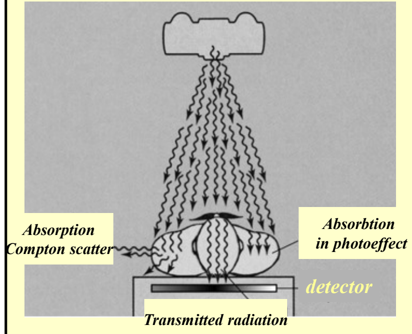
Medical applications of X-rays

X-ray diagnostics and imaging

Diagnostic radiology

Basic principle of X-ray diagnostic is the absorption of radiation

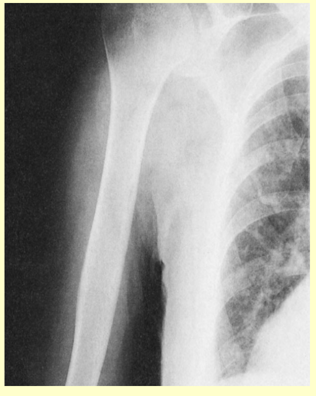


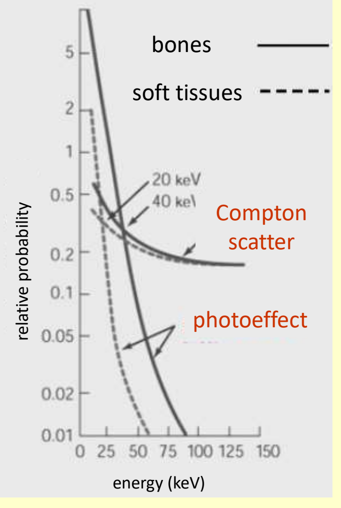
Possible interactions:

Compton scatter

photoeffect

no interaction





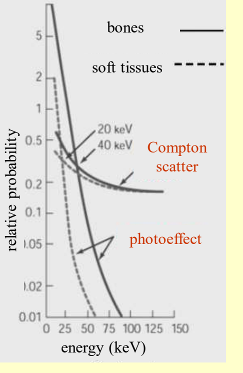
Attenuation decreases with increasing photon energy.

The decrease is more pronounced in the case of photoeffect.

At lower photon energies τ_m is dominant.

τ_m strongly depends on the atomic number.

$$\tau_m \approx \lambda^3 Z^3$$



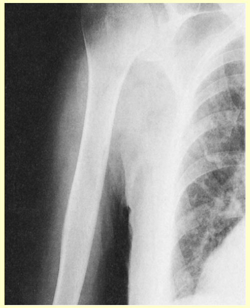
Spectral changes of radiation drastically modify the attenuation processes.

Effective atomic number

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

$$\tau_m = C\lambda^3 Z_{eff}^3$$

matter	Z_{eff}
air	7,3
water	7,7
soft tissue	7,4
bone	13,8



Summary of attenuation mechanisms

	Variation with E	Variation with Z	Energy range in tissues
τ_m	$\sim 1/E^3$	$\sim Z^3$	10 – 100 keV
σ_m	Slightly falls with E	linear	0.5 – 5 MeV
κ_m	Rises slowly with E	$\sim Z^2$	>5 MeV

Main contrast mechanism in diagnostic X-ray: photoeffect ($\sim Z^3$)

Production of X-ray image

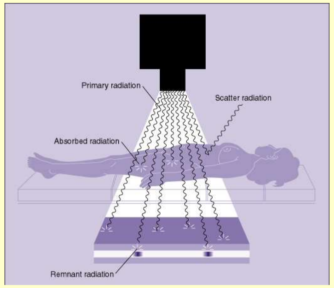
Representation of variations in attenuated intensity

