Physical bases of X-ray diagnostics

Dr. István Voszka

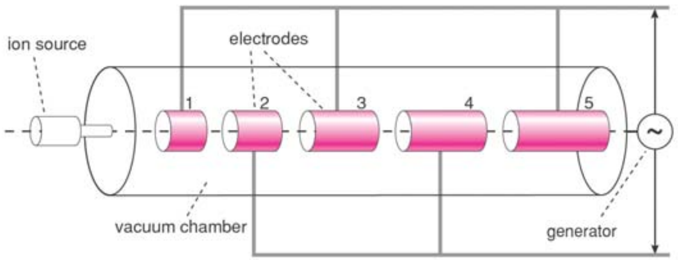
Possibilities of X-ray production
(X-ray is produced, when charged particles of high velocity are stopped)

X-ray tube: Relatively low accelerating voltage– low energy X-ray photons (until 1-200 keV) → diagnostic application

Accelerators: high photon energies can be achieved (MeV) → therapeutic application

Main types of accelerators: - linear accelerator
- cyclotron

Linear accelerator

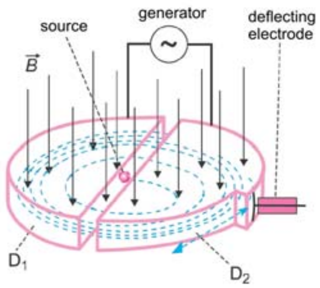


- The particle (electron, proton) is accelerated between the electrodes (but inside the electrode not).
- The velocity of particle increases, so the electrodes are longer in order to keep the synchron.
- X-radiation for therapeutic purposes is produced by the deceleration of accelerated electrons. (higher photon energy – higher penetration depth).

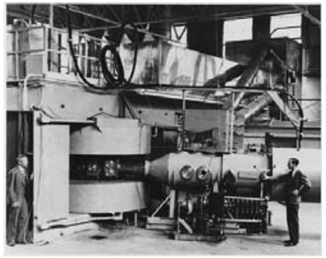
Hungarian National Institute of Oncology

Stanford University

Cyclotron



- Acceleration by electric field between the „dees" (D-shaped „chamber halves").
- The magnetic field perpendicular to the „dees" keeps the particles on circular path.
- The energy of particles can be increased only until a limit, because above this the synchron between the motion of particle and the frequency of electric field is lost. (Special equipment that keeps the synchron also at high energy is called synchrotron.)
- In medical practice cyclotron is used mainly for production of positron radiating isotopes.
- Very high energy X-ray photons are produced by synchrotron for research purposes.



Berkeley, 1939

France, 1937

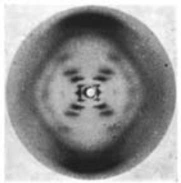
Medical cyclotron

Medical applications of X-rays

In diagnostic X-ray imaging Bremsstrahlung is applied.

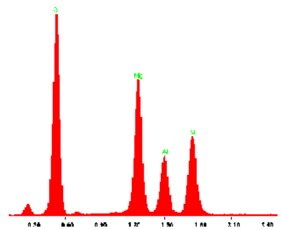
Applications of characteristic radiation:

- Bone densitometry
- Identification of material (e.g. toxic elements – Pb, As)
- Therapy
- Structure analysis (X-ray diffraction)



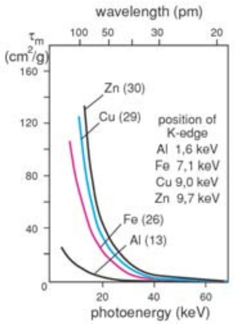
Bone densitometer

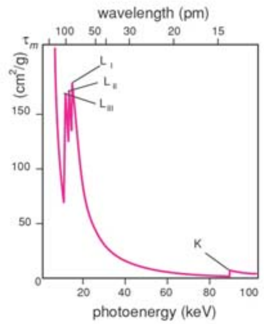
Identification of material



Practical consequences of X-ray absorption:
At low photon energy (diagnostic X- and γ-rays), in case of absorbents with higher atomic number (e.g. Pb, bone) mainly photoeffect.

