

Science > Physics > Physicists

 Contents

Ask the Chatbot a Question

Ask the Chatbot a Question

 More Actions
Also known as: *Wilhelm Conrad Roentgen*Written and fact-checked by [The Editors of Encyclopaedia Britannica](#)Last Updated: Feb 6, 2025 • [Article History](#)
 Table of Contents

Wilhelm Conrad Röntgen (born March 27, 1845, Lennep, Prussia [now [Remscheid](#), Germany]—died February 10, 1923, [Munich](#), Germany) was a physicist who received the first [Nobel Prize](#) for Physics, in 1901, for his discovery of [X-rays](#), which [heralded](#) the age of modern [physics](#) and revolutionized diagnostic medicine.

Röntgen studied at the Polytechnic in Zürich and then was professor of physics at the universities of [Strasbourg](#) (1876–79), Giessen (1879–88), Würzburg (1888–1900), and Munich (1900–20). His research also included work on [elasticity](#), [capillary action](#) of fluids, [specific heats](#) of [gases](#), [conduction of heat in crystals](#), absorption of heat by gases, and [piezoelectricity](#).

On November 8, 1895, while experimenting with [electric current](#) flow in a partially evacuated glass tube ([cathode-ray tube](#)), Röntgen observed that a screen of barium platinocyanide far from the tube gave off light when the tube was in operation. He theorized that when the cathode rays ([electrons](#)) struck the glass wall of the tube, some unknown [radiation](#) was formed that traveled across the room, struck the chemical, and caused the [fluorescence](#). Further investigation revealed that paper, wood, and aluminum, among other materials, are [transparent](#) to this new form of radiation. He found that it affected photographic plates, and, since it did not noticeably exhibit any properties of [light](#), such as [reflection](#) or [refraction](#), he mistakenly thought the rays were unrelated to light. In view of its uncertain nature, he called the phenomenon [X-radiation](#), though it also became known as Röntgen radiation. He took the first X-ray photographs, of the interiors of metal objects and of the bones in his wife's hand.



Britannica Quiz

Physics and Natural Law

X-rays quickly entered use in medicine, the first uses for [medical imaging](#) and treating cancers happening weeks after the announcement of Röntgen's discovery early in 1896. Röntgen did not take out a [patent](#) on his discovery, because he felt his work should benefit all. He rejected a title of nobility but accepted an honorary doctorate of medicine from the [University of Würzburg](#). He also donated his Nobel Prize money to that university.

The Editors of Encyclopaedia Britannica

This article was most recently revised and updated by Encyclopaedia Britannica.



Wilhelm Conrad Röntgen

Quick Facts

Röntgen also spelled: Roentgen**Born:** March 27, 1845, Lennep, Prussia [now Remscheid, Germany]**Died:** February 10, 1923, [Munich, Germany](#) (aged 77)**Awards And Honors:** [Nobel Prize \(1901\)](#)**Subjects Of Study:** [X-ray](#)[See all related content](#)

Wilhelm Conrad Röntgen

Science > Physics > Matter & Energy

X-ray

radiation beam

Ask the Chatbot a Question

More Actions

Also known as: Röntgen radiation, X-radiation

Written by [Glenn Stark](#)

Fact-checked by The Editors of Encyclopaedia Britannica

Last Updated: Dec 27, 2024 • Article History

Table of Contents

News • [Einstein Probe Detects Mysterious Blast of X-Rays From the Early Universe](#) • Jan. 26, 2025, 11:53 PM ET (Gizmodo)

X-ray, [electromagnetic radiation](#) of extremely short [wavelength](#) and high [frequency](#), with wavelengths ranging from about 10^{-8} to 10^{-12} metre and corresponding frequencies from about 10^{16} to 10^{20} [hertz](#) (Hz).

