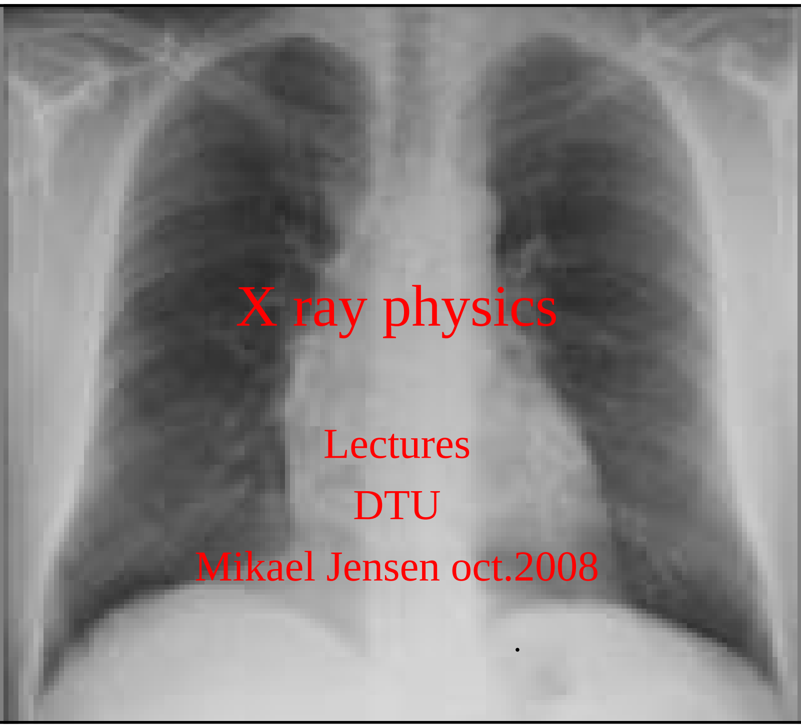


X ray physics

Lectures

DTU

Mikael Jensen oct.2008

Why use x-rays ?

