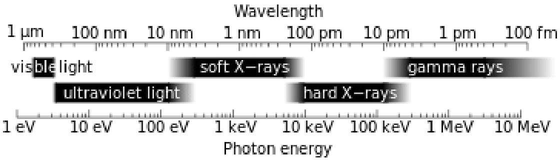
X-rays characteristics

X-rays

X-rays are a form of electromagnetic radiation. They belong to the short-wavelength, high-frequency end of the electromagnetic spectrum, between the gamma and the ultraviolet radiation. They have wavelengths in the range of 10^{-8} m to 10^{-11} m (10nm – 0.01nm). Their frequency range is $3x10^{16}$Hz to $3x10^{19}$Hz.



X-rays can be produced in several ways: by the movement of electrons in atoms or by transformation of kinetic energy to Bremsstrahlung radiation. It is when particles with high energy (ex: electrons, protons or heavier ions) or photons hit the surface of a solid material (ex: metal) that x-rays are produced.

When a photon collides with another atom, the atom may absorb the photon’s energy causing an electron to jump to a higher energy level. This can only happen if the energy level of the photon matches the energy difference between the two electron levels. The electron then falls back to its original energy level, releasing the extra energy in the form of a light photon.

When the fast electrons, protons or heavier ions collide with the atoms of the solid material, they slow down or completely stop. This is when their kinetic energy is transformed to Bremsstrahlung radiation. Bremsstrahlung has a wide rage of X-ray wavelengths and in the spectrum you can also find characteristic X-rays that are associated with the atoms of the material that is used.

The soft tissue in our body is composed of atoms that do not absorb X-ray photons very well, because their energy levels do not match the energy of the photons. However, the bone tissue absorbs these same photons quite well, due to the calcium atoms that have higher energy levels between its atoms that match the photons' energy. In air filled organs there is hardly any absorption (because of the air) and the photons easily just pass through, hence the clear boundaries.

Types of X-rays

There are two types of X-rays, according to their photon energy. The photon energy is given by the formula $E = h\nu$ where E is the energy in Joules, h is Planck's constant and ν is the frequency of the photon. The frequency of the photon (ν) can also be obtained from the equation $c = \lambda\nu$ where c is the speed of light ($\sim 3.0 * 10^8$ m/s) and λ is the photon's wavelength. Because Planck's constant is small ($\sim 6.62 * 10^{-34}$ Joule-seconds), it is typically more convenient to work in electron-Volts (eV) where one eV is about $1.602 * 10^{-19}$ Joule. For example, visible light photons with wavelenths between 700nm and 400nm have energies between 1.77 eV and 3.1 eV respectively.

Soft X-rays

These x-rays are defined by having photon energies below 10keV. They have less energy than the hard x-rays, therefore they have longer wavelength. Soft X-rays are used in radiography to take pictures of bones and internal organs. Because of their lower energy, they do not cause much damage to tissues, unless they are repeated too often.

Hard X-rays

Hard X-rays have photon energies above 10 keV. They have shorter wavelength than the soft x-rays. These X-rays are used in radiotherapy, a treatment for cancer. Due to their higher energy, they destroy molecules within specific cells, thus destroying tissue. Another use for these X-rays is in airport security scanners to examine baggage.

Production of X-rays

The X-rays were discovered in 8th November in 1895 when Wilhelm Conrad Rontgen was working with a cathode ray tube in his laboratory. X-rays for medical diagnostic procedures are produced in a X-ray tube.

X-ray tube

The tube itself is evacuated, and contains two electrodes:

Cathode: the heated filament acts as the cathode (negative) from which electrons are emitted

Anode: the anode (positive) is made of a heavy metal, usually tungsten.

An external power supply produces a voltage of up to 200 kV between the two electrodes. This accelerates the electrons across the gap between the cathode and the anode. The kinetic energy of an electron arriving at the anode is around 200 kV. When the electrons strike the anode at high speed, parts of their kinetic energy is transformed into X-ray photons that emerge in all directions.

Only a small fraction of kinetic energy of electrons are converted into x-rays. The rest of the energy is transfered to the anode as thermal energy. Some X-ray tubes have water circulating through the anode to remove this surplus of heat.

The X-rays that emerge from the x-ray tube have a range of energies, represented in a X-ray spectrum. This spectrum have two components: the Brehmsstrahlung radiation and the characteristic X-rays. These arise from different ways is related to the way which an individual electron loses it's energy when crashes into the anode.

When the electron striking into anode loses its energy and interacts with the electric fields of the anode nucleus this may result in a single X-ray photon or several photons. These all contribute to Brehmsstrahlung radiation.

An electron may cause a rearrangement of the electrons in the anode atom in which an electron drops from a high energy level to a lower energy level. As it does so, it emits a photon with a defined frequency. This contributes to the characteristic X-rays that are characteristic of the anode (if the anode is made of copper instead of tungsten the characteristic X-rays will be different).

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