X-rays are commonly produced by [accelerating](#) (or decelerating) charged particles; examples include a beam of [electrons](#) striking a metal [plate](#) in an [X-ray tube](#) and a circulating beam of electrons in a [synchrotron particle accelerator](#) or [storage ring](#). In addition, highly excited [atoms](#) can emit X-rays with discrete wavelengths characteristic of the [energy level](#) spacings in the atoms. The X-ray region of the [electromagnetic spectrum](#) falls far outside the range of visible wavelengths. However, the passage of X-rays through materials, including biological [tissue](#), can be recorded with photographic films and other detectors. The analysis of X-ray images of the body is an extremely valuable medical diagnostic tool.

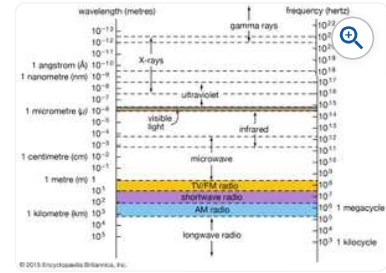
X-rays are a form of ionizing radiation—when interacting with matter, they are energetic enough to cause neutral atoms to eject electrons. Through this [ionization](#) process the [energy](#) of the X-rays is deposited in the matter. When passing through living tissue, X-rays can cause harmful biochemical changes in [genes](#), [chromosomes](#), and other [cell](#) components. The biological effects of [ionizing radiation](#), which are complex and highly dependent on the length and intensity of exposure, are still under active study (see [radiation injury](#)). X-ray [radiation therapies](#) take advantage of these effects to combat the growth of [malignant](#) tumours.

X-rays were discovered in 1895 by German physicist [Wilhelm Konrad Röntgen](#) while investigating the effects of [electron beams](#) (then called [cathode rays](#)) in electrical discharges through low-pressure gases. Röntgen uncovered a startling effect—namely, that a screen coated with a [fluorescent](#) material placed outside a discharge tube would glow even when it was shielded from the direct visible and [ultraviolet light](#) of the gaseous discharge. He deduced that an invisible [radiation](#) from the tube passed through the air and caused the screen to [fluoresce](#). Röntgen was able to show that the radiation responsible for the fluorescence originated from the point where the electron beam struck the glass wall of the discharge tube. [Opaque](#) objects placed between the tube and the screen proved to be transparent to the new form of radiation; Röntgen dramatically demonstrated this by producing a photographic image of the bones of the human hand. His discovery of so-called Röntgen rays was met with worldwide scientific and popular excitement, and, along with the discoveries of [radioactivity](#) (1896) and the [electron](#) (1897), it ushered in the study of the atomic world and the era of modern [physics](#).

Fundamental characteristics

Wave nature

X-rays are a form of electromagnetic radiation; their basic physical properties are identical to those of the more familiar components of the electromagnetic spectrum—visible [light](#), [infrared radiation](#), and [ultraviolet radiation](#). As with other



electromagnetic spectrum The relationship of X-rays to other electromagnetic radiation within the.....(more)

Key People: [Marie Curie](#) • [Walter Bradford Cannon](#) • [Hermann Joseph Muller](#) • [Arthur Holly Comp...](#)([Show more](#))

Related Topics: [cosmic X-ray background](#) • [bremsstrahlung](#) • [secondary X ray](#) • [particle-ii...](#)([Show more](#))

[See all related content](#)

forms of [electromagnetic radiation](#), X-rays can be described as coupled waves of [electric](#) and [magnetic fields](#) traveling at the [speed of light](#) (about 300,000 km, or 186,000 miles, per second). Their [characteristic](#) wavelengths and frequencies can be demonstrated and measured through the [interference](#) effects that result from the overlap of two or more waves in space. X-rays also exhibit particle-like properties; they can be described as a flow of [photons](#) carrying discrete amounts of [energy](#) and [momentum](#). This dual nature is a property of all forms of [radiation](#) and matter and is comprehensively described by the theory of [quantum mechanics](#).