Non invasive,
very high resolution
quick

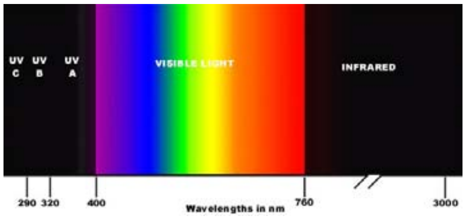
Electromagnetic spectrum

X-ray

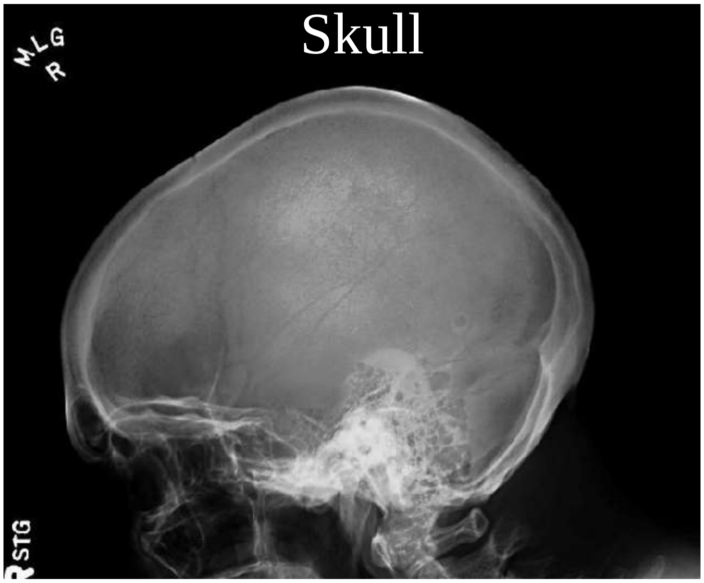
1 nm

gamma-rays

1 fm



X ray image is shadow image


Skull

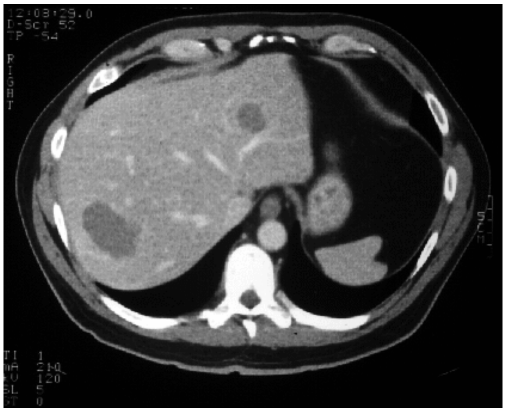
Hand x-ray

Chest

X-rays give rapid, high resolution anatomical information

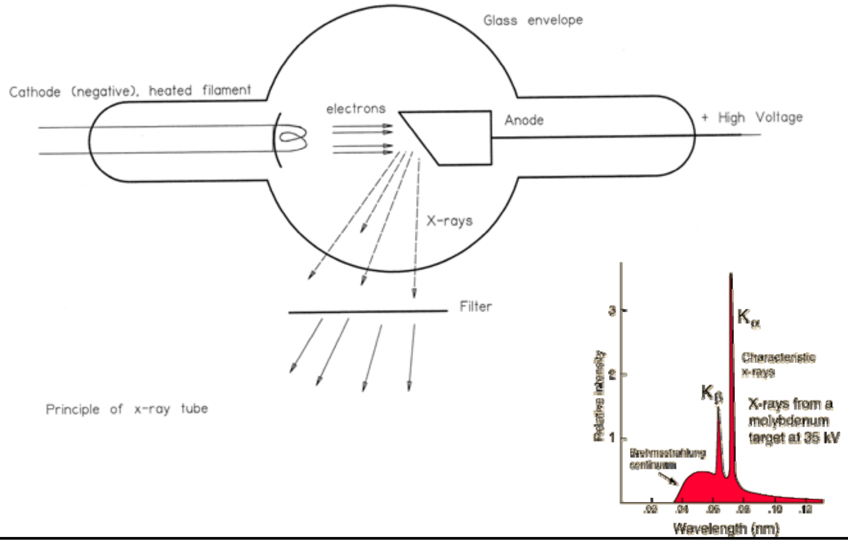
(many photons, good S/N)

Not much soft tissue contrast

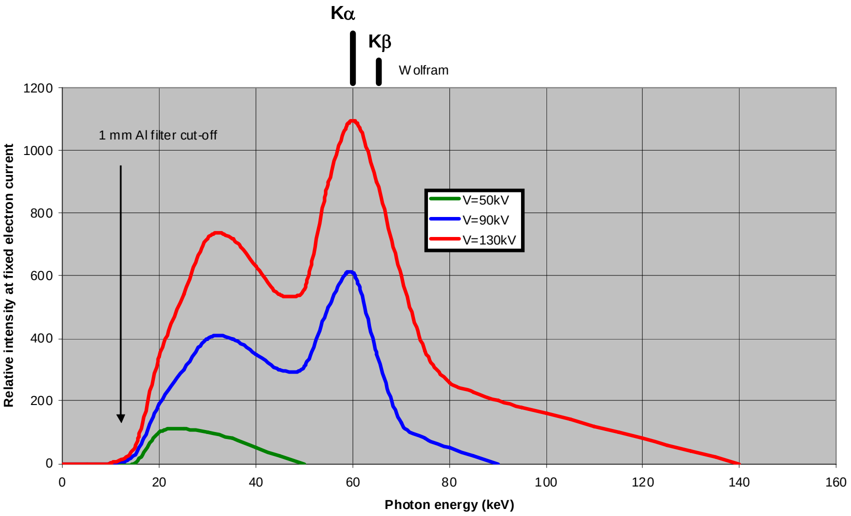


But much can be gained from hgh S/N

Generation of X-rays



X-ray emission from Wolfram Anode X-ray tube



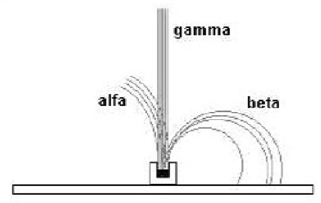
Specify kV and mAs !

