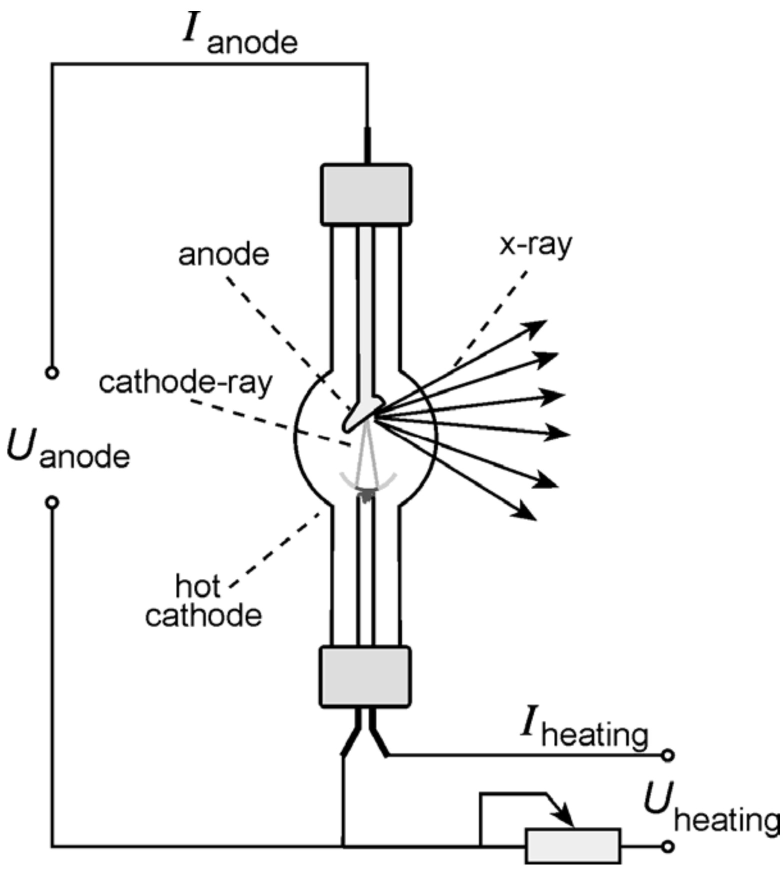
X-ray, X-ray tube



Braking radiation or

Bremsstrahlung

Typically

10 keV –200 keV

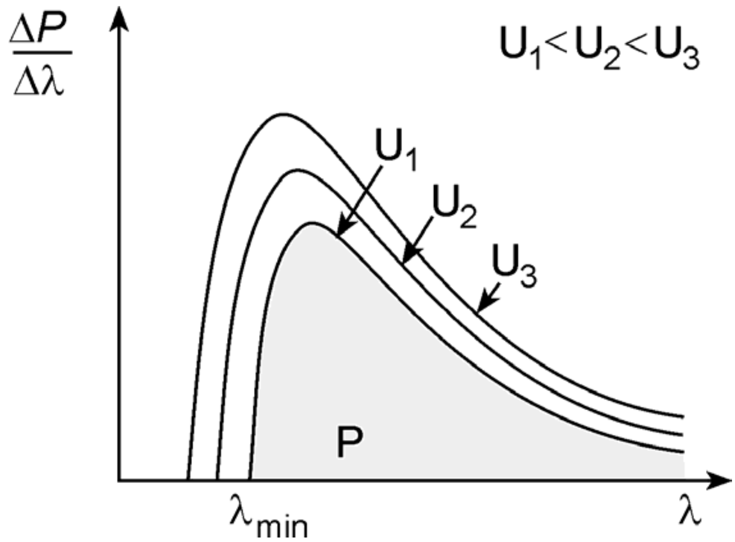
(up to 10 MeV)

Continuous spectrum:

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

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

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



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 $C_{Rtg} = 1.1 \times 10^{-9}\ \text{V}^{-1}$

