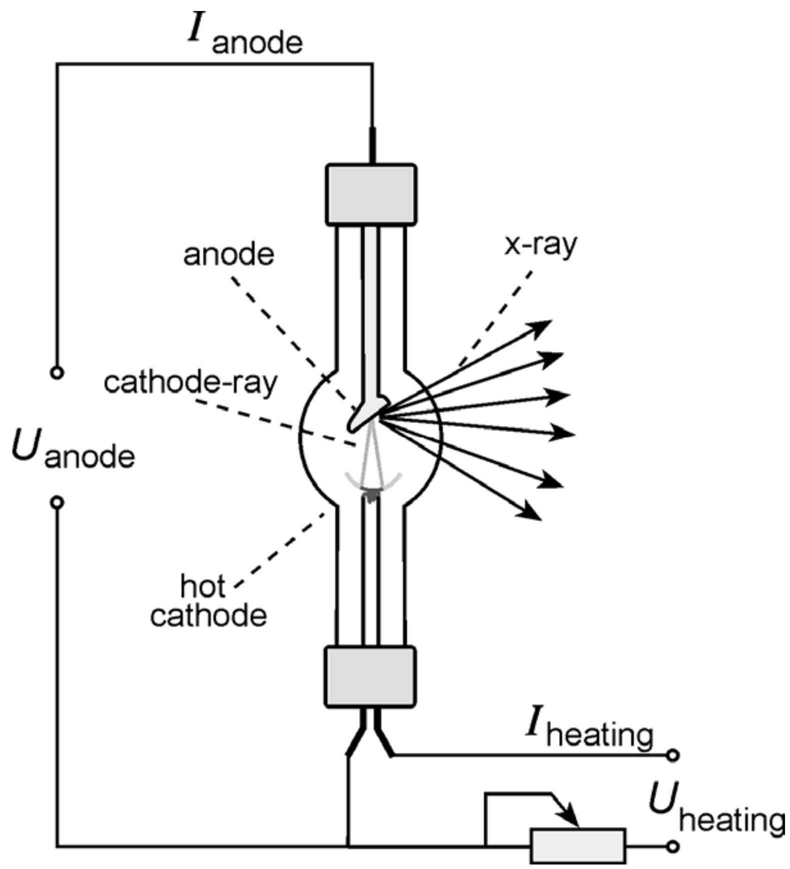
X-ray, X-ray tube



Braking radiation or

Bremsstrahlung

Typically

10 keV –200 keV

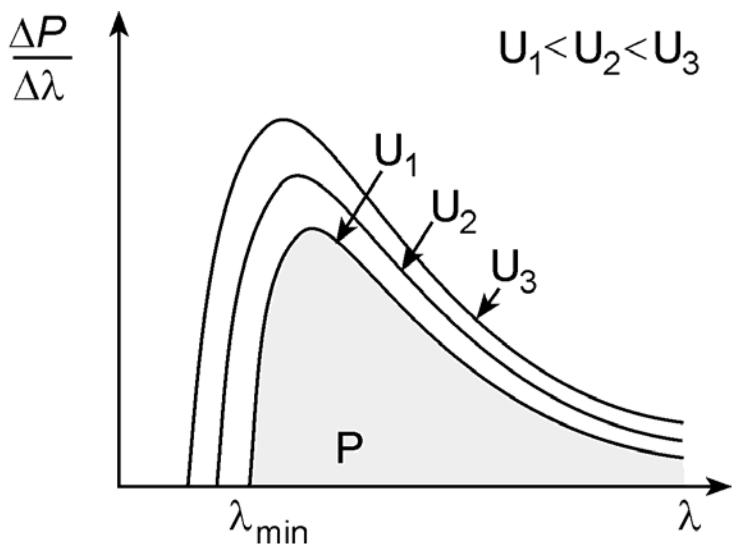
(up to 10 MeV)

