UNIVERSITAT DE BARCELONA

100 years

X-rays: making waves in medical diagnosis for over a century

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Wilhelm Conrad Röntgen (Lennep, Prussia 1845 – Munich, Germany 1923)

On 8 November 1895, a new type of electromagnetic radiation called the X-ray was discovered by Wilhelm Röntgen, who was awarded an honorary doctorate in medicine by the University of Würzburg. He was later honoured with the Nobel Prize in Physics in 1901, the prize money for which he donated to his university. Years later he refused to register any patents related to the X-ray for ethical reasons.

Note: This digital document serves as background material for the exhibition of an antique X-ray machine at the Bellvitge Campus. The machine is on loan from the UB Agustí Pedro i Pons University Foundation and dates to the 1920s.

WHAT ARE THEY?

The electromagnetic spectrum is the range of all the frequencies of electromagnetic radiation from the highest (cosmic rays, X-rays) to the lowest, like radio waves. All electromagnetic waves involve the dispersal of energy through space and, therefore, the transmission of energy from the system that produces them to the system that receives them. Their movement is undulatory, or in other words, they behave like waves.

The difference between the different types of radiation is determined by one of the following parameters, which are also interrelated:

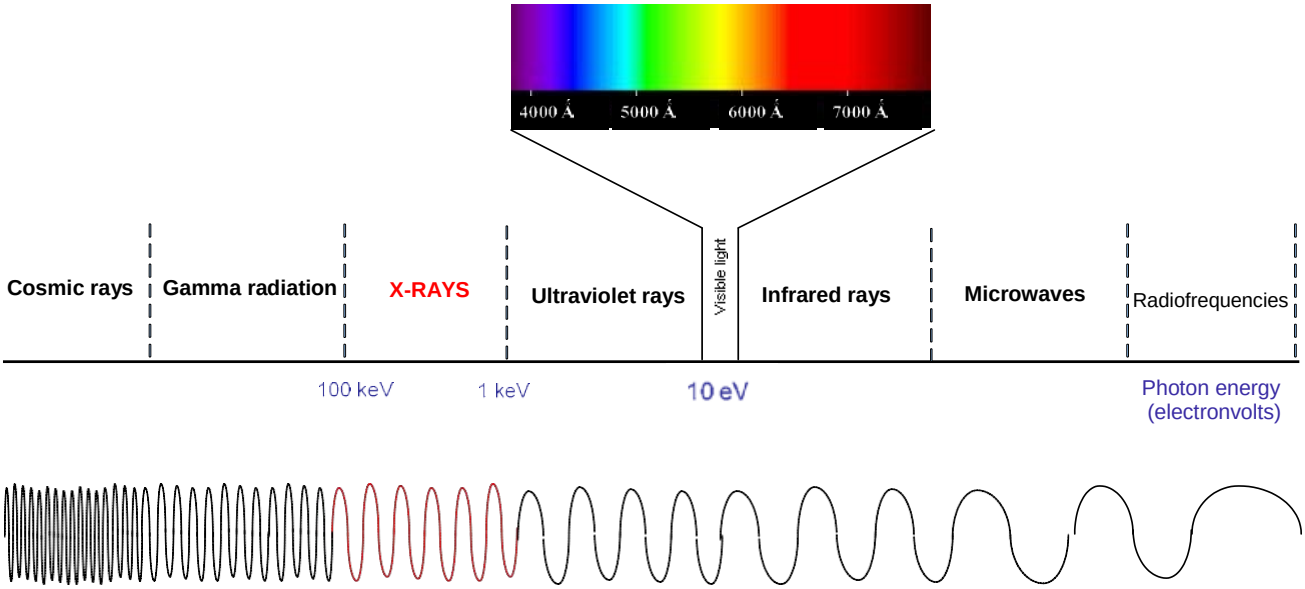
- wavelength (λ, the maximum distance between two repetitions)
- frequency (υ, the number of waves per unit of time; $\upsilon = c / \lambda$)
- energy (E, the product of the Planck constant times frequency; $E = h \cdot \upsilon$; $E = h \cdot c/\lambda$)

As a consequence of these relationships, the more energy a type of electromagnetic radiation has, the higher its frequency and the shorter its wavelength.

The photons of X-rays have an amount of energy on the order of 1 keV to 100 keV.