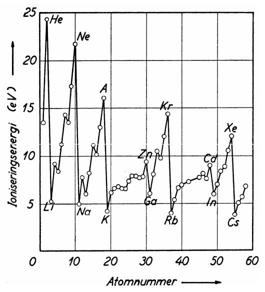
Radiation interaction

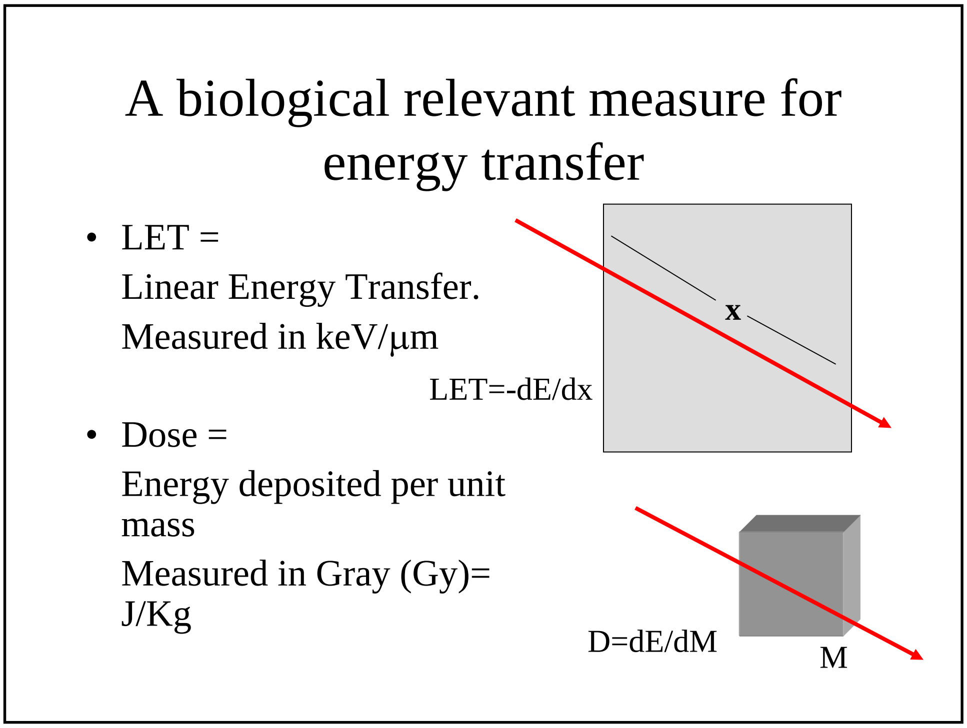
- Ionization
- Direct kinetic energy transfer
- Atomic and molecular exitation
- Radiative processes
- Nuclear reactions

Ionising radiation

- Releases energy through Ionisation
- But also Recombination
- And through Secondary radiation
- Allways ending as heat
- And perhaps chemical change







A biological relevant measure for energy transfer

- LET =

  Linear Energy Transfer.

