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CHAPTER NINE

Rays

In spite of the advances made in the science of healing throughout the nineteenth century, the physician in 1895 shared one handicap with the author of the Ebers Papyrus. Both had only their sense of touch to gain information about the location of normal and diseased structures within a patient's body. But in the final decade of the century, two important discoveries, X rays and radioactivity, were to make possible for the first time the diagnosis of diseased deep structures in a living patient. In addition, the two modalities were soon found to be useful in the therapy of cancer, a disorder that had previously been successfully treated only by surgery.

X rays and radioactivity also marked another milestone in medicine, being discoveries made in the science of physics. Until the beginning of this century, physics had been used to explain many natural phenomena-- gravitation, electromagnetism, light--but had had little application to medicine. Chemistry had played a more important role in understanding biologic phenomena: respiration, digestion, the composition of living tissues. Since 1900, however, physics has become increasingly more fundamental to medicine and biology; indeed, a special branch, biophysics, now concerns itself solely with these disciplines. Biophysics may be said to have begun with X rays and radioactivity.

On Friday, November 8, 1895, Wilhelm Conrad Roentgen, a German physicist, made the simple observation that catapulted him to international fame. While experimenting with an electrical discharge tube connected to an induction coil, he noted that a nearby screen coated with barium platinocyanide was caused to fluoresce. Roentgen's observation was remarkable not only because of its tremendous implications but because it had been made using simple, standard equipment that was readily available to almost anyone. So easy to perform was the experiment that Roentgen said nothing about it to colleagues until he was able to publish and establish his claim to priority. He was doubtless fearful that another physicist with the same apparatus might repeat the procedure and publish first. Indeed, his fears were well grounded, for induction coils and electrical discharge tubes had been standard equipment in physics laboratories for quite some time.

The induction coil had resulted from the discovery that magnetism could be used to produce electricity, made independently in 1831 by Michael Faraday in England and Joseph Henry in the United States. Both men showed in a number of ways that an electric current is induced in a conductor when the conductor and the magnetic field are in motion with respect to each other. This fundamental discovery, basic to the science of electromagnetism, was employed in the construction of the first electric machines: the magneto electric generator, the electric telegraph, and the induction coil.

A now half-forgotten device, the induction coil, evolved in a relatively mature form in the short period between 1836 and 1838. Most of the basic work was performed independently by an American physician and an Irish priest. Ultimately, it played a vital part in three epoch-making discoveries: X rays, radio waves, and the electron, the first subatomic particle to be identified. The induction coil also led to the modern transformer, and before electronic devices it was one of the only sources of high-voltage current.

In its most fundamental form, the induction coil is nothing more than an iron bar wrapped with two insulated windings. A few turns of heavy wire conduct the primary current; many more turns of finer wire conduct the induced secondary current. A burst of high-voltage current is induced in the secondary winding by a collapsing magnetic field when the primary current is interrupted.

Nicholas J. Callan, a priest and physics teacher in County Kildare, Ireland, built the first simple induction coil in 1836 to study the phenomenon of secondary currents described by Faraday. Callan's coil was a horseshoe bar of iron wound with 1,300 feet of thin iron wire and 50 feet of thick copper wire. A small battery furnished the current, which was interrupted by a hand-cranked contact-breaker. Surprisingly, Faraday, who was a wizard at constructing simple but elegant gadgets to study electricity, did not invent the induction coil himself.

Over the next few months, Callan continued to make improvements in his invention. By 1837 he had published a description of "the most powerful electromagnet yet constructed" in a British technical journal, *The Annals of Electricity*. The new coil contained an iron bar more than two inches thick and thirteen feet long, wound with two insulated coils more than ten times the length of the first ones. Employing this device, Callan succeeded in generating a small arc light between carbon rods connected to the secondary terminals. Moreover, he somehow managed to survive using himself as a human voltmeter to estimate the secondary potential, though the high voltage was said to have electrocuted a chicken.