- in radiation sensitive film
- on luminescent screen
- in digitized image

scalp

chest

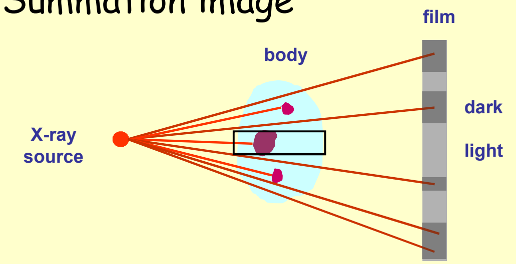
Summation image



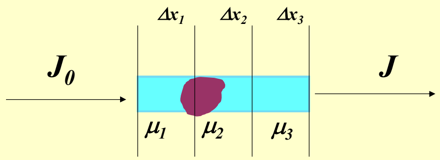
"X-ray image"
or
"radiographic image"

Contrast arises due to relative attenuation

Summation image



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



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

$$J = J_0 e^{-(\mu_1 + \mu_2 + \mu_3)\Delta x}$$

no information about details

Radiographic contrast

If the differences between

$$\tau_m = C\lambda^3 Z_{eff}^3$$

or

densities

of neighboring tissues are not sufficient

alteration of Z_{eff} or density

	Z_{eff}	ρ (g/cm³)
H_2O	7.7	1
soft tissies	7.4	1
bones	13.8	1.7 - 2.0
air	7.3	1.29 x10⁻³

$$\tau_m = C\lambda^3 Z_{eff}^3$$

Positive contrast $\rightarrow$ ***increased attenuation***

$Z_{eff\ contrast} > Z_{surrounding}$

$\mu_{contrast} > \mu_{surrounding}$

$\mu_{m\ contrast} > \mu_{m surrounding}$

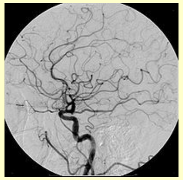
Negative contrast $\rightarrow$ ***decreased attenuation***

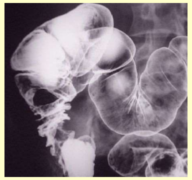
$Z_{eff\ contrast} < Z_{surrounding}$

$\mu_{contrast} < \mu_{surrounding}$

Positive contrast

increased Z_{eff}

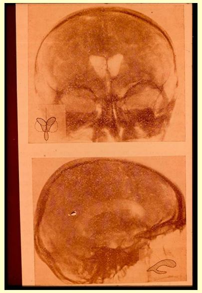




E.g., ^{53}I- or ^{56}Ba-compounds

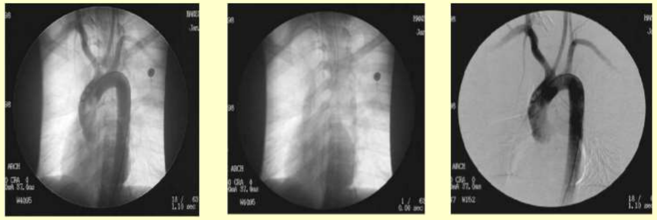
Negative contrast

$\rho_{contrast} < \rho_{surrounding}$



air, CO_2

Digital Subtraction Angiography (DSA)

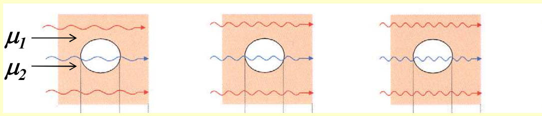


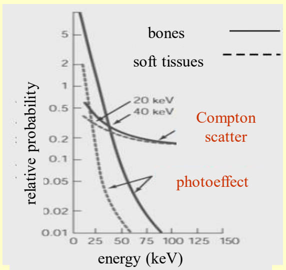
contrast *native* *contrast - native*

images

Photon energy and image quality

$U_1 < U_2 < U_3$

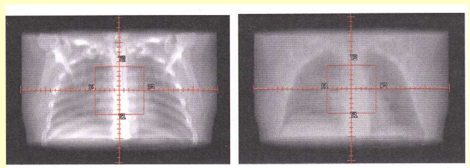




Photon energy and image quality

$U_1 < U_2$

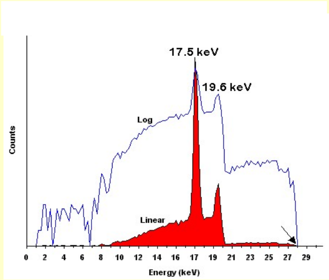
(30 keV) (2 MeV)