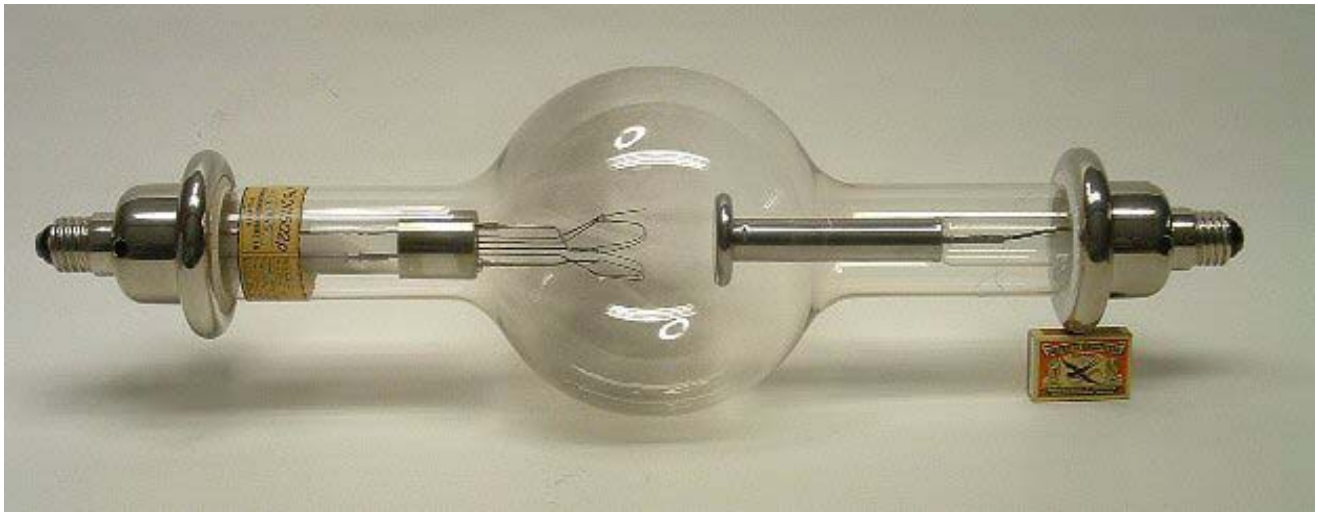
Angstrom (Ǻ); 1Ǻ = 10^{-10} metres
Electronvolt (eV); 1 eV = 1.60210 · 10^{-19} Joules; 1 KeV = 10^{3} eV
Planck constant: h = 4. 1356 ·10^{-15} ·eV· s
Constant of the speed of light in vacuum: c= 299,792,458 m/s