One persistent problem in Callan's coils was the need for continuous hand cranking of the contact-breaker. This tedious chore was finally eliminated in the coils designed by Charles Grafton Page, a Salem physician. Before his death in 1868 Page had devised a variety of automatic contact-breakers. One of the most effective had an iron hammer that moved back and forth like the hammer in an electric doorbell. Page also built coils that worked with only a single winding, the first autotransformers.

The induction coil was quickly recognized as an excellent means of generating high voltages, both for laboratory experiments and for supposedly medicinal purposes. Daniel Davis, a Boston instrument maker, was one of the first to manufacture and sell Page induction coils, as well as magneto machines made by Page. These devices were snapped up by academies with courses in natural philosophy, ostensibly for illustrating basic principles; more often, teachers liked to use the showy electrical arcs to startle bored students. Would-be healers also bought the coils for the reputed revitalizing effects of the severe electric shocks.

Throughout the mid-nineteenth century, improvements in the coil continued to be made. Heinrich Daniel Ruhmkorff, a German instrument-maker living in Paris, was one particularly successful innovator. To produce more powerful coils, Ruhmkorff used glass insulation between the primary and secondary windings. End plates to support the windings and pillars to carry the high-voltage secondary leads were also insulated with glass. Ruhmkorff coils had longer secondary windings than Page coils and also extra insulation between the layers. As a result, they could generate electrical arcs from two to three inches long. Ruhmkorff became so celebrated for his coils that in 1864 Napoleon III awarded him a ten-thousand-dollar prize for the most significant application of electrical science.

But even Ruhmkorff had not been able to overcome one major difficulty, the violent sparking between the vibrating hammer contacts that rapidly ruined the contact surfaces. Armand Fizeau finally solved this dilemma, the distinguished French physicist who had succeeded in accurately measuring the speed of light by means of a spinning toothed wheel. In

1853 Fizeau proposed connecting a capacitor across the hammer contacts. Made of two sheets of tinfoil interleaved with insulating layers, the capacitor was able to absorb the surges of current induced in the primary winding as the circuit was broken. In 1856 Jean Foucault, a colleague of Fizeau who demonstrated the earth's rotation by means of a pendulum, designed a sophisticated mercury contact-breaker as a substitute for the crude vibrating hammer.

Ruhmkorff coils with these two modifications were soon to be found in almost every school, college, and scientific laboratory. Besides making the snapping electric arcs, lecturers liked to awe their classes with spectacular showers of sparks produced by discharging the coil through tinfoil spangles in a glass tube. Other popular experiments: melting fine iron wire, burning wood along a track containing nitric acid as a conductor, igniting paper, setting off gunpowder, and generating a glow discharge in an evacuated tube or globe. The coils became fashionable and profitable, too, in the offices of respectable physicians, who applied the "Faradic currents" to the body with various styles of electrodes.

Showmen and traveling lecturers also became fond of the induction coil when they discovered how much audiences enjoyed watching shocks administered to volunteers. This dubious form of amusement was soon carried over to penny arcades in the form of an induction coil encased in a fancy box with metal handles, activated by a regulator and a coin slot.

But the induction coil was to lead to a medical breakthrough, the discovery of X rays, as a result of serious scientific investigation into the conduction of electricity through gases. Michael Faraday and John P. Gassiot in England, and Julius Plücker and William Hittorf in Germany, carried out the first studies of this phenomenon. Initially, these men used crude glass bowls and relied on balky friction machines with conductive leather pads rubbed on the surface of a rotating glass plate, or batteries connected in series, for high voltage. Soon, the induction coil became the standard high voltage source, and a much improved tube was substituted for the glass bowl. Heinrich Geissler, a skilled instrument-maker who worked with Plücker at the University of Bonn, had constructed the first of these tubes in the mid 1850s. Geissler's tubes had sealed-in electrodes and were connected to highly efficient mercury vacuum pumps.

Over the next two decades many properties of ionized gases and cathode rays, as they were later called, were discovered by Plücker and Hittorf, and by William Crookes in

England. Crookes became internationally known in 1879 after demonstrating the characteristics of low-pressure electrical discharges. He used a specially designed tube, soon to be named a Crookes tube, and this device connected to a Ruhmkorff coil produced the X rays Roentgen observed.