Continuous spectrum:

$$e \cdot U_{\text{anode}} = hf_{\max}$$

$$f_{\max} = \frac{c}{\lambda_{\min}}$$

$$\lambda_{\min} = \frac{hc}{eU_{\text{anode}}}$$



Total power of braking radiation is:

$$P_{\text{total}} = C_{\text{Rtg}} \cdot U_{\text{anode}}^2 \cdot Z \cdot I_{\text{anode}}$$

C_{Rtg} is a proportionality factor with a value $C_{Rtg} = 1.1\times10^{-9}\ \text{V}^{-1}$

Z is the atomic number of the anode

Efficiency that characterizes the radiation produced in X-ray tube can also be given.

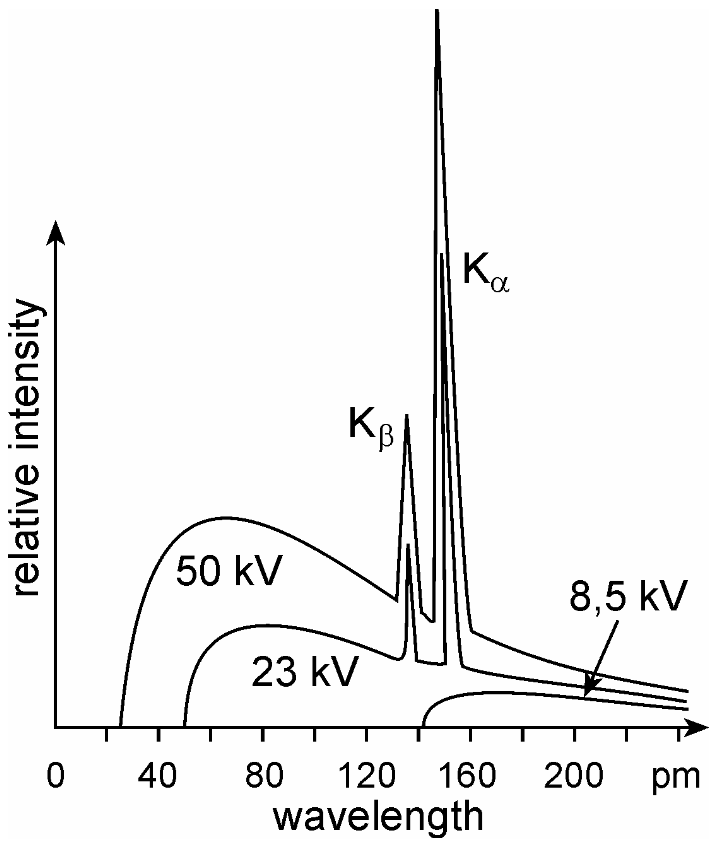
$$\eta = \frac{P_{\text{emitted}}}{P_{\text{invested}}} = \frac{C_{\text{Rtg}} \cdot I_{\text{anode}} \cdot U_{\text{anode}}^{2} \cdot Z}{I_{\text{anode}} \cdot U_{\text{anode}}} = C_{\text{Rtg}} \cdot U_{\text{anode}} \cdot Z.$$

As a general rule it can be stated that inside the anode the energy transferred by electrons transforms to heat therefore X-ray tubes produce X-ray radiation with low efficiency. In case of a tungsten anode and 100 kV accelerating potential $\eta = 0{,}008 < 1\%$.