ELECTROMAGNETIC SPECTRUM

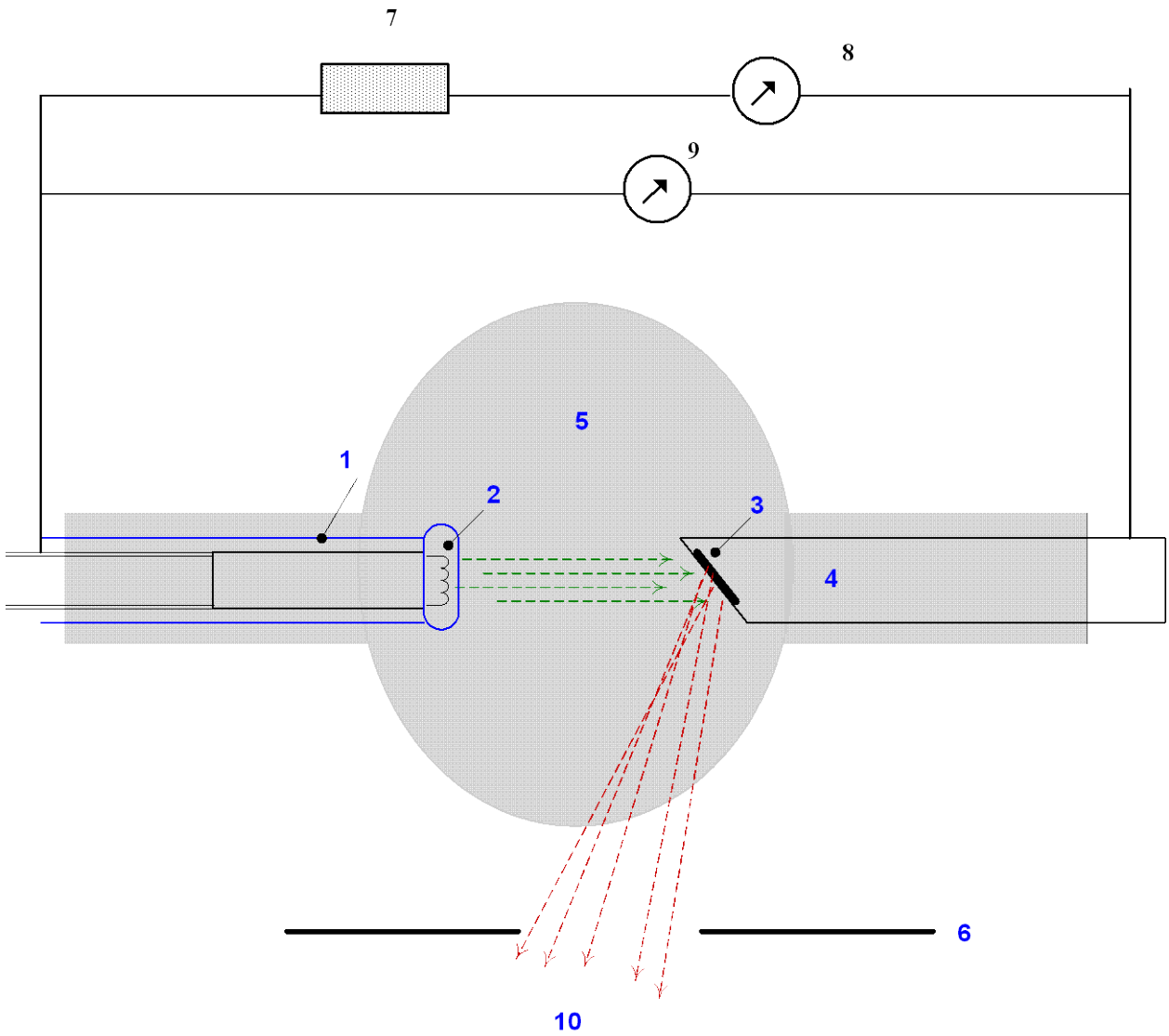


HOW ARE THEY MADE?

The production of X-rays takes place inside a Coolidge tube, which is full of low-pressure gas. It is insulated by a lead casing.



The X-ray tube consists of: a cathode (1), which is an incandescent filament; an electron source (2); a focal spot (3); an anode (4); and the space in which the vacuum occurs (5). The lead casing (6) works like a diaphragm to limit the amount of outgoing X-photons.



This tube is connected to: a high-voltage power source (7); an ammeter (8); a voltmeter (9). This results in the production of X-photons (10).

The high-voltage power source produces the electrical current that passes through the electron source, which consists of an incandescent filament. The variation of the current depends of the quantity of X-rays produced. The electrical current is measured in milliamperes (mA).

The electrons accelerate depending on the voltage applied to the interior of the tube between the filament (cathode) and the metal piece (anode). This voltage is measured in kilovolts (kV) and its variation depends on the quality of the X-rays (low voltage: 40-90 kV, high voltage 100–130 kV). The photons can have any amount of energy below the kinetic energy of the electrons that generated them.

The electrons pass between the cathode and the anode in an area of the tube in which a vacuum has been created. The accelerated electrons crash into a metal plate at a very high speed. A large part of their kinetic energy is transformed into heat and the rest into X-photons by means of two different phenomena: collision (the interaction between an electron from the incident bundle and an atom from the anode) and *bremsstrahlung* (from the German for “braking radiation”, it is the radiation caused by the deceleration of an incident electron near the nucleus of an atom).

The anode is the metallic weight that stops the accelerated electrons. It is generally a metal plate with a high atomic number (Z) and tungsten is one of the most commonly used metals (Z = 74). The surface that receives the accelerated electrons is called the tube’s focal spot. The anode is associated with a cooling system.

The tube is enclosed in a lead casing with an opening in it; only the X-ray photons needed to produce the image pass through this window. A system of lead diaphragms allow the dimensions of the X-ray bundle to be reduced in accordance with the size of the area to be examined, thereby ensuring a high-quality image. The geometry of the anode, which is at approximately 17˚, also contributes to making the X-ray bundle narrower.