On the Friday in 1895 that he made his discovery, the fifty-year-old Roentgen seemed destined to remain an obscure scientist. The majority of physicists do their most innovative work in their twenties and thirties; indeed, many become quite depressed if they have done nothing outstanding by the time they are forty, because this is usually the end of the road, creatively speaking.

But then Roentgen never appeared to anybody as a man about to set the world ablaze. He had been born March 27, 1845, in the little German town of Lennep in the Ruhr valley, the son of a textile worker. His early schooling was erratic, and what little he did get was cut short by a bad incident. When the prank of a schoolmate got him into trouble, he refused to name the offender and so was summarily expelled. Without the final examinations and degree necessary for admission to higher education, Roentgen appeared finished academically.

After a few years of study without credit at the University of Utrecht, Roentgen was allowed to matriculate at the Zurich Polytechnic School, where in 1868 he was awarded a mechanical engineering degree. Ironically, though he was later to become one of the star physicists of his age, he never took a basic college course in physics.

Roentgen continued as a student at the Zurich Polytechnic, and in 1869 was awarded a Ph.D. with a thesis entitled “Studies on Gases.” But his early misfortune continued to plague him. When his preceptor, August Kundt, was offered a chair in physics at the University of Würzburg, he brought Roentgen along as his assistant. Here Roentgen discovered to his dismay that he could not be appointed privatdocent, the first rung in the academic ladder, because of the diploma that had been denied him when he was expelled from preparatory school. In addition to this cruel disappointment, he was forced to contend with poor laboratories and meager equipment.

The situation improved in 1872, when Kundt moved again to the Kaiser Wilhelm University at Strassburg. Roentgen came along, this time as privatdocent, and from here his career continued to progress. Over the next few years he published numerous articles, now largely forgotten, in prominent physical journals. The result was an appointment as professor of physics and director of the new physical institute at the University of Würzburg. At Würzburg Roentgen performed the crucial experiment.

In fact, the first person to notice the glowing screen was not Roentgen but his laboratory assistant, or *Diener* in German. In later years this led to many humiliating jibes. Roentgen was particularly exasperated by some accounts that actually accused him of stealing his *Diener*'s discovery.

Certainly nothing could be further from the truth, since Roentgen was wholly responsible for appreciating the significance of what had occurred. The Crookes tube had been completely covered with black cardboard and the fluorescent screen was across the room. Almost immediately Roentgen realized that he was witnessing the effect of a new kind of ray, one that traveled in a straight line, penetrated opaque substances, and was not deflected by a magnetic field as were the cathode rays. He named his new rays with the mathematician's symbol for the unknown: X. On the same day he made the first medical application of his discovery, an X-ray photograph of his wife's hand.

Roentgen adamantly refused to patent any part of his discovery and indignantly rejected all commercial offers, believing that his professorial income would provide him with lifelong financial security. Alas, all his savings and even his 1901 Nobel honorarium were wiped out by the calamitous postwar German inflation. When he died of rectal cancer in 1923, he had been reduced to a tired, despondent, lonely man, virtually penniless.

But at least he was not maimed by his discovery, unlike many of the early radiologists. Unaware of the hazards, they continually exposed themselves to radiation while X-raying patients. Many were subsequently forced to endure a lifetime of mutilating operations to remove cancerous growths from their hands.

The safety and reliability of the early X-ray machines were increased with the development of the hot cathode or Coolidge tube. The original tubes, very much like Roentgen's, contained a certain amount of gas, necessary to permit the passage of current. As the gas was gradually "used up," more gas had to be let in. Even after the introduction of automatic gas regulating devices, the X-ray output of these tubes was highly unpredictable.

William David Coolidge, an engineer at the General

Electric Research Laboratories in Schenectady, New York, solved the problem. Coolidge devised a method for producing ductile tungsten tube filaments and designed a high-vacuum tube to contain them. Both the penetrating power and the intensity of the X-ray beam from the Coolidge tube could be reliably controlled. The inauguration of this tube in 1913 ushered in what came to be called the golden age of radiology. Results could now be duplicated with an accuracy never dreamed of in the days of gas tubes.