  Measured in keV/µm

LET=-dE/dx

x

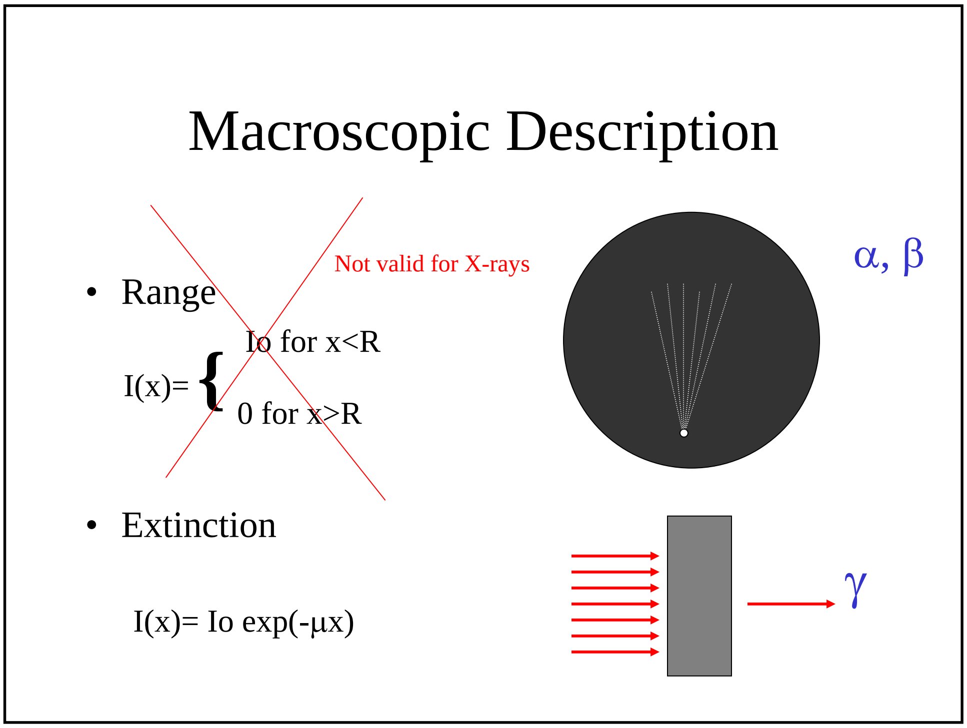
- Dose =

  Energy deposited per unit mass

  Measured in Gray (Gy)= J/Kg

D=dE/dM

M



Macroscopic Description

- Range

Not valid for X-rays

$$\cancel{I(x)=\begin{cases} I_o \text{ for } x<R \\ 0 \text{ for } x>R \end{cases}}$$

α, β

- Extinction

$I(x)= I_o \exp(-\mu x)$

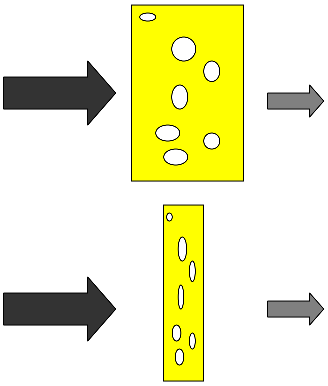
γ

To measures of thickness

- Linear
  x measured in meter
  (µm, mm, cm)

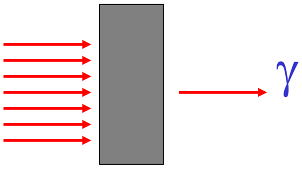
- Area weight
  in gram/m^2
  (g/cm^2, mg/cm^2)

Area weight= $x \bullet \rho$

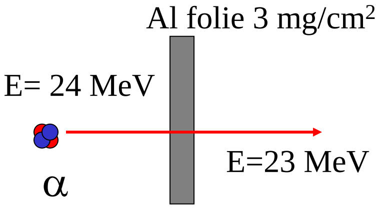


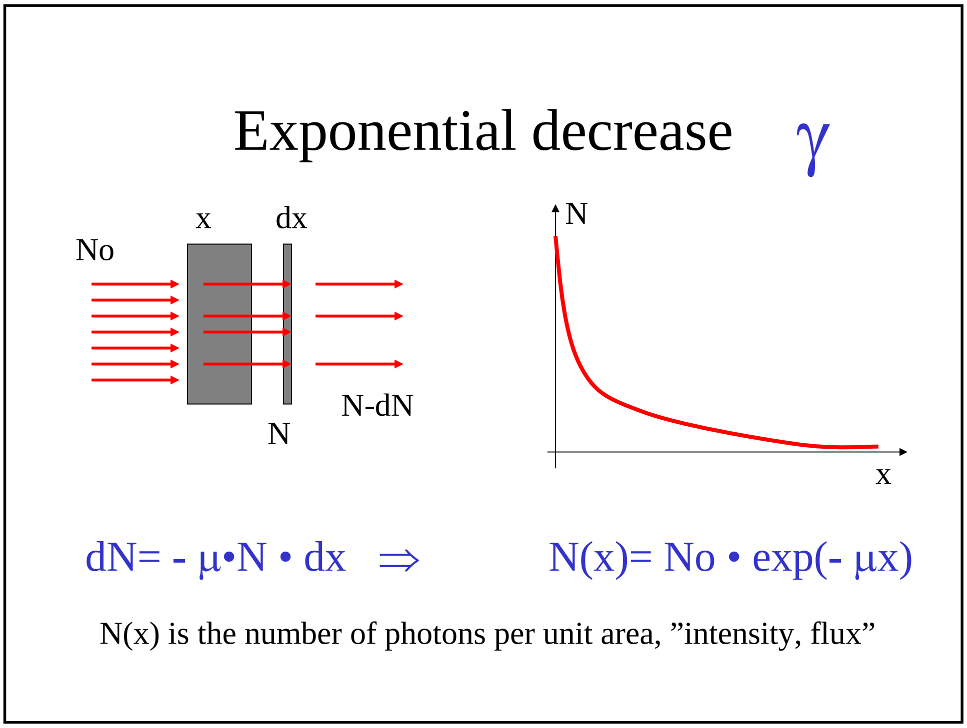
Two types of interaction

A single event removes the particle (the wawe).Constant ”probabiblity of removal” per unit length



The single event ”retards” the ionising particle slightly. Results in a well defined enrgy loss per unit length.

