It would be impossible to run a hospital without extensive use of radiation.

Chapter 1

Radiation is Discovered

Introduction

From the beginning of life on earth, all living things have been exposed to radiation. Life started and developed in spite of, or possibly because of, radiation. It is disquieting to people that they coexist with radiation yet it cannot be seen, heard or felt.

Radiation, when broadly defined, includes the entire spectrum of electromagnetic waves: radio waves, microwaves, infrared, visible light, ultraviolet, x-rays and atomic particles. In this book we are concerned with radiation having energies high enough to ionize matter. Examples are x-rays, cosmic rays, and the emissions from radioactive elements. Although the term "ionizing radiation" is in this case more precise, common usage often omits "ionizing" and this is what is done here. In this book, "*radiation*" means "*ionizing radiation.*"

Prior to the reactor accidents at Three Mile Island in the United States (1979) and at Chernobyl in the former Soviet Union (1986), radiation issues were addressed primarily by specialists. Now, however, radiation and biological effects are debated by the public and political leaders. They use expressions such as: radiation dose, becquerel, gray, cesium and γ-radiation. Because people are easily confused by this technical language, all too often they are left with the perception that *all* uses of radiation are dangerous.

This book is written for those who want to understand radiation in order to make informed decisions about it in their lives. This field of science, founded at the turn of the century, has provided dramatic insights into physics, chemistry, biology, and medicine. The work of the early investigators provided a strong foundation from which to understand radiation phenomena. We will meet a few of them in the following pages and gain insight into their work and lives.

X-rays discovered November 1895	Radioactivity discovered March 1896
This radiation is man-made. We have developed a variety of x-ray equipments. The radiation exists only as long as the x-ray machine is turned on.	Both natural and man-made radioactivity exists. The sources emit radiation all the time – you can not turn them on and off.

X-rays

X-rays were discovered by Wilhelm Conrad Roentgen at the University of Würtzburg in Germany. He, like many others in those days, was studying electric discharges in glass tubes filled with various gases at very low pressures. In experiments on November 8, 1895, Roentgen had covered the tube with some black paper and had darkened the room. He then discovered that a piece of paper painted with a fluorescent dye, at some distance from the tube, would glow when he turned on the high voltage between the electrodes in the tube. Realizing the importance of his discovery, Roentgen focused all his attention on the study of this new radiation that had the unusual property of passing through black paper. He found that the radiation not only could penetrate black paper but also thick blocks of wood, books and even his hand. In the dark room, he observed shadows of the bones in his own hand. This was the first x-ray image. The German anatomist von Koelliker (see his hand below) proposed that the new type of radiation be called *Roentgen rays*. Although this term is used in many countries, the most common name used is that coined by Roentgen himself, "*x-rays*". The letter "*x*" is often used by physicists to indicate something "unknown." Since the nature of these rays was unknown, Roentgen called them x-rays.

X-rays on earth are from man-made sources. There are x-rays from natural sources in outer space. They are, however, absorbed by the upper atmosphere and do not reach the earth's surface.

W. C. Roentgen
(1845 - 1923)

Roentgen discovered x-rays in the fall of 1895. He immediately understood that the radiation from the x-ray tube had special properties, for example, it was possible to "see into" a human body. Within months this new radiation, called x-rays, was used in medical diagnostics.
It was realized that x-rays also could kill living cells, and that the sensitivity for killing varied from one cell type to another. Consequently, x-rays could be used in cancer therapy.

The unit R (roentgen) used for radiation exposure was named after Roentgen. An exposure of 1 R means that the radiation dose to ordinary tissue is approximately 9.3 mGy (see later).