Another significant advance came with the introduction of contrast agents. Though very dense structures, such as bones, can be distinguished from soft tissue on an ordinary X-ray film, the many soft-tissue structures--kidneys, liver, digestive tract--cannot be distinctly identified. To visualize the soft tissue structures, investigators began to administer a number of contrast agents, substances that will produce a distinct outline of the structure in which they are contained.

One of the first to employ a contrast agent was Walter Bradford Cannon, a Harvard physiologist. Recognizing that X rays could be used to study digestion, Cannon set up an apparatus in which animals could be observed. In early experiments, he watched a button pass down the esophagus of a dog and an opaque bolus slide through the neck of a goose. But soon he began to employ liquids, among them bismuth subnitrate, bismuth oxychloride, and barium sulfate. He mixed these tasteless salts of heavy metals with the animals' natural food and then would watch for hours at a time the passage of his "contrast meals" through the digestive tract, shadowed on a glowing fluoroscopic screen. Cats, he soon discovered, were especially well suited for such investigations.

During the course of his experiments, Cannon was able to observe the movements of the alimentary tract without disturbing the animal to any degree. "By use of X rays," he reported in 1898, "the rate of passage of food through the oesophagus, the speed of gastric peristalsis and rhythm, the oscillating contractions of the small intestine, the peculiar anti-peristalsis of the large intestine, the rapidity of discharge of gastric contents into the duodenum, the time required for material to be carried to the colon, and all the influences external and internal that affect these processes, can be observed continuously for as long a time as the animal remains in a state of peace and contentment. . . ."

One of Cannon's most interesting findings was the effect of changes in the emotional state on digestion. Anxiety, distress, or rage, he noted, were accompanied by complete cessation of stomach movements. Further investigation was devoted to the autonomic nervous system, which controls these movements. In 1915 he published a classic book on his work, *Bodily Changes in Pain, Hunger, Fear, and Rage*. He also coined the term *homeostasis* to designate the steady state achieved by all the coordinated physiologic processes.

During his many experiments, Cannon had the foresight to partially shield his X-ray apparatus with lead sheets. But like the other early X-ray workers, he was not aware of the dangerous nature of the useful new tool. As a consequence, he suffered intensely during the last years of his life from an acute dermatitis attributed to the effects of radiation.

To the contrast agents employed by Cannon a number of others were soon added. These contained iodine and could be administered to make the gall bladder or the urinary tract visible on X-ray film. The internal architecture of the living heart, however, remained invisible to radiologists until the dramatic discovery of heart catheterization by Werner Forssmann, a German surgeon.

Until the late 1920s, inability to observe the valves and chambers of the heart frustrated any attempts at cardiac surgery. For how could mechanical disorders, such as damaged valves, be rectified if they could not be assessed before the operation? Only then would the surgeon know where to cut.

As a student, Forssmann had seen old drawings in French physiology books of a thick tube inserted through the jugular vein into the heart of a horse. He felt that the same thing might be done to a man if the tube could be put into a vein at the elbow. In the summer of 1929, shortly after graduation from medical school, he determined to try the procedure on himself.

Because his supervisor had sternly forbidden his carrying out such an apparently crazy experiment, Forssmann made his first attempt secretly one afternoon. After injecting a small amount of anesthetic into his arm, he proceeded to intubate his heart with a long tube called a catheter, ordinarily used in the urinary tract.

"When my anesthetic began to take effect," he wrote, "I quickly made an incision in, my skin, inserted a Dechamps aneurysm needle under the vein, opened it and pushed the catheter about a foot inside. I packed it with gauze and laid a sterile splint over it." But as he was making an X-ray picture, a colleague named Peter Romeis burst in and became angry when he saw what was happening.

"You idiot," Romeis screamed, "what the hell are you doing?" Romeis was so desperate, Forssmann wrote, that "he almost tried to pull the catheter out of my arm. I had to give him a few kicks on the shin to calm him down."