Though it was immediately suspected, following Röntgen's discovery, that X-rays were a form of electromagnetic radiation, this proved very difficult to establish. X-rays are distinguished by their very short wavelengths, typically 1,000 times shorter than the wavelengths of visible light. Because of this, and because of the practical difficulties of producing and detecting the new form of radiation, the nature of X-rays was only gradually [unraveled](#) in the early decades of the 20th century.

In 1906 the British physicist [Charles Glover Barkla](#) first demonstrated the [wave](#) nature of X-rays by showing that they can be “polarized” by [scattering](#) from a solid. [Polarization](#) refers to the orientation of the oscillations in a transverse wave; all electromagnetic waves are transverse oscillations of electric and magnetic fields. The very short wavelengths of X-rays, hinted at in early [diffraction](#) studies in which the rays were passed through narrow slits, was firmly established in 1912 by the pioneering work of the German physicist [Max von Laue](#) and his students Walter Friedrich and Paul Knipping. Laue suggested that the ordered arrangements of atoms in [crystals](#) could serve as natural three-dimensional [diffraction gratings](#). Typical atomic spacings in crystals are approximately 1 [angstrom](#) (1×10^{-10} metre), ideal for producing diffraction effects in electromagnetic radiation of [comparable wavelength](#). Friedrich and Knipping verified Laue's predictions by photographing diffraction patterns produced by the passage of X-rays through a [crystal](#) of zinc sulfide. These experiments demonstrated that X-rays have wavelengths of about 1 angstrom and confirmed that the atoms in crystals are arranged in regular structures.

In the following year, the British physicist [William Lawrence Bragg](#) devised a particularly simple model of the [scattering of X-rays](#) from the parallel layers of atoms in a crystal. The [Bragg law](#) shows how the angles at which X-rays are most efficiently diffracted from a crystal are related to the X-ray wavelength and the distance between the layers of atoms. Bragg's physicist father, [William Henry Bragg](#), based his design of the first X-ray [spectrometer](#) on his son's analysis. The pair used their X-ray spectrometer in making [seminal](#) studies of both the distribution of wavelengths in X-ray beams and the crystal structures of many common solids—an achievement for which they shared the [Nobel Prize](#) for Physics in 1915.

Particle nature

In the early 1920s, experimental studies of the scattering of X-rays from solids played a key role in establishing the particle nature of electromagnetic radiation. In 1905 German physicist [Albert Einstein](#) had proposed that electromagnetic radiation is granular, consisting of [quanta](#) (later called [photons](#)) each with an energy hf , where h is [Planck's constant](#) (about 6.6×10^{-34} joule-second) and f is the [frequency](#) of the radiation. Einstein's [hypothesis](#) was strongly supported in subsequent studies of the [photoelectric effect](#) and by the successes of Danish physicist [Niels Bohr](#)'s model of the hydrogen [atom](#) and its characteristic emission and [absorption spectra](#) (see [Bohr atomic model](#)). Further verification came in 1922 when American physicist [Arthur Compton](#) successfully treated the scattering of X-rays from the atoms in a solid as a set of collisions between X-ray photons and the loosely bound outer electrons of the atoms.

Adapting the relation between momentum and energy for a classical electromagnetic wave to an individual [photon](#), Compton used [conservation of energy](#) and [conservation of momentum](#) arguments to derive an expression for the wavelength shift of scattered X-rays as a function of their scattering angle. In the so-called [Compton effect](#), a colliding photon transfers some of its energy and momentum to an [electron](#), which [recoils](#). The scattered photon must thus have less energy and momentum than the incoming photon, resulting in scattered X-rays of slightly lower frequency and longer wavelength. Compton's careful measurements of this small effect, coupled with his successful theoretical treatment (independently derived by the Dutch scientist [Peter Debye](#)), provided convincing evidence for the existence of

photons. The approximate wavelength range of the X-ray portion of the [electromagnetic spectrum](#), 10^{-8} to 10^{-12} metre, corresponds to a range of photon energies from about 100 eV ([electron volts](#)) to 1 MeV (million electron volts).