For this: $\tau_m = c\,\lambda^3 Z^3$



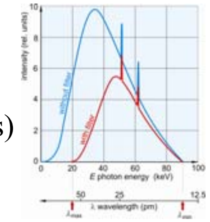


Absorption edges are appearing corresponding to electron transitions

In case of absorbents with lower effective atomic number (water, soft tissues) mainly Compton-effect ($Z_{eff,water} = 7{,}69$, $Z_{eff,air} = 7{,}3$)

For this: $\sigma_m \sim Z$

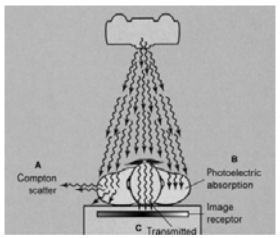
Practical consequences:
- Radiation protection with elements of high atomic number (Pb)
- Filters (Al) – the long wavelength („soft") components are filterd out, that do not take part in the image formation, only increase the radiation hazard.

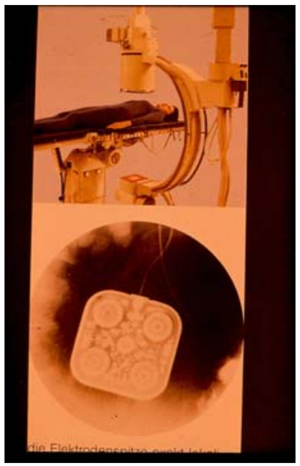


- X-ray diagnostics (contrast of image, contrast materials)

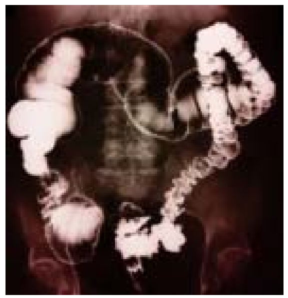
- therapy: - low photon energy - surface
  - high photon energy– deep

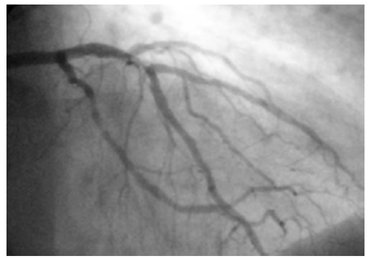
X-ray diagnostics
Summation image
- All the layers between X-ray source and the detctor or film take part in the absorption
- No information about the third dimension

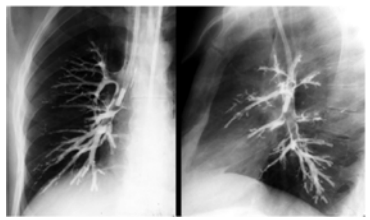




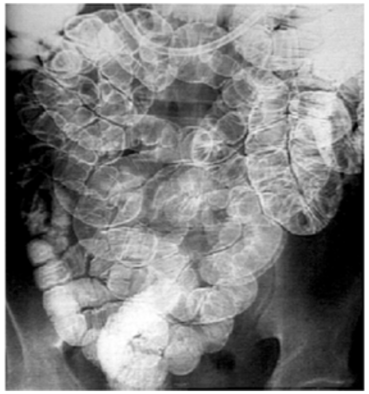
Application of contrast materials I.
-positive (absorbs better, than the environment – higher effective atomic number)
e.g.: $BaSO_4$ – in the gastrointestinal tract
iodine containing organic compounds – intravenously







Application of contrast materials II.
-negative and dual contrast
(negative contrast material: absorbs less, than its environment – lower density)
Gases, e.g. air, O_2, CO_2
Dual contrast: simultaneous application of positive and negative Contrast materials.