Z is the atomic number of the anode

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

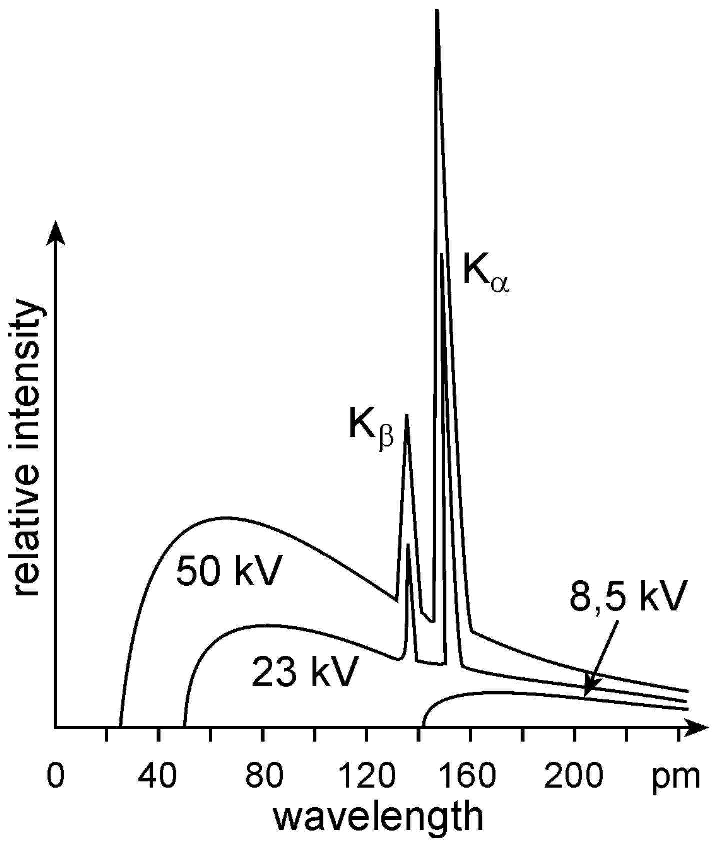
$$\eta = \frac{P_{\text{emitted}}}{P_{\text{invested}}} = \frac{C_{\text{Rtg}} \cdot I_{\text{anode}} \cdot U_{\text{anode}}^{\ 2} \cdot Z}{I_{\text{anode}} \cdot U_{\text{anode}}} = C_{\text{Rtg}} \cdot U_{\text{anode}} \cdot Z.$$

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

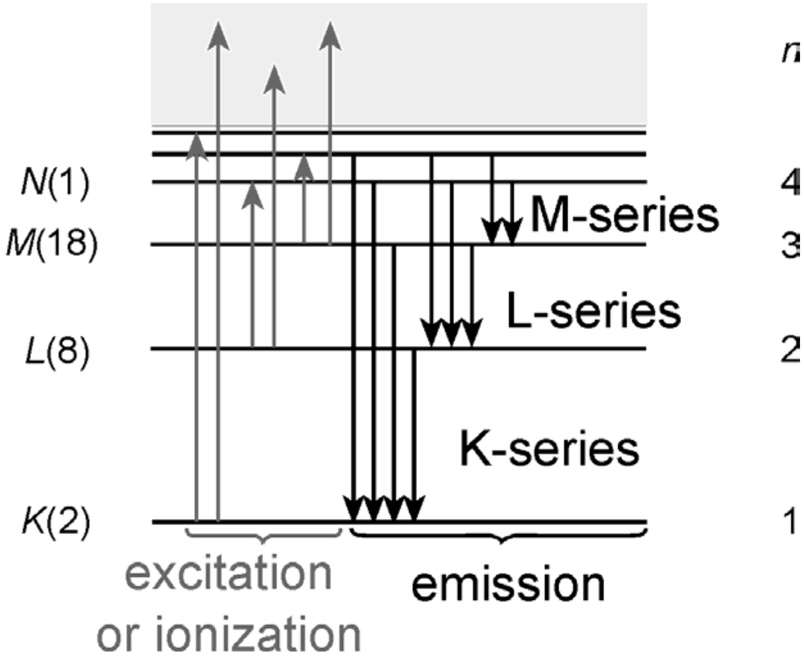
Characteristic radiation consisting of **emission lines** that are characteristic of the **material of the anode** (superimposed to the continuous spectrum).

