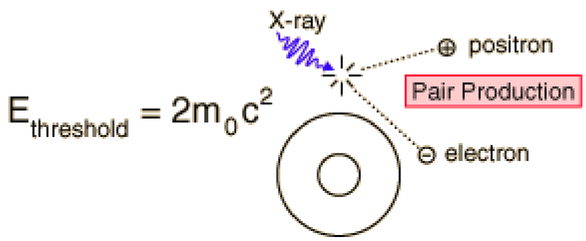
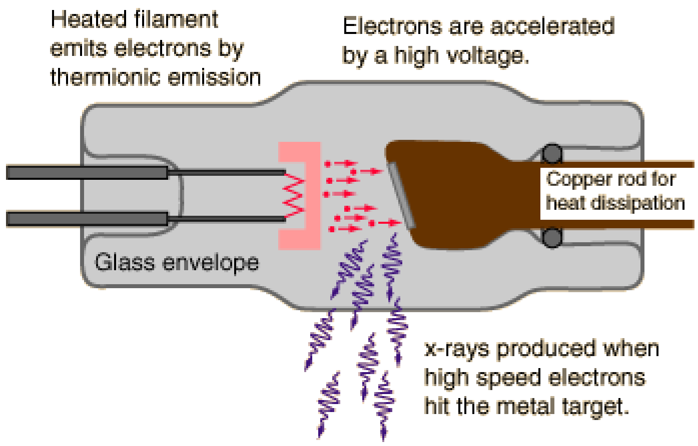
Pair Production

Every known particle has an antiparticle; if they encounter one another, they will annihilate with the production of two gamma-rays. The quantum energies of the gamma rays is equal to the sum of the mass energies of the two particles (including their kinetic energies). It is also possible for a photon to give up its quantum energy to the formation of a particle-antiparticle pair in its interaction with matter.

The rest mass energy of an electron is 0.511 MeV, so the threshold for electron-positron pair production is 1.02 MeV. For x-ray and gamma-ray energies well above 1 MeV, this pair production becomes one of the most important kinds of interactions with matter. At even higher energies, many types of particle-antiparticle pairs are produced.



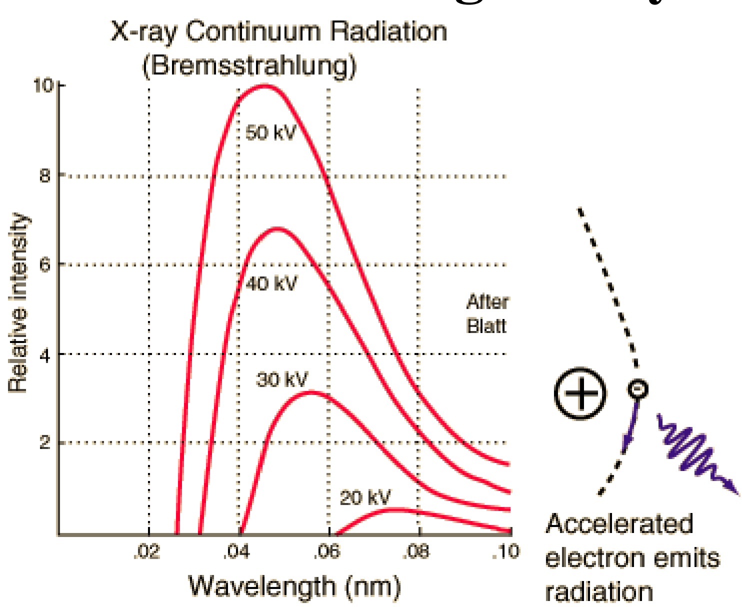
X-ray Tube



X-rays for medical diagnostic procedures or for research purposes are produced in a standard way: by accelerating electrons with a high voltage and allowing them to collide with a metal target. X-rays are produced when the electrons are suddenly decelerated upon collision with the metal target; these x-rays are commonly called brehmsstrahlung or "braking radiation". If the bombarding electrons have sufficient energy, they can knock an electron out of an inner shell of the target metal atoms. Then electrons from higher states drop down to fill the vacancy, emitting x-ray photons with precise energies determined by the electron energy levels. These x-rays are called characteristic x-rays.

Characteristic x-rays	Brehmsstrahlung

Bremsstrahlung X-Rays



"Bremsstrahlung" means "braking radiation" and is retained from the original German to describe the radiation which is emitted when electrons are decelerated or "braked" when they are fired at a metal target. Accelerated charges give off electromagnetic radiation, and when the energy of the bombarding electrons is high enough, that radiation is in the x-ray region of the electromagnetic spectrum. It is characterized by a continuous distribution of radiation which becomes more intense and shifts toward higher frequencies when the energy of the bombarding electrons is increased. The curves above are from the 1918 data of Ulrey, who bombarded tungsten targets with electrons of four different energies.

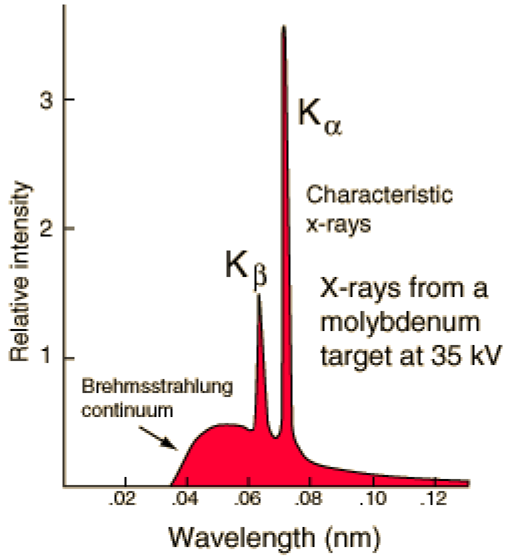
$$eV = hf$$

$$eV = h\left(\frac{c}{\lambda}\right)$$

$$\lambda = \frac{hc}{eV}$$

Wavelength of X-ray

Characteristic X-Rays



Characteristic x-rays are emitted from heavy elements when their electrons make transitions between the lower atomic energy levels. The characteristic x-rays emission which shown as two sharp peaks in the illustration at left occur when vacancies are produced in the n=1 or K-shell of the atom and electrons drop down from above to fill the gap. The x-rays produced by transitions from the n=2 to n=1 levels are called K-alpha x-rays, and those for the n=3->1 transiton are called K-beta x-rays.

Transitions to the n=2 or L-shell are designated as L x-rays (n=3->2 is L-alpha, n=4->2 is L-beta, etc.). The continuous distribution of x-rays which forms the base for the two sharp peaks at left is called "bremsstrahlung" radiation.

X-ray production typically involves bombarding a metal target in an x-ray tube with high speed electrons which have been accelerated by tens to hundreds of kilovolts of potential. The bombarding electrons can eject electrons from the inner shells of the atoms of the metal target. Those vacancies will be quickly filled by electrons dropping down from higher levels, emitting x-rays with sharply defined frequencies associated with the difference between the atomic energy levels of the target atoms.

The frequencies of the characteristic x-rays can be predicted from the Bohr model . Moseley measured the frequencies of the characteristic x-rays from a large fraction of the elements of the periodic table and produces a plot of them which is now called a "Moseley plot".

Characteristic x-rays are used for the investigation of crystal structure by x-ray diffraction. Crystal lattice dimensions may be determined with the use of Bragg's law in a Bragg spectrometer.