Ampere (A) = coulomb / second; milliampere (mA) = 10^{-3}

A Volt (V) = joule / coulomb; kilovolt (kV) = 10^{3} V

A FEW IMPORTANT FACTS ABOUT THE BASIC PHYSICS OF X-RAYS

1887 H. Hertz discovered the photoelectric effect, which would be explained many years later and which consists of the interaction of an incident photon with an electron inside of an atom.

1887-1892 N. Tesla discovered the *bremsstrahlung* phenomenon, which is the radiation produced by the deceleration of an incident electron near the nucleus of an atom.

1895 W.C. Röntgen discovered X-rays through experiments to analyse cathode rays. In recognition of his accomplishment he was awarded the Nobel Prize in Physics in 1901.

1897 J.J. Thomson announced the existence of negatively charged particles smaller than a hydrogen atom called electrons. This discovery led him to receive the Nobel Prize in Physics in 1906.

1905 A. Einstein postulated the corpuscular behaviour of light, which allowed the photoelectric effect to be interpreted. This theory garnered him the Nobel Prize in Physics in 1921.

1912 M. von Laue perfected the method for measuring X-ray wavelengths, thus proving that they are of a nature analogous to light. He was awarded the Nobel Prize in Physics in 1914.

1913 W.D. Coolidge designed the cathode in the X-ray tube and the anode in tungsten, which allowed high voltages to be used. The invention of this tube represents the greatest contribution to the development of the X-ray machine.

1923 A.H. Compton discovered the effect caused by the interaction of an incident photon and a peripheral electron. This confirmed that electromagnetic radiation has properties of both a wave and a particle.

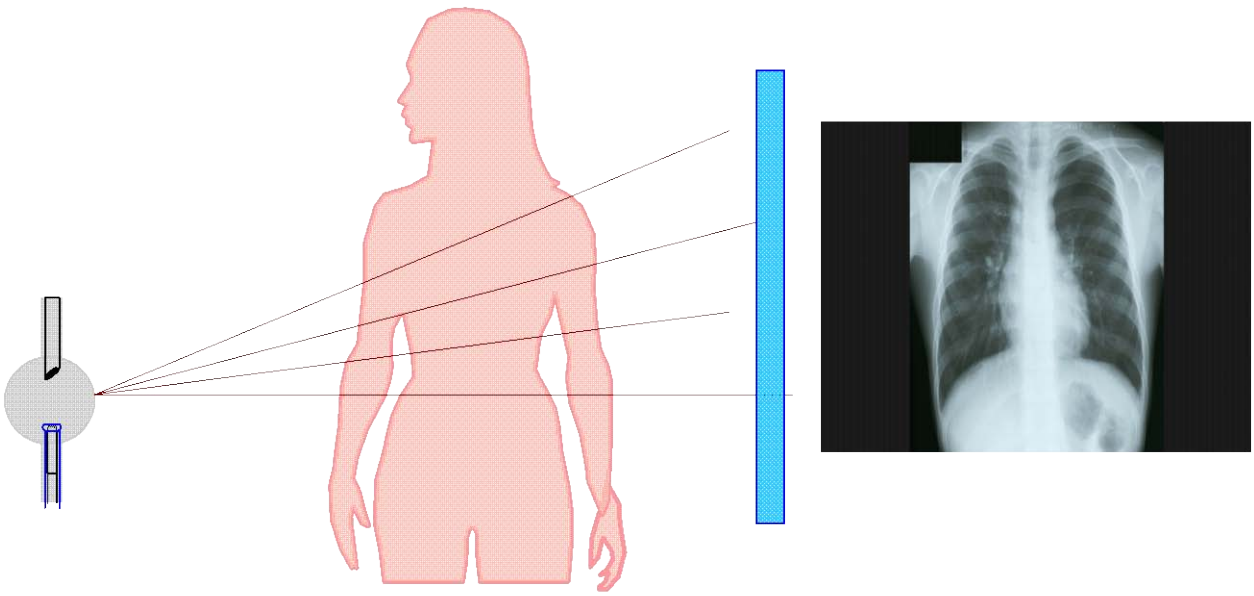
USE IN IMAGE-BASED DIAGNOSIS

Radiodiagnostics consists of the exploration of internal anatomic structures with the help of an image provided by an X-ray bundle, which has the ability to pass through the subject. Dense structures, like bones, block most of these photons and are displayed as white in the resulting image. Metal and contrast media are also seen as white. Structures that contain air are displayed in black, and muscles, fat and liquids are a shadowy grey.