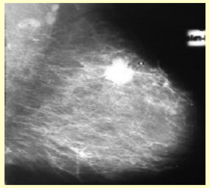
	U_1 (30 keV)	U_2 (2 MeV)
Photo effect	*36%*	*0%*
Compton scatter	*51%*	*99%*
Pair production	*0%*	*1%*

Average values

Typical spectrum used in mammography

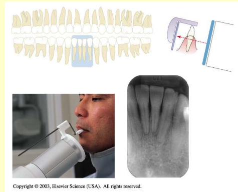


Characteristic lines of Molybdenum

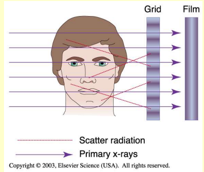


Malignant tissue in a mammogram

Intra-oral radiography

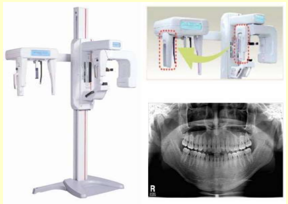


Extra-oral radiography



Dental panoramic radiography

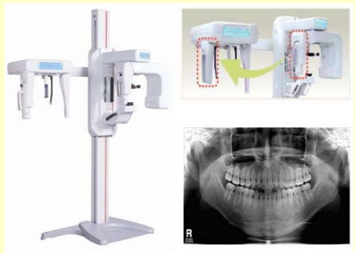
The equipment consists of a horizontal rotating arm which holds an X-ray source and a moving film mechanism (carrying a film) arranged at opposed extremities.



overlapping individual images projected on the film

Dental panoramic radiography

overlapping individual images projected on the film



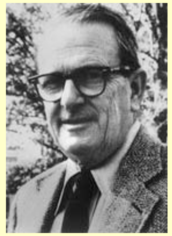
a composite picture of the maxillo-facial block is created

Limitations of conventional radiography

- **Superposition** – inability to resolve spatially structures along the X-ray propagation axis resulting in loss of depth information (flat picture), because the three-dimensional body is projected on to a two-dimensional receptor.
- Difficulty in **distinguishing** between homogenous objects of **non-uniform thickness**.
- In-ability to distinguish soft body tissue because of **limited contrast.**

X-Ray Transmission Computed Tomography

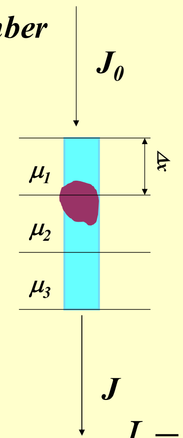
Godfrey Hounsfield

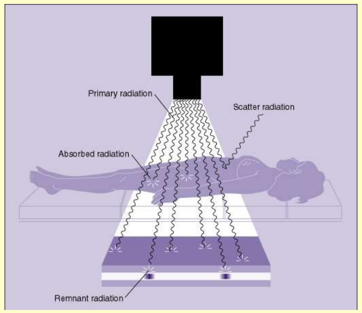


Allan Cormack

1979 Nobel-prize in Medicine

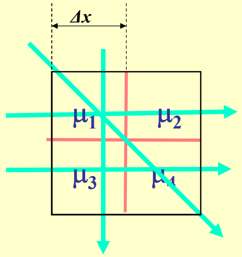
remember





$$J = J_0 e^{-(\mu_1 + \mu_2 + \mu_3)\Delta x}$$

Mathematical interpretation with a simple example



$$J = J_0 e^{-(\mu_1 + \mu_2)\Delta x}$$

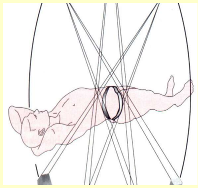
$$J = J_0 e^{-(\mu_3 + \mu_4)\Delta x}$$