With a mirror placed in front of the fluoroscopic screen, Forssmann was able to see what he had accomplished: "As I'd expected, the catheter had reached the head of the humerus. Romeis wanted me to stop at this point and remove it. But I wouldn't hear of it. I pushed the catheter in further, almost to the two-foot mark. Now the mirror showed the catheter inside the heart, with its tip in the right ventricle, just as I'd envisioned it. I had some X-rays taken as documentary evidence."

When these amazing films were published in a leading medical journal, the *Klinische Wochenschrift*, in 1929, they caused an immediate sensation. A newspaper, the *Nachtausgabe*, reprinted them, and reporters besieged Forssmann. One magazine, the *Berliner Illustrierte*, even offered him a thousand marks for the rights to the pictures.

But the effect on other physicians was far less favorable. Ernst Unger, an eminent surgeon, accused Forssmann of attempting to steal priority for the discovery. Unger wrote to the surgeon Ferdinand Sauerbruch, Forssmann's new supervisor, who determined to squelch the young upstart quickly.

"Very late one evening," Forssmann recalled, "I was summoned to Sauerbruch. He'd prepared himself, or had been prepared, very well; on his desk lay the *Klinische Wochenschrift*, the *Nachtausgabe*, and a letter from Unger. He sat behind them and looked at me for some time in silence. Then, `This is an absolute disgrace!' He slammed his palm down repeatedly on the *Nachtausgabe*. `And then this!' He handed me Professor Unger's letter. `I'm obliged to read that one of my doctors has attempted to steal priority from an eminent surgeon and disregarded the elementary rules of scientific priority. . . . As for your work, what's it all supposed to mean?'"

Patiently, Forssmann tried to explain the implications of his experiments and added that one day he hoped they would help him meet the qualifications for a lectureship.

"You might lecture in a circus about your little tricks," Sauerbruch retorted angrily, "but never in a respectable German university! What do you really want to be, an internist or a surgeon?"

"I'm afraid I can't answer that yet, Herr Geheimrat. I've only been qualified for nine months and I don't yet know which I'm more suited to," Forssmann answered carefully.

"There we have it! The real Forssmann who can't make up his mind about anything! Every inch an internist! A true surgeon thinks of only one thing: operate! operate! operate!"

By this time Forssmann was furious, too, and he replied with an expression that has a scatological double meaning in German: "Herr Geheimrat Sauerbruch, there are hunters and there are shooters."

This was too much for Sauerbruch. His eyes flashed behind his thick spectacles, and he screamed, "Get out! Leave my department immediately!"

Undaunted, Forssmann obtained another position and continued his experiments. To see whether iodine-containing contrast media were harmful in high concentrations, he injected these substances directly into the hearts of dogs through a catheter. The animals survived unscathed, though the same material was lethal for rabbits. Nonetheless, Forssmann then determined to attempt the crucial experiment: opacification of the chambers of a human heart--his own.

"People often ask me if I wasn't afraid," he recalled. ". . . I must confess that I was slightly nervous . . . and it took me a few days to make up my mind to carry out the injections. For while it was possible to remove the catheter immediately if anything went wrong, there was no way of removing the contrast media once they'd been injected.”

As Forssmann had guessed, the contrast solution he prepared was indeed non-toxic. "I felt no effect when I injected it," he wrote, "only afterward a slight haziness, a disturbance of consciousness and vision which lasted only a second or two, presumably as the concentrated fluid first flowed through the brain."

The X-ray films taken were not very clear because the equipment at his disposal was not powerful enough. But he had proved that contrast media could be safely injected into the human heart. A few years later two American physicians, André F. Cournand and Dickinson W. Richards, Jr., perfected Forssmann's technique, making possible the dramatic heart operations that are familiar today. In 1956 all three men were awarded the Nobel Prize in Medicine.

Within the very near future, X-ray pictures of the interior of the heart may be possible without contrast media and catheters. These images will be produced with the computerized axial tomographic (C.A.T.) scanner, a device used to make visible previously hidden human organs, such as the pancreas.

