrate bones and stone, thick metal, and other high-density material. Röntgen also found that the rays affected photographic plates: in other words, the phenomenon he had observed on the fluorescent screen could be photographed.

It seems clear in retrospect that others before Röntgen had accidentally stumbled across these rays but had failed to pursue leads that now strike us as obvious. Crookes, for example, had noticed that the photographic plates lying near his experimental tubes frequently became fogged. He even returned some of these plates to the manufacturer, complaining of their poor condition. Other scientists had observed a fluorescent glow in materials located near Crookes tubes but, unlike Röntgen, neither identified the nature of the fluorescence nor realized its source.

The fluorescent screen indicated that the mysterious rays could travel through the glass of the tube, the cardboard box, and air.

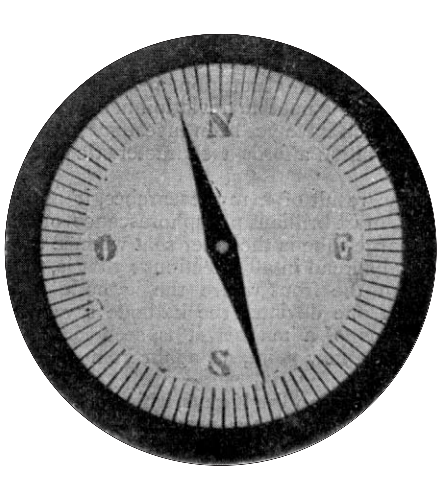


Figure 2. Shadow graph of a compass card and needle completely enclosed in a metal case. (*Source: W. Röntgen, "A New Type of Rays," (1895).*)

After carefully repeating his experiments over a six-week period to ensure the soundness of his results, Röntgen prepared a short manuscript in the form of a preliminary report that he delivered on 28 December 1895 to the president of the Physiological Society of Würzburg, a comparatively obscure organization. His first communication was translated and published in English, French, Italian, and Russian. Röntgen also dispatched copies of his early photographs to scientists.

His report describes the experimental apparatus and the resulting x rays, as he called them. It also describes a series of experiments that clarified the differences between these rays and the cathode rays that were already familiar to physicists.

Röntgen then turned to the various photographs taken with the apparatus to demonstrate the true "ray" character of the emanations. One photograph showed the shadow of a wire wrapped around a wooden spool, another a shadow of weights set in a covered wooden box, another the needle and degree markings of a compass in an enclosed metal case (Fig. 2).

The most dramatic were the photographs of his own hand, showing the bony structure (Fig. 3), and a photograph made through his laboratory door which registered the varying thickness of stiles and panels, and especially the streaked areas made by brushing on lead-based paint. Finally, he insisted that x rays were not ultraviolet rays because they were not refracted in passing from air into various substances, such as water, carbon disulfide, aluminum, rock salt, glass, or zinc. Nor did these substances, in turn, reflect the rays. Further, x rays were not polarized like ultraviolet rays. He speculated that they might represent longitudinal rather than transverse vibrations in the aether and that this opened up the need for a new chain of experiments.

The announcement in the closing months of 1895 that an obscure German professor had discovered rays that could make invisible things visible, that could pass through clothes, skin, and flesh to cast the shadows of the bones themselves on a photographic plate, caused a sensation in late Victorian society. To put it in context, though Ford had built his first car in 1893, transportation was still in the horse and buggy era. Flying was still a pipe dream of mad inventors. The transmission of sound by wireless was only a year in the future, but it would be twenty years before the first broadcast of a wireless program for the public would go out over the air waves. Cinema was a year old, thanks to the opening of the first "kinetoscope parlour" on Broadway by Thomas Alva Edison (1837-1941), which showed moving pictures of the peepshow variety.

The Victorian mindset reacted with horror to the announcement. In London, an opportunist advertised x-ray-proof underwear: "No lady safe without it!" A New Jersey lawmaker introduced a bill to prohibit the potential use of x-ray-opera glasses. The issue here was privacy: the possibility of seeing other people's internal organs was considered by many to be a serious threat. Yet enthusiasm outweighed disapproval. The frenzy of excitement had no earlier parallel. At no point in the annals of science was so much research concentrated on a single problem. Virtually all the principal laboratories in Europe began dedicating their efforts to exploration of the effects and the probable causes of this new phenomenon. Despite the fact that the experiment was difficult to repeat (English lead glass was much less suitable than soft German glass to excite and transmit the rays), over one hundred papers appeared about this discovery in the first year after its announcement in 1895. Anyone and everyone who could lay their hands on a Ruhmkorff coil (Fig. 4) and a gas discharge tube got involved, from professional physicists to physicians, to a host of amateur scientists.