$$J = J_0 e^{-(\mu_1 + \mu_4)\Delta x}$$

$$J = J_0 e^{-(\mu_1 + \mu_3)\Delta x}$$

4 independent equations, 4 unknowns

New – axial – arrangement



The 2D CT image corresponds to a 3D section of the patient

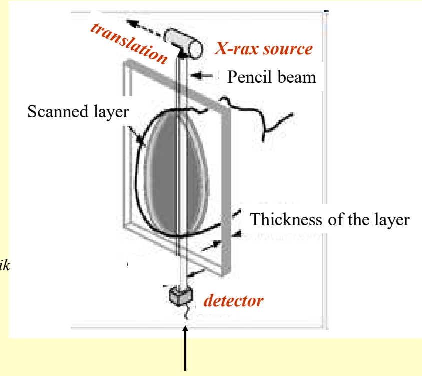
Computed tomography (CT) techniques allows sectional imaging .

Innovation of CT

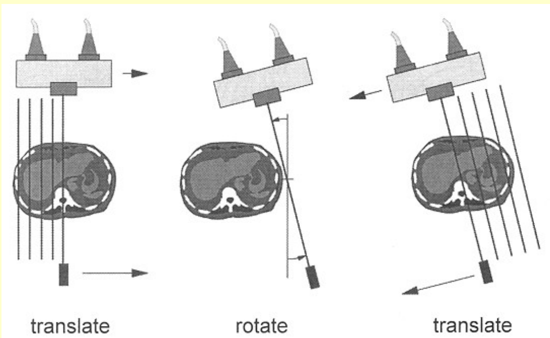
$$J_k = J_0 e^{-(\Sigma \mu_{ik})\Delta x}$$

μ_i**:** attenuation coefficient of volume element along the beam

$$\lg \frac{J_0}{J} = \lg e \Delta x \sum_{i=1}^{n} \mu_{ik}$$



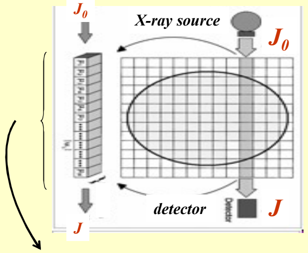
First generation CT



To store the multitude of images and process the data requires computer.

objekt

digital image



Voxel :
volume element

Pixel :
picture element

Each ***pixel*** on the CT image displays the average x-ray attenuation properties of the tissue in the corrsponding ***voxel.***