Johann Radon, an Austrian mathematician, discovered the principle of the C.A.T. scanner in 1917. Radon was the first to prove that a two- or three-dimensional image can be reconstructed uniquely from the infinite set of all its projections. Ordinary tomographic images or "slices" through the body have been made since 1922 by using an X-ray source which moves in one direction while a piece of X-ray film moves simultaneously in the other direction. If the patient lies in between, one thin flat slice of his body will appear on the film. Radon's tomographic method, considerably more complex, could only be applied in practice with the arrival of the modern computer. The first C.A.T. scanners were built by a British engineer, Godfrey Hounsfield, and used in the United States at the Mayo Clinic in 1973

A second scanning method, magnetic resonance imagery (MRI) is based on the 1946 discovery, made independently by Felix Bloch and Edward Purcell, that a magnetically energized substance bombarded with radio frequency waves emits a "tune" similar to a tuning fork. They found that the nuclei of different atoms absorb radio waves at different frequencies. In 1952, Bloch and Purcell received the Nobel Prize for their discovery of what was referred to as Nuclear Magnetic Resonance (NMR), eventually to be known as Magnetic Resonance. In 1970, Dr. Raymond Damadian found that the structure and abundance of water in the human body was the key to magnetic resonance imaging, and that the hydrogen in water molecules emitted a signal that was both detectable and recordable. Dr. Damadian spent the next few years designing and creating the first MRI scanner for medical imaging of the human body.

Radioactivity

Two months after Roentgen's report of X rays, Henri Becquerel, a French scientist, published the first paper describing natural radioactivity. Becquerel had noted the phenomenon after leaving some uranium salt crystals on top of a photographic plate. A few hours later, the plate had been blackened though it had not been struck by light. An Englishman, Silvanus P. Thompson, had made the same observation simultaneously, but Becquerel published first, in the *Comptes Rendus*, February 24, 1896. During the rest of the year, Becquerel wrote six more papers on the subject, and two the following year. His interest in the phenomenon then began to dwindle, but by this time a young physicist, Marie Curie, had decided to investigate natural radioactivity further as part of her doctoral thesis.

Marie Curie, née Sklodowska, had been born November 7, 1867, in a small Warsaw apartment. Her father, Jozef Sklodowska, an impecunious Polish pedagogue, had little money to spend on the education of his five children. When Marie went off to Paris to study science at the Sorbonne, she lived barely at the subsistence level. Yet she still retained a strong sense of middle-class morality and indignantly refused an offer to move in with Pierre Curie, a gifted young physicist friend. Her refusal seems to have been well considered, for shortly thereafter the free-thinking Pierre married her.

Pierre and his elder brother Jacques had already made a name for themselves while studying the generation of electric charges in heated crystals. The two soon discovered that mechanical stresses on crystals would also generate electric charges, a phenomenon later to be named piezoelectricity, from the Greek *piezein*, "to press." Using their discovery, they succeeded in building a highly sensitive device, the quartz piezoelectrometer, for detecting small electric currents. This electrometer proved extremely useful in the subsequent measurement of radioactivity.

Marie and Pierre Curie isolated their first new radioactive element from the ore pitchblende. On June 6, 1898, the laboratory notes, underlined with Marie's thin-nibbed pen, record that the substance was 150 times more active than uranium. "If the existence of this new metal is confirmed," the Curies wrote in their paper on the discovery, "we propose to call it *polonium* from the name of the country of origin of one of us."

At the time, Marie Curie believed that polonium was to be her most important discovery, but she and Pierre presently identified an even more radioactive material in pitchblende. Their initial measurements revealed this substance to be an astounding nine hundred times more radioactive than uranium. In mid-December 1898 they decided to name the element radium; yet they needed a much larger quantity than they had on hand in order to characterize it fully.