Applications

The defining characteristics of X-rays—their ability to penetrate optically [opaque](#) materials, their wavelengths of atomic dimension, the high energy of individual X-ray photons—lead to a wide range of industrial, medical, and scientific applications. Specialized X-ray sources, detectors, and analysis techniques have been developed to address a range of questions from the study of the interactions of the simplest molecules to the structure of the human brain.

X-ray images of the body are an indispensable diagnostic tool in modern medicine. Medical imaging allows for the noninvasive detection of dental cavities, [bone](#) fractures, foreign objects, and diseased conditions such as [cancer](#). Standard X-ray images easily [differentiate](#) between bone and soft tissue; additional contrast between different areas of soft [tissue](#) is afforded by the injection of a contrast medium—a liquid or gas that is comparatively opaque to X-rays (see [diagnostic imaging](#)). In the 1970s a powerful new X-ray imaging technique, [computed tomography](#) (CT), was developed. Now in widespread use, CT scans produce detailed high-resolution cross-sectional images of internal organs and structures; they are far more sensitive to small density variations than conventional X-ray images.



X-ray of foot X-ray of a human foot.

As with other forms of [ionizing radiation](#), X-rays cause biochemical changes in living cells. A high-energy X-ray photon deposits its energy by liberating electrons from atoms and molecules. These free electrons may themselves ionize additional neutral species. Through this process, reactive ions and free radicals are formed, leading to further chemical reactions. The resulting radiation-induced chemistry can break the molecular bonds needed for [cell](#) growth and can induce genetic damage (see [radiation injury](#)). While there are significant health risks associated with exposure to X-rays, radiation therapies exploit the above effects to treat cancerous tumours and blood disorders such as [leukemia](#). X-rays (and higher-energy [gamma rays](#)) are directed at target tissues; the consequent molecular damage blocks the growth of the diseased cells. Nearby normal cells, also exposed to the ionizing X-rays, are typically more capable of repair. In a related application, in agricultural industries the irradiation of some foods with X-rays and gamma rays is used to [inhibit](#) selectively the growth of bacteria (see [food preservation: Food irradiation](#)).

X-rays are a powerful diagnostic tool for revealing the structure and [composition](#) of [materials](#). The great utility of X-ray images derives from the differential [absorption](#) of X-rays by materials of different density, composition, and [homogeneity](#). In a common application, X-rays are used for quick examination of the contents of airline baggage. In industry, X-ray images are used to detect flaws nondestructively in castings that are inaccessible to direct observation. X-ray microscopes are capable of magnifying X-ray absorption images so as to resolve features on scales as small as about 40 nanometres (nm; billionths of a metre), or roughly 400 atomic [diameters](#). This resolution, about five times greater than that achieved by the best visible light microscopes, is possible because of the small diffraction effects associated with the very short wavelengths of X-rays. X-ray microscopes usually operate with “soft” X-rays (wavelengths in the 1- to 10-nm range) and rely on reflective optics (see [spectroscopy: X-ray optics](#)) or “zone plates” (see [optics: Filtering](#)) to achieve focusing. Because water is relatively transparent in the soft X-ray region, these microscopes are ideal for studying biological materials in an aqueous [environment](#). Another sophisticated absorption technique, called EXAFS (“extended X-ray absorption fine structure”), is capable of identifying the short-range ordering of atoms and molecules in unstable samples of crystals and [amorphous solids](#).