Nobel prize in Physics 1901

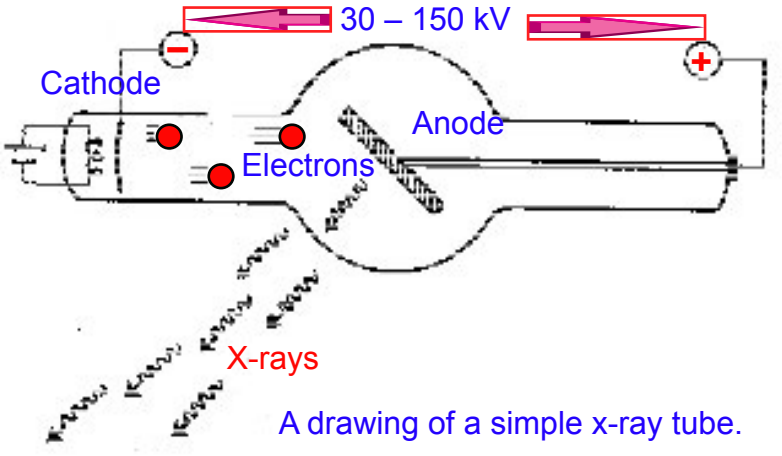
To Wilhelm Conrad Roentgen
"In recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him".

This was the very first Nobel Price.

This x-ray picture was taken by Roentgen in January 1896. It is the hand of von Koelliker who suggested the name Roentgen rays.

What is X-rays?

In order to produce x-rays you must have equipment like that shown in the drawing. It consists of an evacuated glass tube with two electrodes and a high voltage between the electrodes. The cathode is heated and electrons are emitted. They have a negative charge and is accelerated towards the positive electrode (the anode). The larger the voltage between the electrodes the higher speed and energy will the electrons attain.

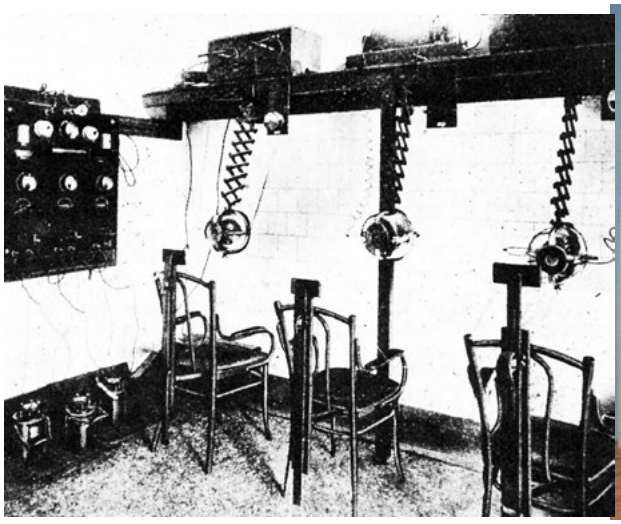


A drawing of a simple x-ray tube.

The fast electrons smash into the anode which is made of tungsten or another heavy metal. The electrons are stopped and loose their energy. Most of the energy is transformed into heat in the anode (which is cooled with water), and a small part is transformed into radiation – x-rays!

The part of energy that is transformed into radiation varies from zero up to the maximum energy of the electron when it hits the anode. This implies that the x-ray photons from the tube have a number of different energies – in fact a whole spectrum. Due to the mechanism for the formation we sometimes call this radiation for "***bremstrahlung***" (from the German word for brake or stop).

X-rays are usually described by their maximum energy, which is determined by the voltage between the electrodes. It may range from about 20 kV up to 300 kV. Radiation with low voltage is called "*soft*" – and radiation with high voltage is called "*hard*". We shall return to this in combination with the use of x-rays in medicine.



Here you can see some of the progress that has taken place during the last 100 years. Both pictures show equipment for radiation therapy for cancer. To the left is shown equipment from 1903, designed to treat 3 patients simultaneously.