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 $\boldsymbol{K\alpha}$ and $\boldsymbol{K_\beta}$ 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:

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

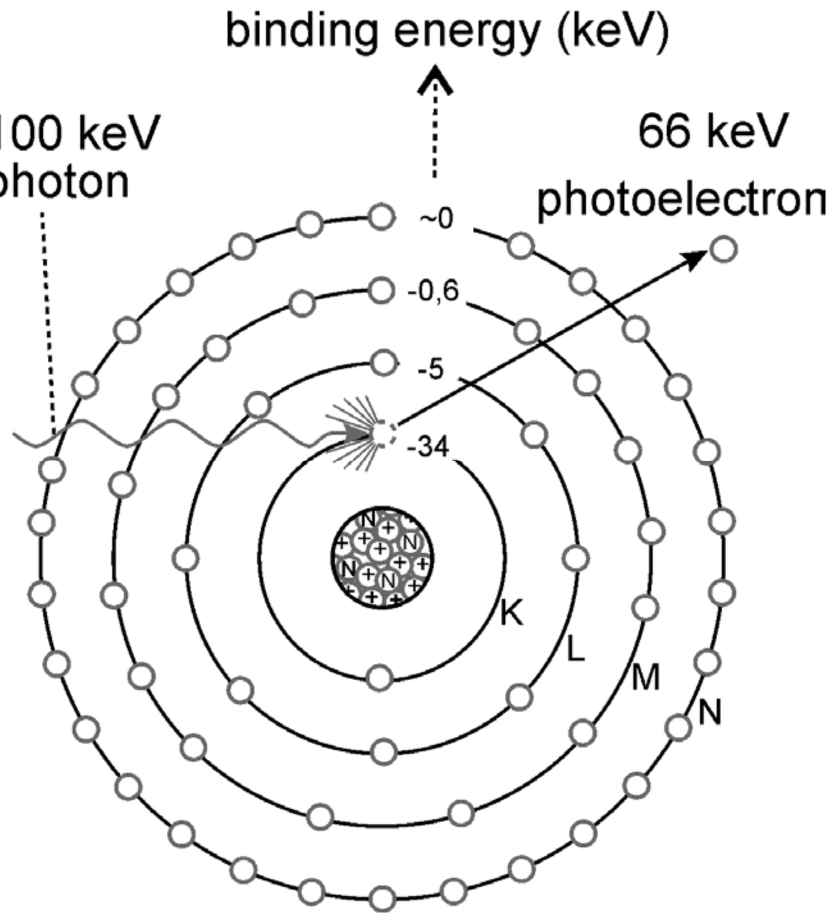
$$\mu = \mu_{\mathrm{m}} \cdot \rho$$

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.

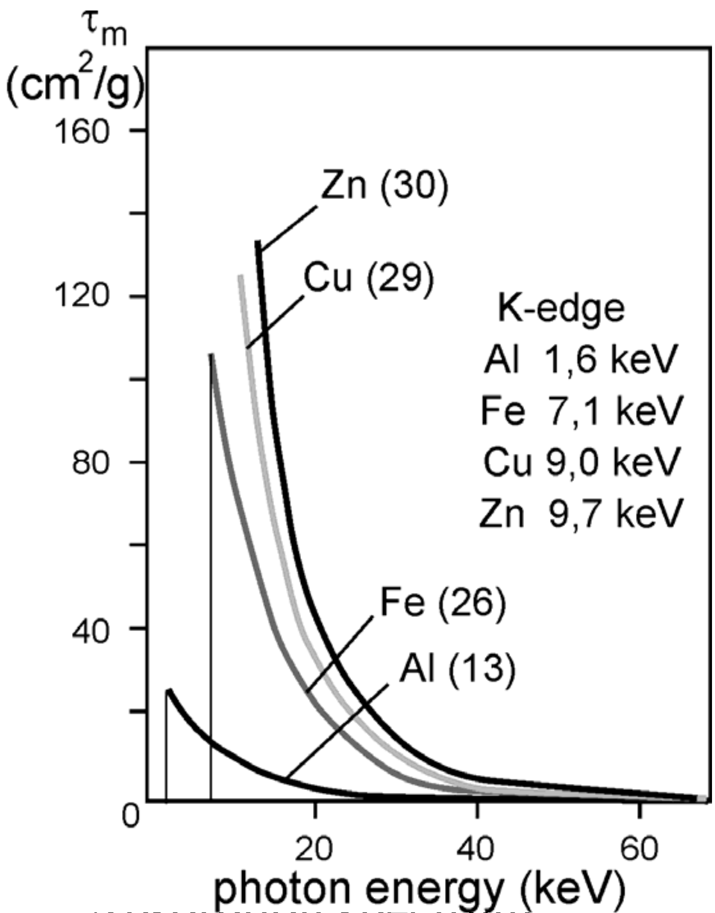
$$hf = \varepsilon = E_{\text{bind}} + E_{\text{kin}}$$

