



X-radiation and its interaction with matter

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Outline



- Discovery of X-rays
- What is X-ray?
- Production of X-ray
- Bremsstrahlung and characteristic X-ray
- Interaction of X-ray with the matter
- Bases of X-ray diagnostics



Warning: This presentation on its own is not enough to learn this topic!

Textbook chapter: II/3.1.

Related practices: X-ray, CAT Scan (2nd semester)

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Discovery of X-rays



Wilhelm Conrad Röntgen
1845-1923
Nobel prize: 1901



Crookes tube



„Hand mit Ringen“
22 Dec 1895

What is X-radiation?

A form of electromagnetic waves.

X-rays

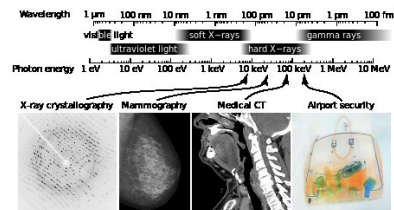
$f = 10^{15} - 10^{18}$ Hz (penta-exahertz)

$\lambda = 10 \text{ nm} - 0.01 \text{ nm}$

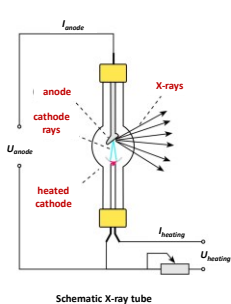
$\epsilon = 100 \text{ eV} - 100 \text{ keV}$ (-MeV)

(diagnostic: up to 200 keV; therapeutic: approx. 10 MeV)

$$\epsilon = h \cdot f = h \cdot \frac{c}{\lambda}$$



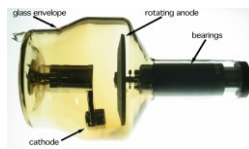
Production of X-ray



Schematic X-ray tube



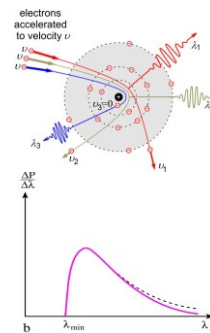
X-ray tube from the 1930-s.



X-ray tube with rotating anode

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Bremsstrahlung: „braking radiation“



$$\left. \begin{aligned} \epsilon_{kin} &= e \cdot U_{anode} \\ \epsilon_{max} &= h \cdot \frac{c}{\lambda_{min}} \end{aligned} \right\}$$

Duane-Hunt law:

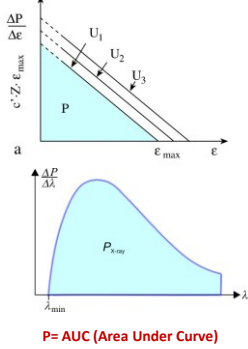
$$\lambda_{min} = \frac{h \cdot c}{e \cdot U_{anode}}$$

$$\lambda_{min} = \frac{k}{U_{anode}}$$

$$(k = 1230 \text{ pm} \cdot \text{kV})$$

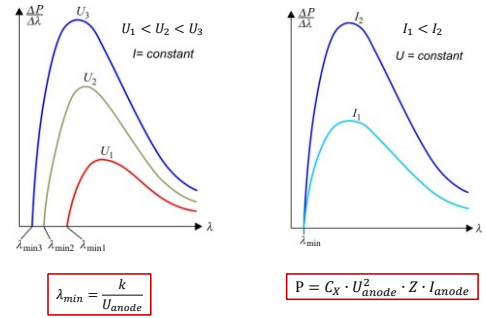
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Bremsstrahlung

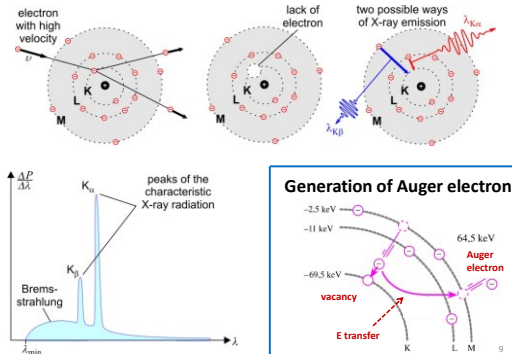


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Bremsstrahlung – characteristic spectral changes

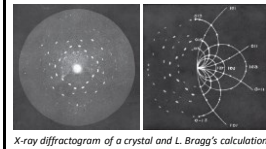
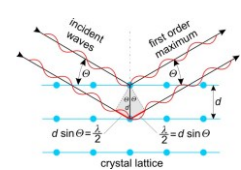
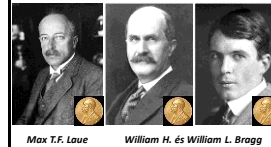


Characteristic X-radiation



Interaction of X-ray with the matter I.