Characteristic X-ray

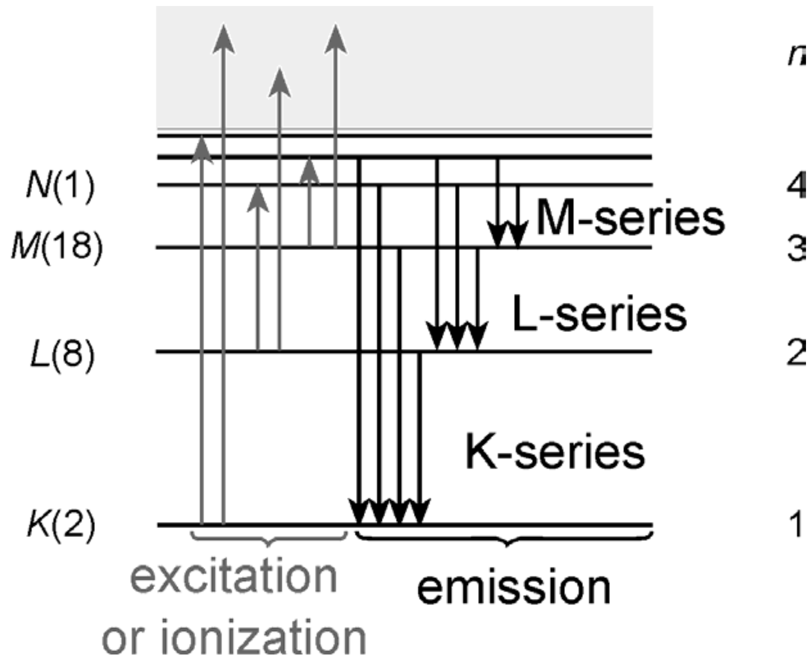
Characteristic radiation consisting of **emission lines** that are characteristic of the **material of the anode** (superimposed to the continuous spectrum).

Characteristic lines can only be experienced **above** a definite accelerating **voltage**



Explanation

Line-emission spectra originates from the **transitions between discrete electronic states**.



Electronic orbital energies of Cu-atom with principal quantum numbers of n=1,2,3… on a relative energy scale (K, L, M…etc. are used, respectively).

In case electrons enter from the neighboring shell, *α*, in case they enter from the second level in accordance with the electron extruded, *β* subscripts indicate the process in detail.
In case of shell *K*, for example, we talk about ***Kα*** and K_β characteristic rays between the transitions ending on the shell.

Characteristic X-ray radiation is induced when the **kinetic energy of the bombarding electrons is commensurable with the binding energy** of the electrons revolving on the inner shells, and as a consequence of their interaction **one of the inner electrons drops out of the atomic bond**.

Absorption of X-ray

The absorption of X-ray radiation is described by the general exponential radiation attenuation law:

$$J = J_0 \cdot e^{-\mu x}.$$

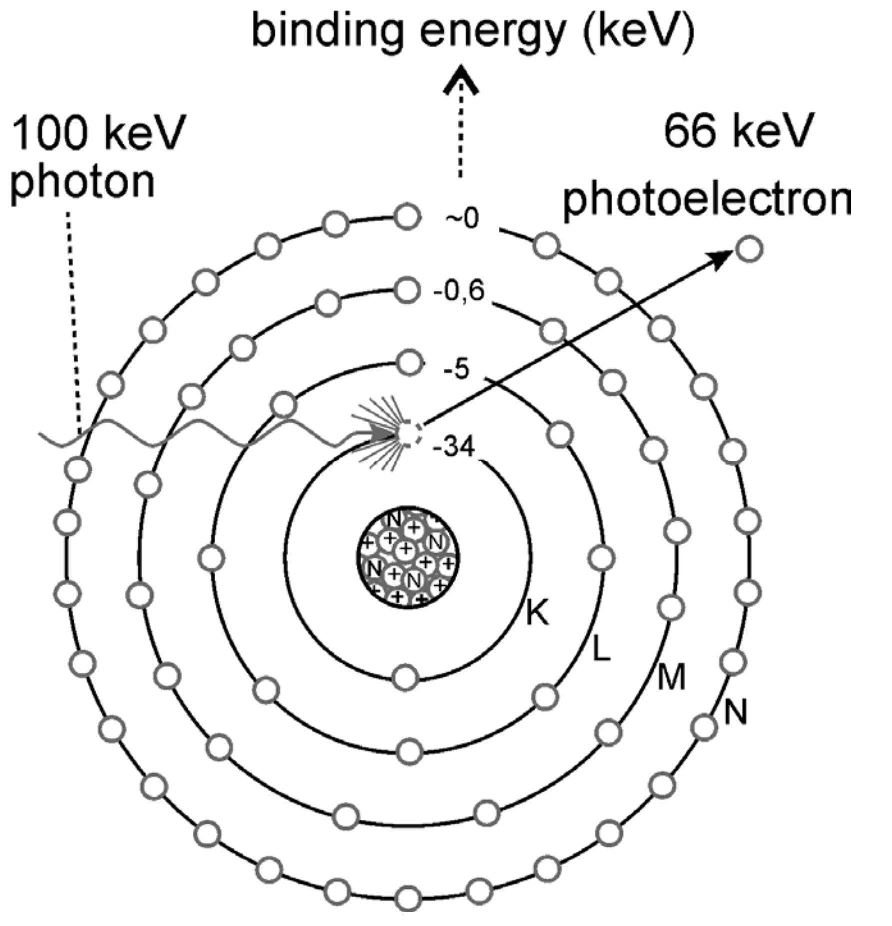
$$\mu = \mu_{\mathrm{m}} \cdot \rho$$

where ρ is the mass density (defined as a multiplying factor), and μ_m is the mass attenuation coefficient expressed in cm^2/g which therefore contains the dependence on the photonenergy of the radiation and the quality of the matter.

Interactions leading to absorption of X-ray

Ionizing radiations, i.e. it generates primary and secondary energy transfer mechanisms and charged particles (high energy free electrons).

In X-ray diagnostic the primary process of absorption is the **photo(electric)-effect** (10-200keV).



In such cases the X-ray photon transfers its total energy to an electron located on one of the inner shells resulting in subsequent ejection of the electron.

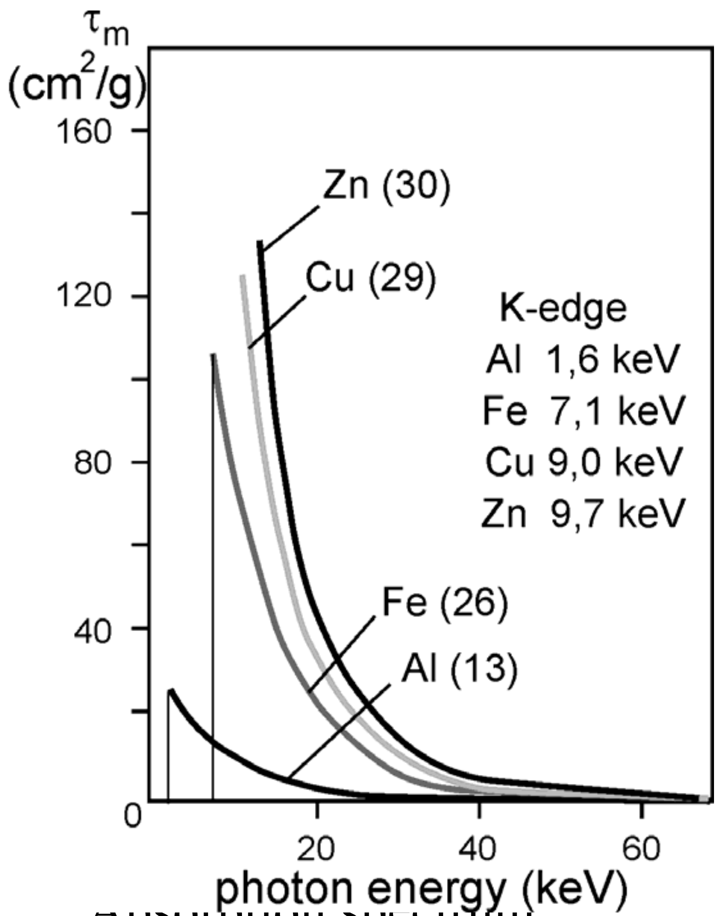
$$hf = \varepsilon = E_{\text{bind}} + E_{\text{kin}}$$