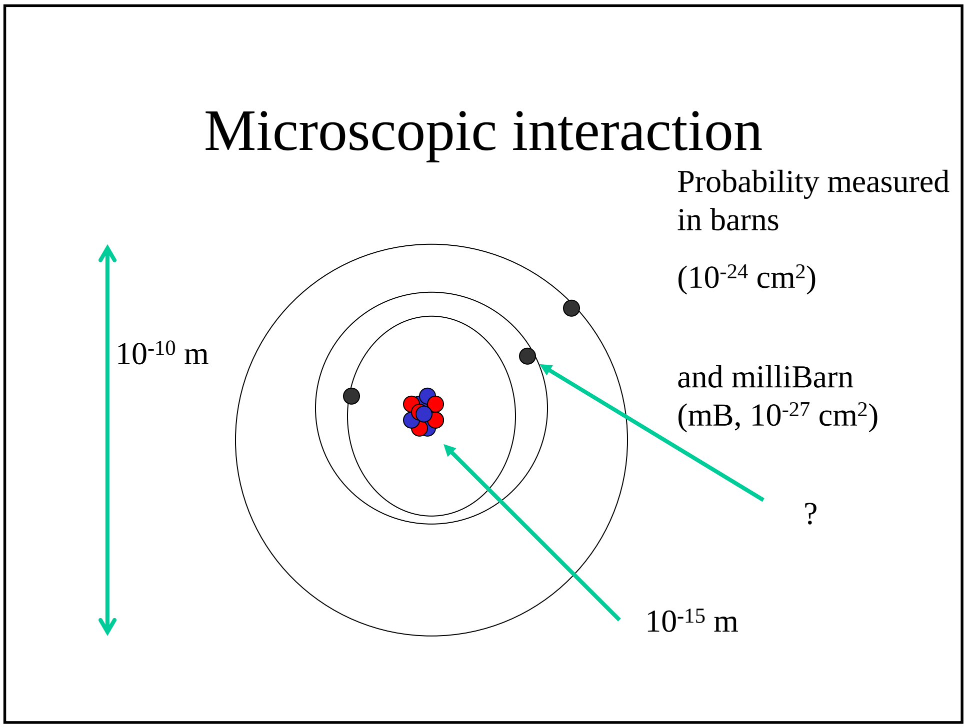




Exponential decrease γ

$$dN = -\mu \bullet N \bullet dx \Rightarrow N(x) = No \bullet \exp(-\mu x)$$

N(x) is the number of photons per unit area, ”intensity, flux”



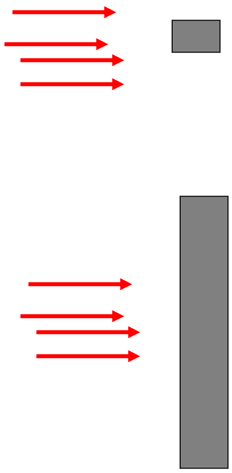
Microscopic interaction

Probability measured in barns

(10^{-24} cm^2)

and milliBarn (mB, 10^{-27} cm^2)

Number of Reactions P



N_{target} number
N_{beam} number per area

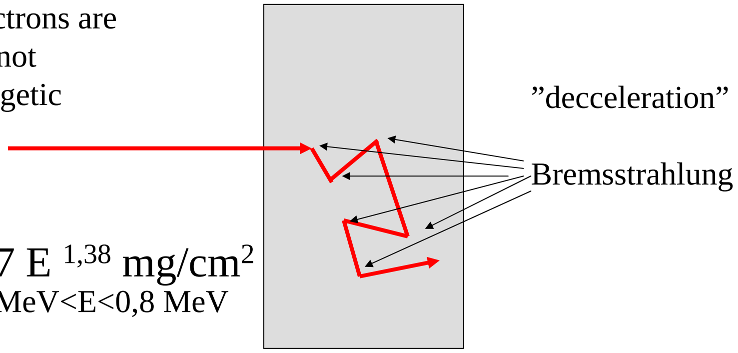
$$\mathbf{P=\sigma N_{target}\ N_{beam}}$$

N_{target} number per area
N_{beam} number

Energy loss betaparticles (electrons)

Range ?