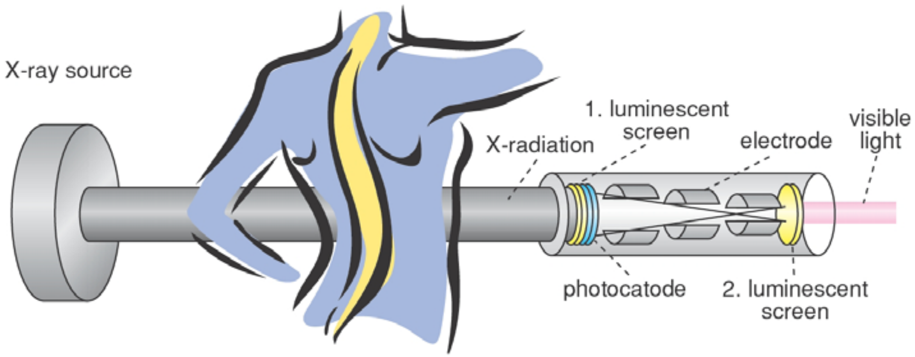
Digital subtraction angiography (DSA)

without contrast material

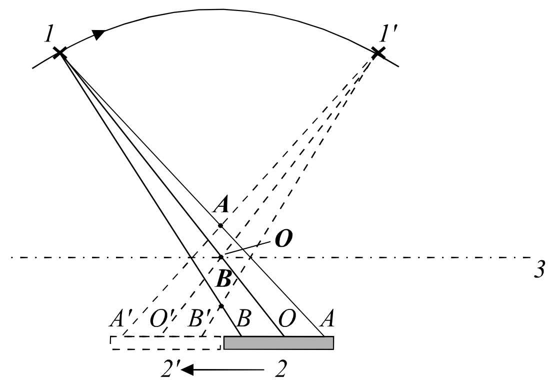
with contrast material

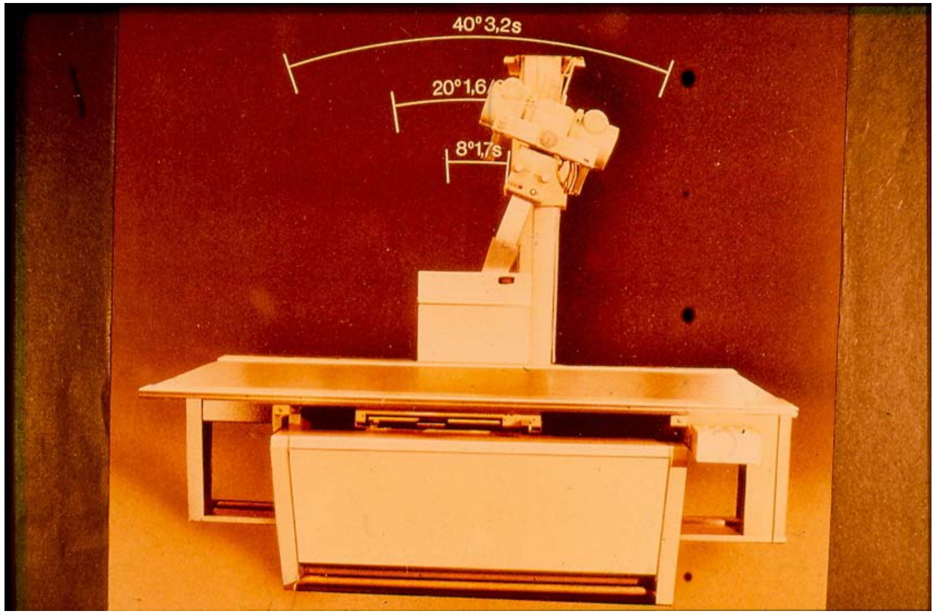
difference of them

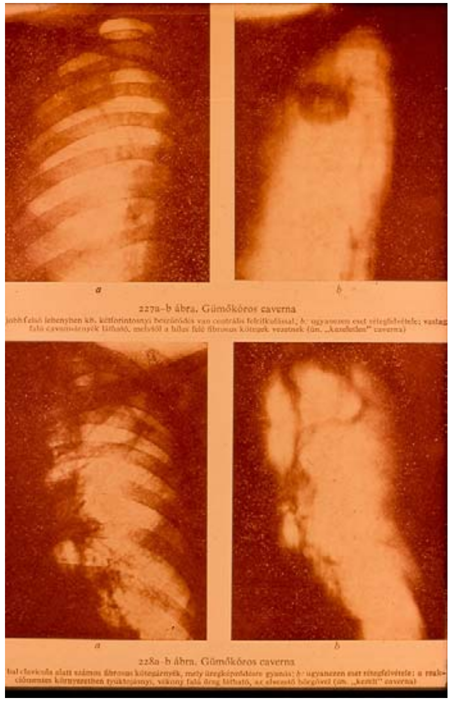
Electronic X-ray image amplifier
goal: better image quality and lower radiation exposure



Traditional tomography
- Sharp image is obtained from a layer parallel with the body axis, that contains the centre of the circular path. The image of layers above and below it will be blurred.
- It is applied in pulmonology to exclude the shadowing caused by the ribs.







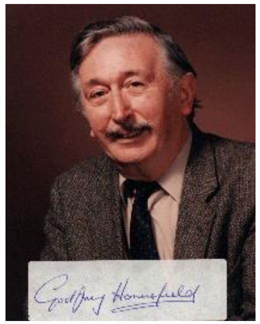
Special application of traditional tomography:
dental panoramic image