The mysterious x-rays

In the first period after the discovery of x-rays many people had a number of strange ideas as to what x-rays really are, and how they could be used. Here are a couple of examples of what one could see in the newspapers and magazines at that time.
The examples are taken from the book of R. F. Mould "*A Century of X-Rays and Radioactivity in Medicine: With Emphasis on Photographic Records of the Early Years*" (1993)

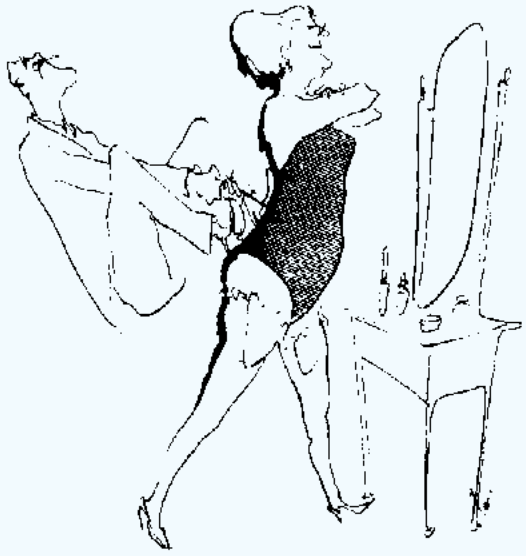
The newspapers very often had headlines such as; *Electric Photography Through Solid Bodies* and *Photography of Unseen Substances*.

The drawing to the left is from *Life* magazine, February 1896.
The picture shows a common misunderstanding. Some people believed that it was possible to take x-ray pictures with reflected x-rays. This means that both the x-ray tube and film is in the photographer's box, as shown. This is wrong, the source and detector must be on opposite side of the object. The x-rays must penetrate the body and hit a detector (e.g. a film) on the other side.

Note added 2009

Both these two cartoons which resulted in a big smile a few years ago is today a reality. In Chapter 9 we shall learn about "backscattered x-ray technique". In a Compton process an x-ray photon may be scattered 180 degrees and it is possible to obtain a picture – and in fact see a naked person. This technique is in use for security at some air ports (see Chapter 9).

In the first period after the discovery of x-rays, people had a lot of ideas of what you could see, for example, through clothes. Some rumors said it was possible to watch people when they changed into swimming suits inside the small cabins on the beach. It is, therefore, not so surprising that a London tailor company advertised that they could make *x-ray proof underclothing for ladies*.
The drawing to the right was used as an advertisement for x-ray proof underwear.



To the left: The Physical Institute in Wûrzburg in 1896. Here was Roentgen`s laboratory when he discovered the x-rays. Today this laboratory is a museum.

X-ray celebration and wine bottles

In the fall of 1995 a large international conference was held in Wûrtsburg, Germany where the 100 year anniversary of Roentgens discovery was celebrated. A wine bottle, with the picture of Roentgen, was made – and served at the reception. The text you can see around the picture of Roentgen is:

"1995 . Vor 100 Jahren entdeckte Conrad Wilhelm Röntgen eine neue art von Strahlen"

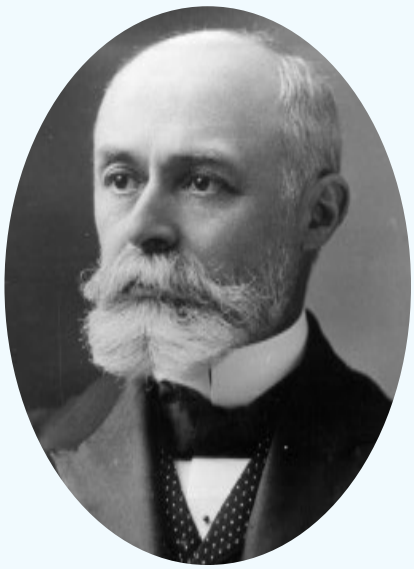
Radioactivity

Ionizing radiation can neither be seen nor felt. It is therefore a challenge just to know whether it is present or not. The situation is the same for radio and TV signals; you can not see or feel them. But if you have a radio tuned to the correct frequency, it will detect the presence of the radio signal. Similarly, in order to detect ionizing radiation, a special detector or sensor is needed.

The French physicist Henri Becquerel was using a photographic plate when he discovered radioactivity in the spring of 1896. Becquerel was 44 years old and was working with compounds that could emit light after being exposed to sunlight. The light (called fluorescence) from the exposed samples was then detected by these photographic plates.