Cave: electrons are normally not monoenergetic



$R= 407\ E^{1,38}\ mg/cm^2$
0,15 MeV<E<0,8 MeV

$R= (542\ E\text{-}133)\ mg/cm^2$
0,8 MeV<E<3 MeV

Glendenin formulas

Interaction of gamma and X-rays

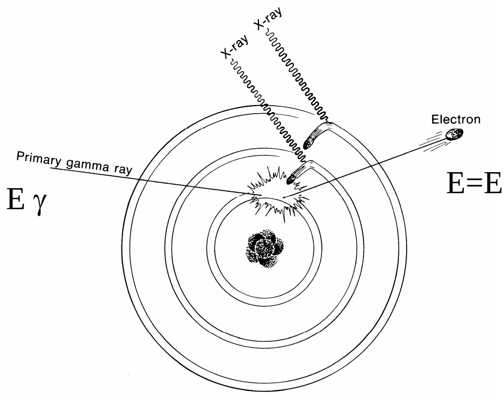
3 important ways of interaction
- Photoelectric effect
- Compton scattering
- Pair production (Eγ >1022 keV)

$$\sigma_{tot}=\sigma_{foto}+\sigma_{compton}+\sigma_{pair}$$!

Photoelectric effect

$$\sigma_{foto} = konstant\ Z^5\ E_\gamma^{(-3,5)}$$

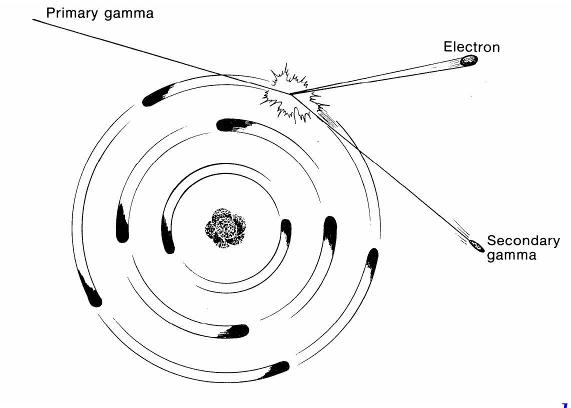
Einstein

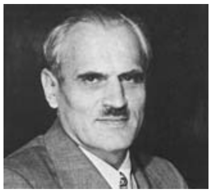


E γ

E=Eγ-Eb

Compton effect

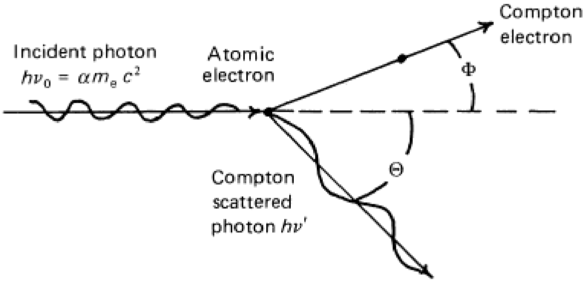




Compton

$$\sigma_{compton} = \frac{konstant\ Z}{E}$$

Compton scattering



Compton shift

$$\frac{c}{\nu'} - \frac{c}{\nu_0} = \lambda' - \lambda_0 = \frac{h}{m_e c}(1 - \cos\theta).$$

Energy of scattered photon

$$h\nu' = \frac{m_e c^2}{1 - \cos\theta + (1/\alpha)}, \quad \alpha = h\nu_0/m_e c^2.$$

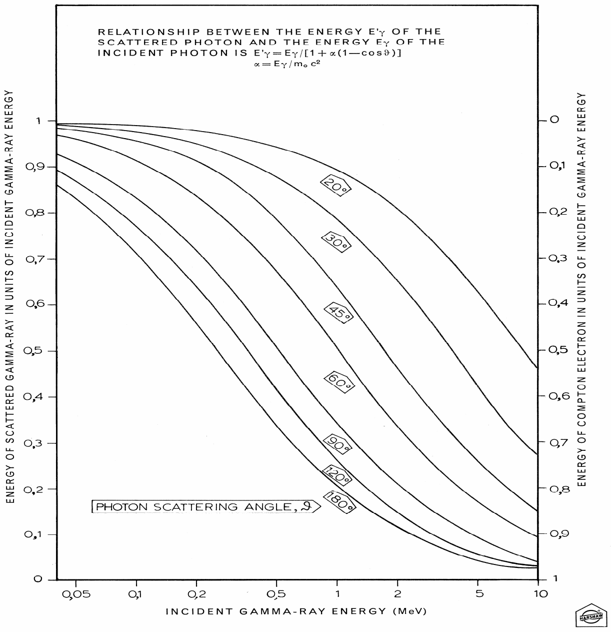
Klein-Nishina formula for Compton scattering