Computer assisted X-ray tomography (CAT-scan)

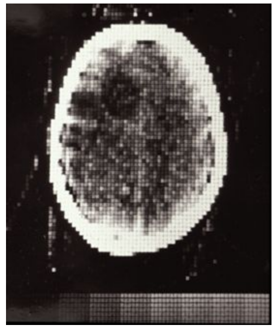
Cormack and Hounsfield –Nobel-prize in physiology or medicine 1979.

(The first CAT-scan was done in 1971.)

Allan M. Cormack
1924-1998



Godfrey N. Hounsfield
1919-2004

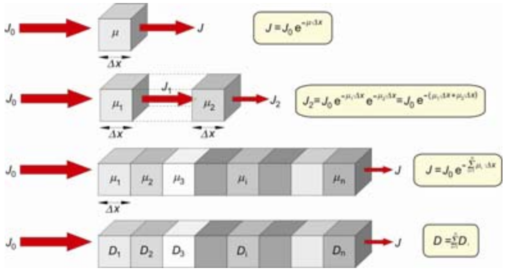


the first CAT-scan

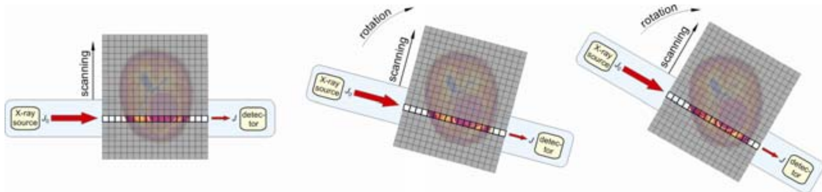
X-ray absorption CT

transillumination from many directions – the computer calculates the density of different elements of the examined body part.

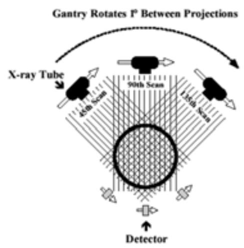
D = μ x lg e

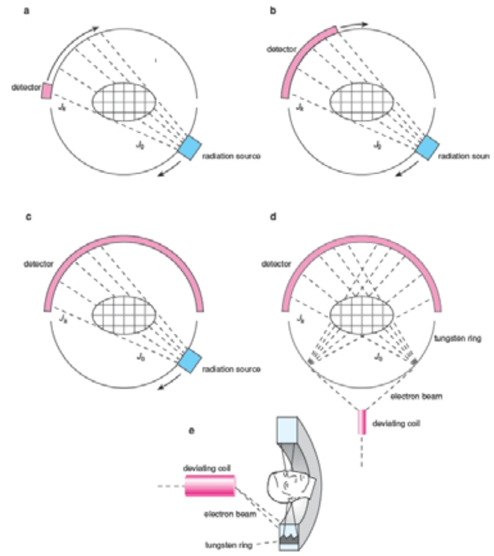


Cross-sectional images are obtained, but from the proper parts of images above each other section of any direction can be reconstructed.