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 $cm^2/g\ nm^3$



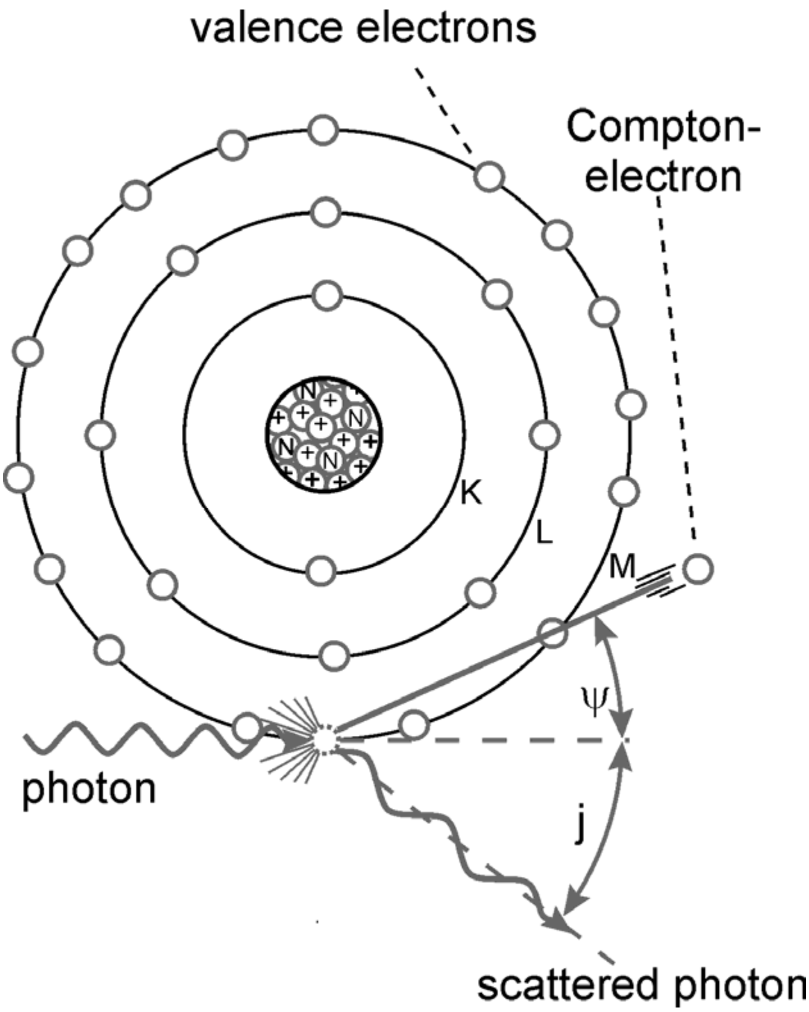
Absorption spectrum

“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'*.



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

The decrease of ray-intensity caused by this phenomenon, also named Compton-scattering and is described by the $\sigma = \sigma_{\text{m}} \cdot \rho$ 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.

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