[X-ray diffraction](#) techniques (or “X-ray crystallography”) allow for the determination of crystal structures in inorganic, organic, and biological materials. The detailed atomic structure of the double-helix polymer deoxyribonucleic acid (DNA) was famously revealed by [James Watson](#) and [Francis Crick](#) via the X-ray crystallography studies of [Maurice Wilkins](#). X-ray fluorescence is a complementary method for the [quantitative analysis](#) of the composition of materials. In this technique, a sample is exposed to either an [electron beam](#) or a beam of primary X-rays; the resulting atomic excitations lead to [X-ray emissions](#) with wavelengths characteristic of the elements in the sample. The [electron](#)

[microprobe](#) uses this process to identify the [constituents](#) of sample regions as small as a few micrometres (millionths of a metre). X-ray fluorescence and diffraction techniques are valuable methods for the nondestructive analysis of art objects. Brushstroke techniques and the arrangements of painted-over pigments in oil paintings, the presence of coatings and varnishes, and the [compositions](#) of glasses, porcelain, and enamels are revealed through X-ray analysis.

Many of the above techniques are [enhanced](#) by the exceptionally high X-ray intensities produced in modern [synchrotron](#) light facilities. Extremely bright, short X-ray pulses, tuned to selected wavelength regions, are used to probe chemical reactions on surfaces, the electronic structures of semiconductors and magnetic materials, and the structure and function of proteins and biological macromolecules. Another promising source of high-intensity X-rays is the X-ray [laser](#). [Coherent](#) X-rays (a signature of lasing) at the longer-wavelength end of the spectral region have been produced in the laboratory. In 2009 lasing was achieved at the Linac [Coherent](#) Light Source facility in Menlo Park, Calif., at a wavelength of 0.15 nm, but construction of a practical device at such short wavelengths remained a difficult technological challenge.

Production and detection of X-rays

Production of X-rays

There are three common mechanisms for the production of X-rays: the acceleration of a charged particle, atomic transitions between discrete [energy](#) levels, and the radioactive decay of some atomic nuclei. Each mechanism leads to a characteristic [spectrum](#) of X-ray radiation.

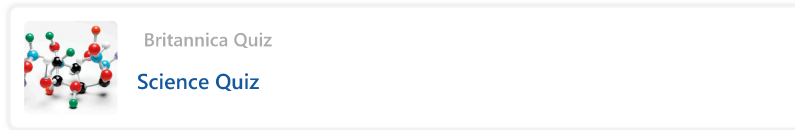
In the theory of classical electromagnetism, accelerating electric charges emit electromagnetic waves. In the most common terrestrial source of X-rays, the [X-ray tube](#), a beam of high-energy electrons impinges on a solid target. As the fast-moving electrons in the beam interact with the electrons and nuclei of the target atoms, they are repeatedly deflected and slowed. During this abrupt deceleration, the beam electrons emit [bremsstrahlung](#) (German: “braking radiation”)—a continuous spectrum of [electromagnetic radiation](#) with a peak intensity in the X-ray region. Most of the energy radiated in an X-ray tube is contained in this continuous spectrum. Far more powerful (and far larger) sources of a [continuum](#) of X-rays are [synchrotron particle accelerators](#) and storage rings. In a synchrotron, charged particles (usually electrons or [positrons](#)) are accelerated to very high energies (typically billions of [electron](#) volts) and then confined to a closed orbit by strong magnets. When the charged particles are deflected by the magnetic fields (and hence accelerated via the change in their direction of motion), they emit so-called [synchrotron radiation](#)—a continuum whose intensity and [frequency distribution](#) are determined by the strength of the magnetic fields and the energy of the circulating particles. Specially designed synchrotron [light](#) sources are used [worldwide](#) for X-ray studies of materials.

In an X-ray tube, in addition to the continuous spectrum of radiation emitted by the decelerating electrons, there is also a spectrum of discrete X-ray emission [lines](#) that is characteristic of the target material. This “characteristic radiation” results from the excitation of the target atoms by collisions with the fast-moving electrons. Most commonly, a collision first causes a tightly bound inner-shell electron to be ejected from the atom; a loosely bound outer-shell electron then falls into the inner shell to fill the vacancy. In the process, a single [photon](#) is emitted by the [atom](#) with an energy equal to the difference between the inner-shell and outer-shell vacancy states. This energy difference usually corresponds to photon wavelengths in the X-ray region of the spectrum. [Characteristic](#) X-ray radiation can also be produced from a target material when it is exposed to a primary X-ray beam. In this case, the primary X-ray photons initiate the sequence of electron transitions that result in the [emission](#) of secondary X-ray photons.