X-ray diffraction (Bragg-diffraction)



Bragg formula:

$$2d \cdot \sin \theta = n \cdot \lambda$$

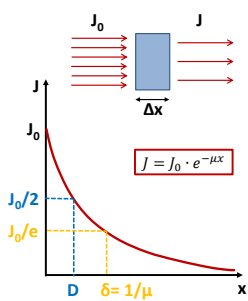
Application:

- spectrum measurement
- crystallography

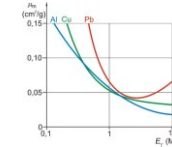
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Interaction of X-ray with the matter II.

Absorption – general rules



Strong dependence on absorbent's Z and E_{photon} :



Mass attenuation coefficient:

$$\mu_m = \frac{\mu}{\rho} \quad [cm^2 \cdot g^{-1}]$$

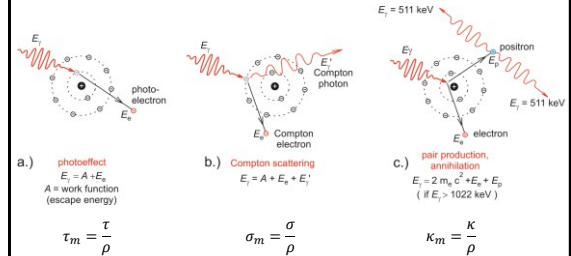
Mechanisms at atomic scale:

- Photoeffect
 - Compton scattering
 - (Pair production)
- $\mu = \tau + \sigma + \kappa$

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Interaction of X-ray with the matter III.



Atomic scale absorption processes



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Bases of X-ray diagnostics

- Shadow image.
- Based on absorption.
- Summation image: 2D representation. (except for 3D reconstructions in tomography)

$$J = J_0 \cdot e^{-\mu_m \cdot \rho \cdot x}$$

μ_m mass attenuation coeff. ρ density

$$\mu_m = \tau_m + \sigma_m$$

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

medium	Z_{eff}	ρ [g/cm ³]
air	7.3	$1.3 \cdot 10^{-3}$
water	7.7	1
soft tissue	7.4	1
bone	13.8	1.7-2

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Bases of X-ray diagnostics

Absorption in tissues

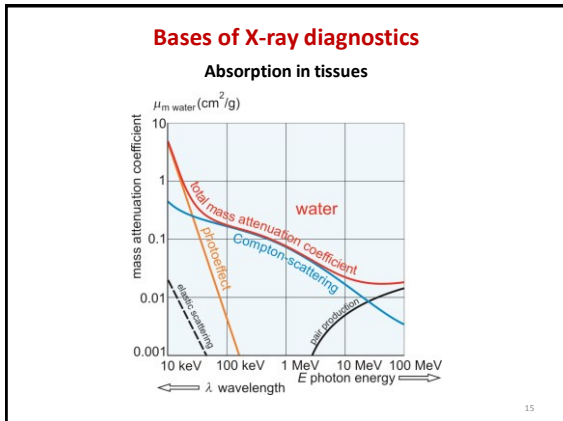
ABSORPTION PROCESS	μ_m as a function of the atomic number Z	μ_m as a function of the photon energy E
elastic scattering	$\mu_m \sim Z^2$	$\mu_m \sim 1/E^2 \sim \lambda^2$
photoeffect	$\mu_m \sim Z^3$	$\mu_m \sim 1/E^3 \sim \lambda^3$
Compton scattering	does not depend	decreasing slightly

- Contrast between soft tissues and bone : mainly photoeffect.
- Contrast inside soft tissues: mainly Compton scattering.
- Importance of „soft“ and „hard“ radiation.

Effective atomic number of a tissue:

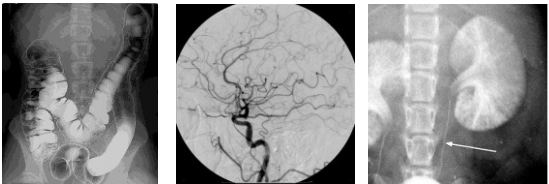
$$Z_{eff} = \sqrt[3]{\sum_{i=1}^n w_i \cdot Z_i^3}$$

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Bases of X-ray diagnostics

Contrast agents



double contrast: BaSO₄ + air cerebral angiography with KI contrast gold nanoparticles in the kidney

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