Physicians who recognized the great utility of the new rays besieged physicists. When the right technique had been elaborated, the discovery proved invaluable to physics, medicine, crystallography, and metallurgy. Before the end of the nineteenth century, "radiography" was being applied in diagnosing lesions of the skull, the heart, and the lungs, and in renal pathology. Antoine Béclere (1856-1939) inaugurated a course in radiology in Paris in 1897. That year, opaque substances were first used to radiograph the digestive system. Soon photographs of the human fetus, a tubercular patient's lungs, the heart and other organs were published. Soon too the power of x rays to destroy organic cells was noticed. Many cases of severe skin burns and loss of hair were reported, but no one appreciated the real danger. Noting their depilatory effect, one enterprising Frenchman, M. Gaudoin of Dijon, offered to use x rays to remove unwanted hair from women's faces. He had numerous clients. Röntgen himself worked in a zinc cabinet with a lead plate on the side, which afforded him considerable protection. The precaution, however, was taken to filter out stray emanations, and not to prevent exposure to such powerful penetrating rays.

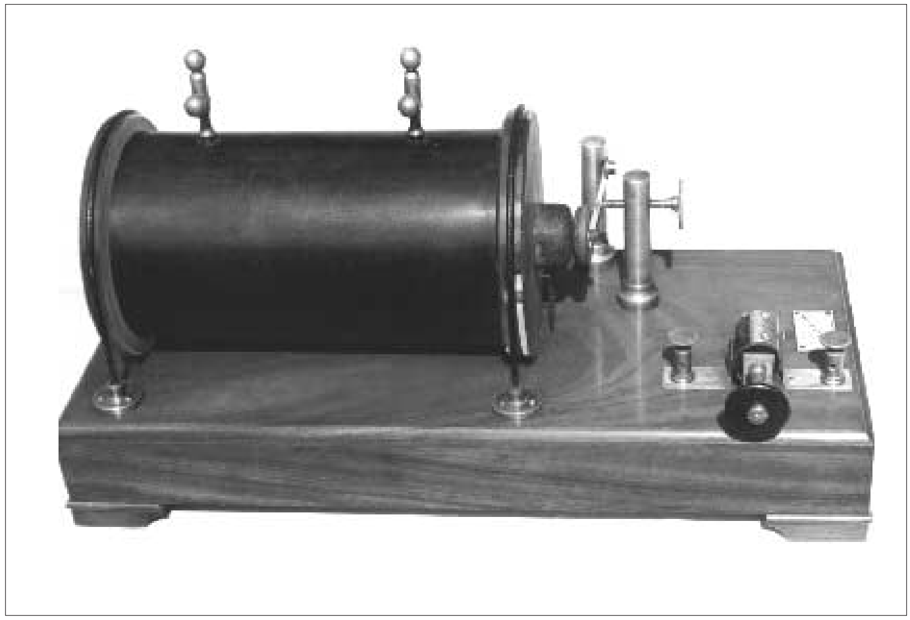


Figure 4. Rumkorff induction coil. (*Photo credit: Daniel Giroux.*)

In London, an opportunist advertised x-ray-proof underwear: "No lady safe without it!"

Figure 3. Shadow graph of the bones in the fingers of a living human hand. There is a ring on the third finger. (*Source: W. Röntgen, "A New Type of Rays," (1895).*)

Notes

1. Jed. Z. Buchwald, *The Creation of Scientific Effects: Heinrich Hertz and the Electric Waves*, The University of Chicago Press, Chicago, (1994).
2. Wilhelm Conrad Röntgen, translated by Arthur Stanton, Nature **53**, 274-6 (1896).
3. G. L'E. Turner, "Röntgen, Wilhelm Conrad," *Dictionary of Scientific Biography*, ed. C. C. Gillispie, Charles Scribners Sons, New York, **11**, 529-31 (1970).

Brian Baigrie is associate professor at the Institute for History and Philosophy of Science and Technology, University of Toronto, Toronto, Canada. He can be reached by e-mail at baigrie@attcanada.net.