Becquerel had a compound – a uranium salt, in one of his desk drawers. When exposed to sunlight the uranium salt emitted fluorescence. During a period of cloudy weather in Paris, Becquerel was unable to carry out his usual experiments involving fluorescence induced by sunlight. Instead, he decided to check for any possible light leaks by developing some of his unexposed photographic plates. To his surprise, he found that a plate on top of the uranium salt was black. Somehow, intense radiation had exposed the plate. Becquerel was puzzled at first then realized that some unknown type of radiation had to be emanated from the uranium salt - *radioactivity was discovered.*

Marie Sklodowska Curie and her husband Pierre Curie managed to isolate the radioactive materials from the parent rocks. After a large amount of work, they isolated two radioactive elements. The first one was called *polonium* (after Marie's homeland Poland), and the other one was called *radium* (which is "the thing that radiates"). Marie Curie died in 1934 from a blood disease, possibly leukemia, which may have been caused by her work. She became 67 years old.



Henri Becquerel
(1852 – 1908)

Becquerel was French, a third generation professor of physics. His father, Alexander Edmond Becquerel, was a Professor of Applied Physics and had done research on solar radiation and on phosphorescence. His grandfather, Antoine César Becquerel was the inventor of an electrolytic method for extracting metals from their ores.
Henri Becquerel's earliest work was concerned with the plane polarization of light, with the phenomenon of phosphorescence and with the absorption of light by crystals. On March 2nd of 1896 Henri discovered radioactivity. For this discovery, he was awarded the Nobel prize in Physics, together with the Curies, in 1903.

The unit for the intensity of a radioactive source is named after Becquerel. Thus, 1 becquerel (abbreviated Bq) indicates that, on average, one atom in the source disintegrates per second.

The Nobel Prize in Physics 1903

To Henri Becquerel.
"In recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity".

To Marie Sklodowska Curie and Pierre Curie.
"In recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel".

The Curie Family

Marie Sklodowska Curie
(1867 – 1934)

Curie is a prominent name in radiation science. For their work, the Curies won 3 Nobel prizes.
Marie and Pierre shared the prize in physics with Becquerel in 1903.
Marie got the prize in chemistry in 1911, and finally, their daughter Irene won the prize in chemistry in 1935 together with her husband Frederic Joliot.

Nobel Prize in Chemistry 1911

To Marie Curie.
"In recognition of her services to the advancement of chemistry by the discovery of the elements radium and polonium, by the isolation of radium and the study of the nature and compounds of this remarkable element".

The nice picture to the left is taken around 1903 when Marie and Pierre were awarded the first Nobel prize. The couple got two daughters Irene which is seen in the picture, and Ève Denise born in 1904 and died in 2007 – almost 103 years old.

Marie Curie (1867 - 1934) came from Poland and her name was Sklodowska before she married Pierre Curie in 1895. Marie was very gifted and worked all her life with radioactive compounds. She discovered the elements radium and polonium, the latter being named after her homeland. It was the purification of radium that earned her the Nobel prize in chemistry. She is the only person who has ever won the Nobel prize in both physics and chemistry.

Pierre Curie (1859 - 1906) worked with radioactive compounds together with Marie. However, Pierre is also well known for his work in magnetism. Named after him we have "the Curie point", "Curie`s law" and "the Curie constant".

Pierre was only 47 years old when he died in a traffic accident (involving a horse drawn carriage) in Paris in 1906.

Irene Joliot-Curie
(1897 – 1956)

Frederic Joliot-Curie
(1900 – 1958)

Frederic Joliot became an assistant to Marie Curie in 1925. He fell in love with Irène Curie, and they married in 1926. They both took the name Joliot-Curie.

Irene Joliot Curie (1897 - 1956) was the oldest of the two girls in the Curie family. She became a physicist and married:

Frederic Joliot (1900 - 1958). Together they discovered man-made radioactivity in 1934. By bombarding aluminum with α-particles, they produced a radioactive isotope of phosphorus, P-30.

The Nobel Prize in Chemistry 1935

To Irene Joliot Curie and Frederic Joliot
"In recognition of their synthesis of new radioactive elements"