$$\frac{d\sigma_c}{d\Omega} = r_0^2 \left[\frac{1}{1+\alpha(1-cos\theta)}\right]^3 \left[\frac{1+cos\theta}{2}\right] \left[1+\frac{\alpha^2(1-cos\theta)^2}{(1+cos^2\theta)[1+\alpha(1-cos\theta)]}\right]$$

θ Is the angle of deflection for the photon

α Is the energy of the primary gamma ray relative to 511keV (m_ec^2)

Angles



Compton angular description

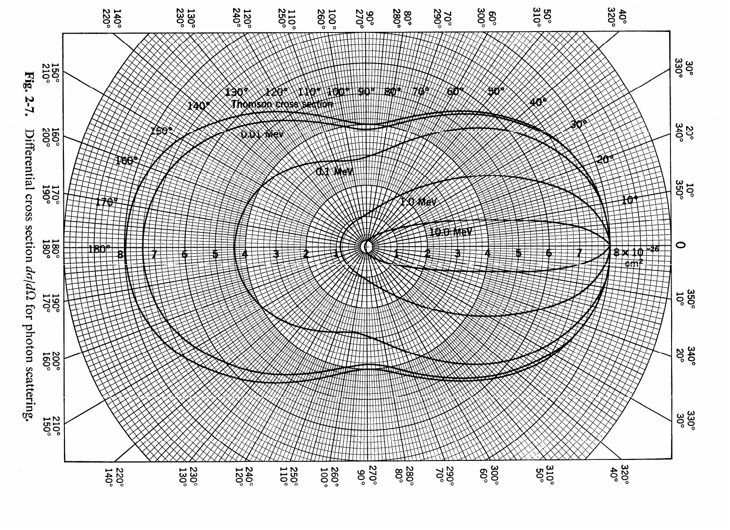
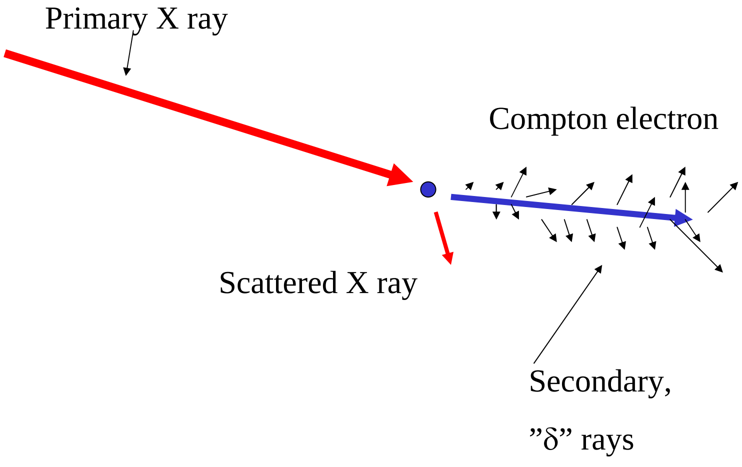


Fig. 2-7. Differential cross section $d\sigma/d\Omega$ for photon scattering.