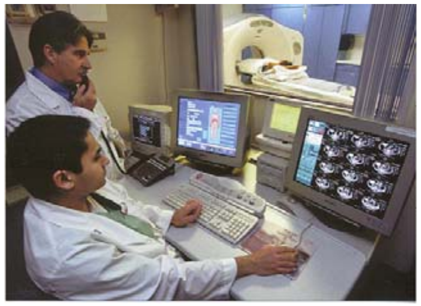


Generations of CAT scan



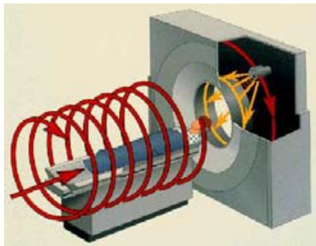


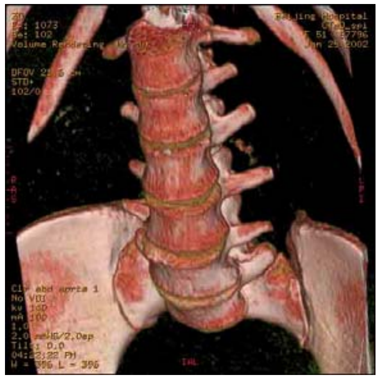
CT equipment



Spiral CT and 3D reconstruction

X-ray tube is rotated around the patient, while the patient is moved parallelly with the body axis.





Shoulder osteochondroma visualised by different methods

Summation X-ray image

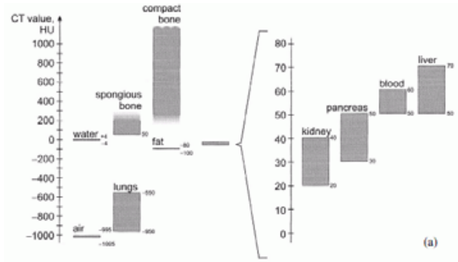
CAT scan

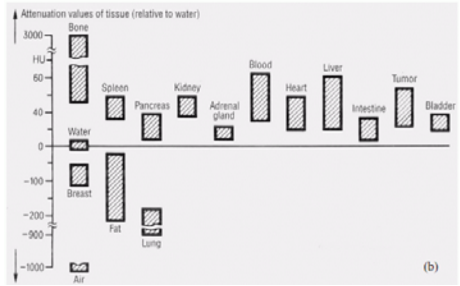
CAT scan 3D reconstruction

Hounsfield-scale

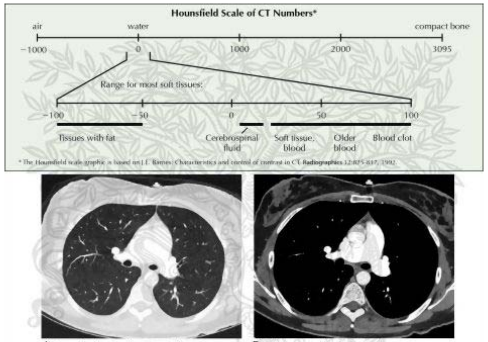
The attenuation of the given material is related to that of water

$$HU = \frac{\mu - \mu_{water}}{\mu_{water}} 1000$$





Windowing: the grey scale is related to a smaller part of Hounsfield scale. (Above the window – white, below it – black)



A. Lung window Level −550, width 1600

B. Soft tissue (mediastinal) window Level 70, width 450, contrast in arterial phase

C. Bone window Level 570, width 3077

D. Bone window Level 455, width 958

© ELSEVIER, INC. – NETTERIMAGES.COM