In 1913 the English physicist [Henry Moseley](#) discovered a simple relationship between the wavelengths of the X-ray emission lines from a target and the atomic number of the target element—the wavelengths are inversely proportional to the square of the [atomic number](#). Known as Moseley’s law, this relationship proved to be a definitive tool in the determination of atomic numbers in the early days of [atomic physics](#). X-ray fluorescence techniques, in which the wavelengths of characteristic X-rays are recorded following the excitation of a target, are now commonly used to identify the elemental [constituents](#) of materials.

X-ray emission is sometimes a by-product of a [nuclear transformation](#). In the process of [electron capture](#), an inner-shell atomic electron is captured by the atomic nucleus, initiating the transformation of a nuclear [proton](#) into a [neutron](#) and

lowering the atomic number by one unit (see [radioactivity: Types of radioactivity](#)). The vacant inner-shell orbit is then quickly filled by an outer-shell electron, producing a characteristic X-ray photon. The relaxation of an excited nucleus to a lower-energy state also sometimes results in the emission of an X-ray photon. However, the photons emitted in most nuclear transitions of this type are of even higher energy than X-rays—they fall into the [gamma-ray](#) region of the [electromagnetic spectrum](#).



Many astronomical sources of X-rays have been discovered over the past 50 years; collectively they are a rich resource of information about the universe (see [X-ray sources](#)). X-rays are emitted by the Sun's hot [corona](#) (outer atmosphere) and by the coronas of other ordinary stars in the [Milky Way Galaxy](#). Many [binary star](#) systems emit [copious](#) X-rays; the strongest such sources produce, in the X-ray region alone, more than 1,000 times the entire energy output of the Sun. [Supernova](#) remnants are also strong sources of X-rays, which are sometimes associated with synchrotron radiation produced by high-energy charged particles circulating in intense magnetic fields and sometimes with atomic emissions from extremely hot gases (in the range of 10 million kelvins). Powerful extragalactic sources of X-rays, including active galaxies, quasars, and galactic clusters, are currently under intense scientific scrutiny; in some cases the exact mechanisms of X-ray production are still uncertain or unknown. As the Earth's atmosphere strongly absorbs X-rays, astronomical observations in the X-ray region must be made from orbiting satellites. The launch of the [Chandra X-Ray Observatory](#) in 1999 greatly advanced the observational [capabilities](#) of [X-ray astronomy](#) (see [telescope: X-ray telescopes](#)).

Detection of X-rays

Photographic film was used by Röntgen as one of the first X-ray detectors, and this simple technique remains in wide use in medical applications. The process of exposure is initiated by X-ray photons ionizing radiation-sensitive [silver](#) halide crystals in an emulsion on the film surface; the resulting photochemical change of the affected crystals darkens the exposed area (see [radiation measurement: Photographic emulsions](#)).

Photographic techniques, while much improved upon since the time of Röntgen and still extremely useful for qualitative applications, are not well-suited for more quantitative measurements of X-ray intensities and spectral content. A number of more effective detection methods have been developed. In a Geiger-Müller tube, or [Geiger counter](#), incoming X-ray photons [ionize](#) atoms in a gas-filled volume. An applied high voltage [induces](#) further ionizations from collisions between liberated electrons and neutral atoms, creating an avalanche of charged particles and a large electrical pulse that is easily detected. More sophisticated detection schemes based on the [ionization](#) of gas atoms can discriminate between X-rays of different energies (see [radiation measurement: Proportional counters](#)). Other common detection schemes rely on the ability of X-rays to produce visible fluorescence in crystals (see [scintillation counter](#)) and [charge](#) separation in [semiconductors](#) (see [radiation measurement: Semiconductor detectors](#)).

Glenn Stark

Load Next Page ▾