The fundamental basis for the application of X-rays is their property for exponential attenuation. The degree of penetration of these photons into a certain medium depends on the nature of that medium and the energy of the photons. As they pass through a material, they can be absorbed or dispersed from their trajectory. This results in a reduction in their general intensity.

The processes of absorption and dispersion are caused by the interactions between the atoms of the medium and the X-photons. The most significant of these interactions are the photoelectric effect (the interaction of an incident photon with an electron inside an atom), the Compton effect (the interaction of an incident photon with a peripheral electron) and materialization (a high-energy photon interacting with the electrical field in the vicinity of a nucleus).

THE FORMATION OF AN X-RAY IMAGE



X-ray tube

In conventional radiology the most common specialist techniques and equipment are:

- Equipment: mammography unit, bone densitometer, dental X-rays
- Radiological treatments: fluoroscopy, angiography and surgical devices
- Computed tomography

With the advent of information technology and its use in the control of diagnostic equipment and in methods of obtaining and reconstructing images, a second great stride forward was made in the history of radiodiagnostics.

A FEW IMPORTANT FACTS ABOUT THE MEDICAL APPLICATIONS OF X-RAYS

1896 T. Edison has been attributed with the design and manufacture of the first fluoroscope (an X-ray device that allowed internal organs to be seen in movement). He developed fluorescent screens from tungsten.

1896* C. Comas took the first X-rays in Barcelona.

1906 J. Bergonié and R. Tribondeau described the law of tissue radiosensitivity. When studying the effects of ionizing radiation in mice, they reached the conclusion that cells have differing sensitivity to radiation depending on different intrinsic factors.

1910* The First International Congress of Medical Electrology and Radiology was held in Barcelona.

1914 The Radiology Institute was founded to study the applications of X-rays and radioactivity in different fields of medicine. M. Curie was named the director.

1914-1918 M. Curie was the leading professional in medical physics. She participated in solving problems related to injuries and fractures through the use of radiography. She also proposed the use of mobile X-ray machines to help injured soldiers on the front.

1920 The first X-ray protection committee was founded. It was called the American Röntgen Ray Society and it proposed regulations for radiation protection in 1922.

1927 Egas Moniz developed angiography using contrast radiopacity to diagnose different cerebral vascular disorders.

1928 At the International Radiology Congress in Stockholm: 1) the Röntgen unit (R) was formally adopted and 2) the International Committee on X-ray and Radiation Protection was formed.

1946 H.J. Muller won the Nobel Prize in Physiology and Medicine for discovering that X-rays cause mutations.

1951 **C. Thompson** defined the concept of a gamut (a complete list of causes of a pattern or a specific radiological finding). Radiological pathology records were kept from then on.

1963 **J. Cameron** and **J. Sorenson** described a new method for measuring the density of bone mass by means of simple photon absorptiometry (SPA), which over the years would evolve into what is now bone densitometry.

1966 **P. Strax, S. Shapiro** and **L. Venet** evaluated the use of the mammogram as a technique for detecting breast cancer.

1967 **A.M. Cormack** published the first works on computed tomography (CT).

1969 **G.M. Hounsfield** led the team that created the first applicable CT prototype. For their work and the development of CT, Cormack and Hounsfield shared the Nobel Prize in Physiology and Medicine in 1979.

1984 **F. Mouyens** invented the first radiology system with direct digital imaging.

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* diagnostic imaging in Catalonia.

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Internet links

AIP center for history of physics. http: //www.aip.org/history

The cathode ray tube site. http://www.harvardsquarelibrary.org/unitarians/coolidge.html

The Nobel Foundation. http://nobelprize.org

Image sources

Röntgen caricature: http://radiologia.iespana.es/hr/hri1.htm

Electromagnetic spectrum: author

Coolidge tube (Siemens Reiniger-werke V150/1502p):
http://www.harvardsquarelibrary.org/unitarians/coolidge.html

Diagram of Coolidge tube: author

Example of the formation of an X-ray image: author