The principal European source of pitchblende was the St. Joachimsthal mine in Bohemia, a part of the Austro-Hungarian Empire. The Austrian government worked this mine with considerable profit, as the uranium it contained was quite valuable. The Curies knew that once the recoverable uranium had been extracted, the residual material was discarded as waste. Through the Vienna Academy of Science, they succeeded in persuading the Austrian government to intercede with the Joachimsthal mine authorities on their behalf. The aim of their research, Marie emphasized, was purely scientific and would benefit the Joachimsthal factory, since it could sell or otherwise exploit the valueless residues. With their own funds, the Curies were quickly able to obtain several tons of dirt-cheap residue, which the Bohemians were doubtless overjoyed to see removed from their dumping ground at a small profit. Little did anyone suspect how precious the radium extract would be.

In the early months of 1899 the first heavy sacks of extracted pitchblende were dumped in the yard of the School of Physics and Chemistry near the Curies' laboratory. To the eye, the mixture appeared to be composed of nothing more than brown dust and pine needles. But tests for radioactivity revealed that the material was "hotter" than the unrefined pitchblende from which it had come.

By March 28, 1902, according to Marie Curie's laboratory notes, one-tenth gram of radium chloride had been isolated from the yard full of sacks. On that day Marie had recorded the estimation of molecular weight that had required over two years' work: Ra = 225.93. The element was so radioactive that it was beyond the range of a delicate charged electrometer. Even today, three quarters of a century since they were first contaminated by the fingers of Marie and Pierre, their laboratory notebooks are still considered dangerous to handle.

Like the early X-ray workers, the Curies had no notion of the hazards they were facing. So beneficial to mankind did Marie believe radium that as the end of her life approached she refused to accept the fact that the element was harmful as well. Yet the warnings were certainly dramatic. Shortly after they had begun working with radium, the Curies had noticed the early signs of what was later recognized as radiation sickness: weakness, severe fatigue, rheumatic pains. Pierre's fingers became so sore that he could scarcely hold a pen; permanent scars were left on his skin.

Pierre continued to sicken, and his severe malaise may have been indirectly responsible for his untimely death. On April 19, 1906, the forty-seven-year-old physicist was struck by a large cart while crossing a street.

"He was walking quickly, his umbrella was up in his hand and he literally threw himself on my left side horse," the driver told reporters. Pierre's head was smashed into fifteen or sixteen pieces by the rear wheel, and a large crowd gathered to watch the blood mix with the rain in the gutter.

Marie's life entered a long period of decline after her husband's death. When she had recovered from her grief, she entered into an affair with a young physicist, Paul Langevin. A married man with four children, Langevin maintained a small pied-a-terre in Paris, and here the trysts took place. On November 4, 1911, *Le Journal* learned of the situation, and it became a sensation.

"A Story of Love. Mme. Curie and Professor Langevin," blared the headlines. Under a striking photograph of "pécheuse" Marie, the titillating story began, "The fire of radium had lit a flame in the heart of a scientist, and the scientist's wife and children were now in tears."

By the next day, every newspaper in Paris carried the story, and news of the scandal had passed by wireless to tabloids in London, Berlin, New York, and San Francisco. There was even speculation that Pierre had been driven to suicide when he learned that his wife was carrying on with a former pupil. White with rage, Langevin challenged the newspaperman who had broken the story to a duel. The event, complete with pistols and seconds, took place at the Parc des Princes bicycle stadium. But at the count of *trois*, neither man would fire at the other. Relieved, the seconds removed their hats, wiped their brows, and cautiously took the pistols from the contestants. The weapons were discharged into the air, the doctors closed their bags, and the reporters put away their notebooks. The farce had come to an end; Langevin's marriage and the well-publicized affair soon ended also.

The situation had been too much for Marie. On December 29, 1911, she was carried off by stretcher to a sanatorium. Sympathetic with her plight, the Nobel Committee awarded her the prize in chemistry; she had previously shared the 1903 physics prize with her husband and Henri Becquerel.

In the years following her recovery, Marie worked for increased application of her discovery. The usefulness of radium in the treatment of cancer, especially of the cervix and uterus, was ascertained, and a Curie Institute in Paris was founded. During the First World War, Marie and her daughter Irène instructed the Allied soldiers in radiology. Marie suffered horribly during her last years from radiation bums to her hands. In 1934 she died of leukemia, another sequela of radiation exposure.