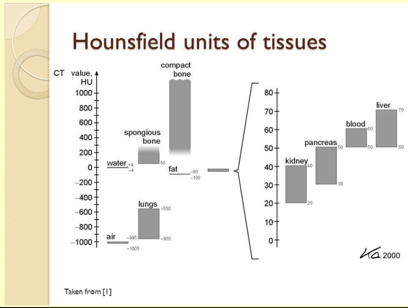
Reconstruction of the image

Density matrix

Hounsfield units

$$H_{CT} = 1000 \frac{\mu - \mu_{water}}{\mu_{water}}$$

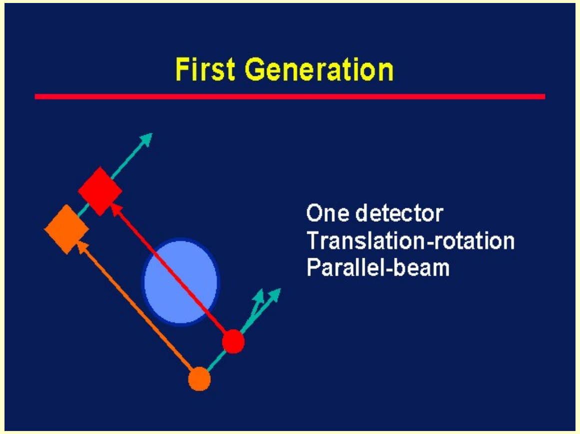
Hounsfield scale



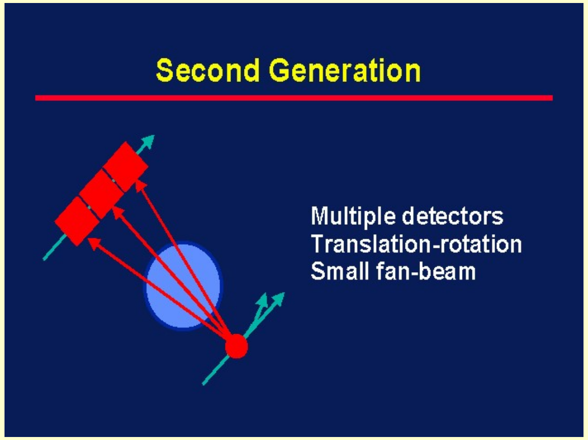
GOALS OF CT

- Minimal superimposition
- Image contrast improvement
- Small tissue difference recording

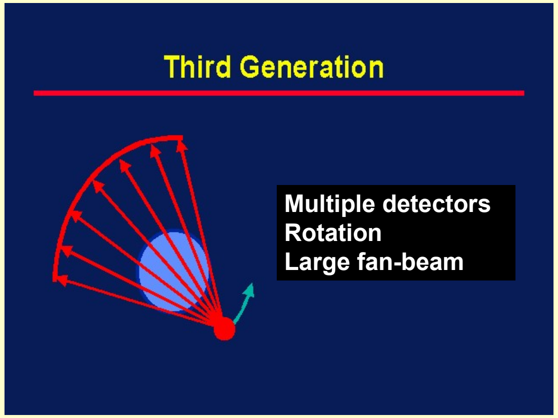
180 DEG ROTATION



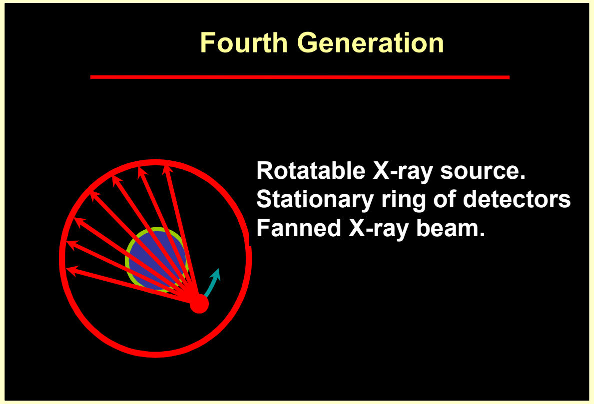
180 DEG ROTATION



360 DEG ROTATION



360 DEG ROTATION

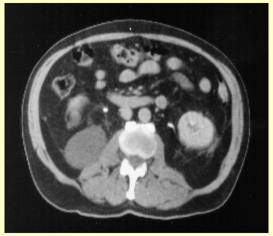


Early days vs Today

Second generation

5 minutes

Fourth generation



2 seconds

AXIAL SCAN

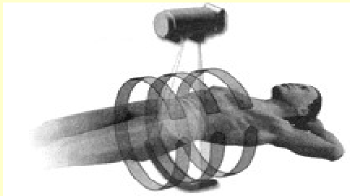
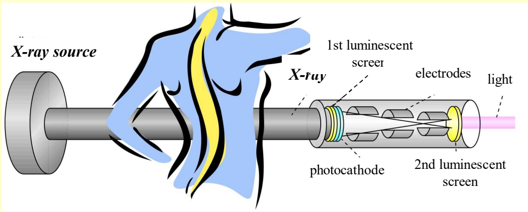


Table stops at the scanning position and the tube rotates around a patient.

Patient continuously moves in the Z-axis direction while the tube rotates around.

X-ray image intensifier



Possibility of image digitization

Smaller patient exposure

Manipulation under X-ray control

Checklist

Absorption of X-ray
Mass-attenuation coefficient
Basic concept of X-ray imaging
Optimal setting of X-ray tube
Summation image – role of the atomic number
Contrast materials
Panoramic X-ray
X-ray image amplifier
Concept of CT
Hounsfield unit
Generations of CT

Damjanovich, Fidy, Szöllősi: Medical Biophysics

VIII. 3.1
3.1.1
3.1.2
VIII.4.3