Instead of μ the use of τ is more common for the attenuation coefficient of photo-effect.

$$\tau = \tau_{\text{m}} \cdot \rho$$

$$\tau_m = C \cdot \lambda^3 \cdot Z^3$$

Where the value of C is 5,5-6,5 $cm^2/g\ nm^3$



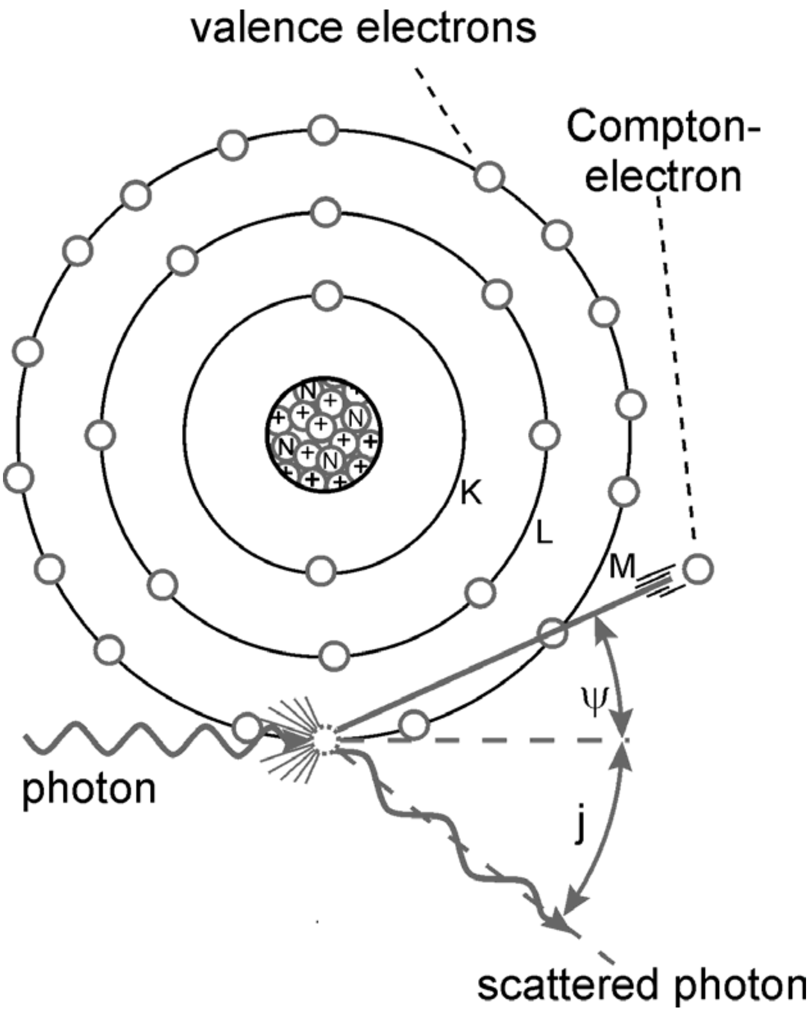
Absorption spectrum

“Soft” and “hard” radiation

Contrast materials

Compton-effect

photon only transfers a certain amount of its total *hf* energy to the electron. The photon with its residual *hf'* energy moves on with a φ angle to its original direction i.e. the incident photon no longer exists but it is rather replaced by a scattered photon with a much lower energy *hf'*.



$$hf = \varepsilon = E_{\mathrm{bind}} + E_{\mathrm{kin}} + hf'$$

The decrease of ray-intensity caused by this phenomenon, also named Compton-scattering and is described by the $\sigma = \sigma_m \cdot \rho$ absorption coefficient. Considering the decrease in intensity as results of photo effect and Compton-effect as two independent events, the attenuation coefficients of the two different phenomena are summed up.

$$\mu = \tau + \sigma$$