A very likely event



Primary X ray

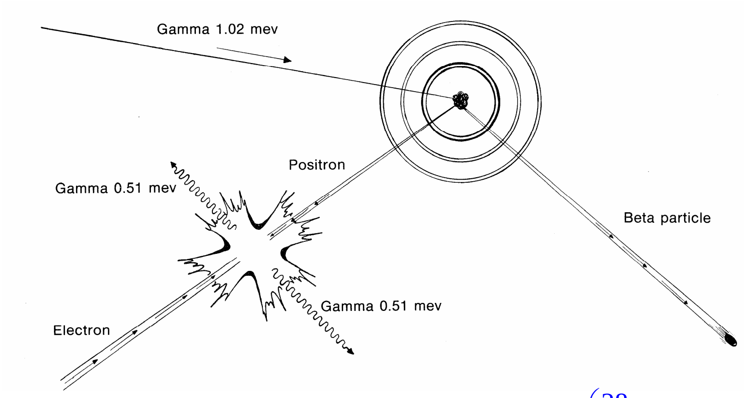
Compton electron

Scattered X ray

Secondary,

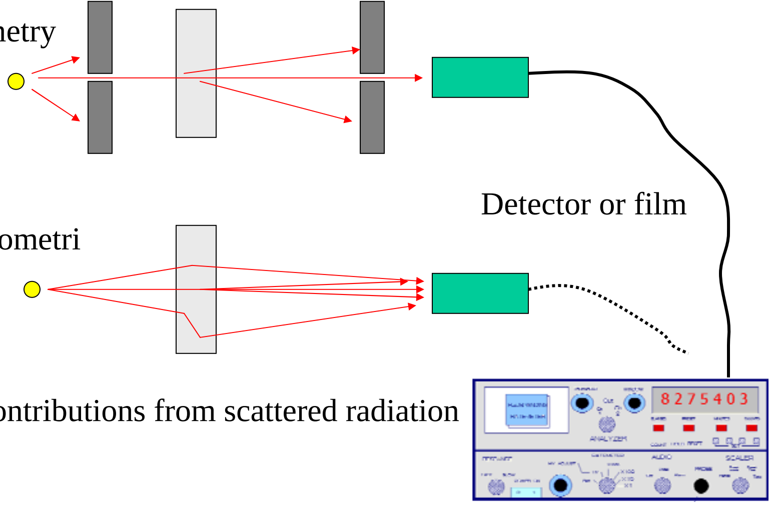
”δ” rays

Pair production (no importance for medical x-ray use)



$$\sigma_{pair} = konstant\ Z^2 \left(\frac{28}{9} \ln(2\alpha) - \frac{218}{27} \right)$$

Two types of geometry



Good geometry

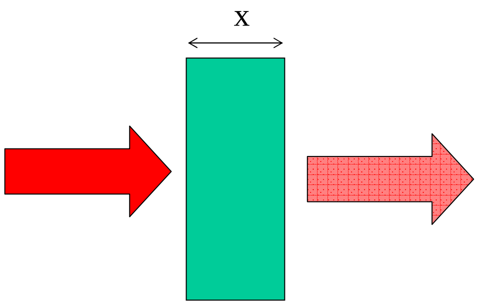
Detector or film

”poor” geometri

Contributions from scattered radiation

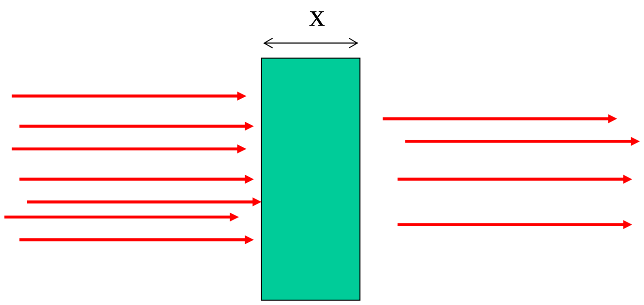
Loss of energy
(macroscopic description)

$E = E_0\ \mathrm{exp}(-\mu_{en}x)=E_0\ \mathrm{exp}(-\mu_{en}/\rho\cdot\rho x)$



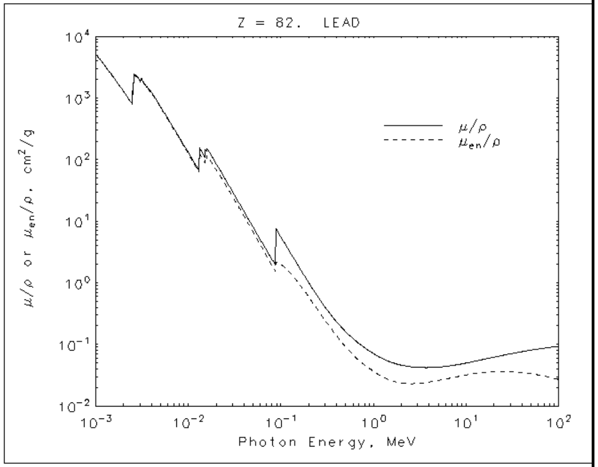
Loss of intensity

$I = I_0\ \mathrm{exp}(-\mu x) = I_0\ \mathrm{exp}(-\mu/\rho\cdot\rho x)$

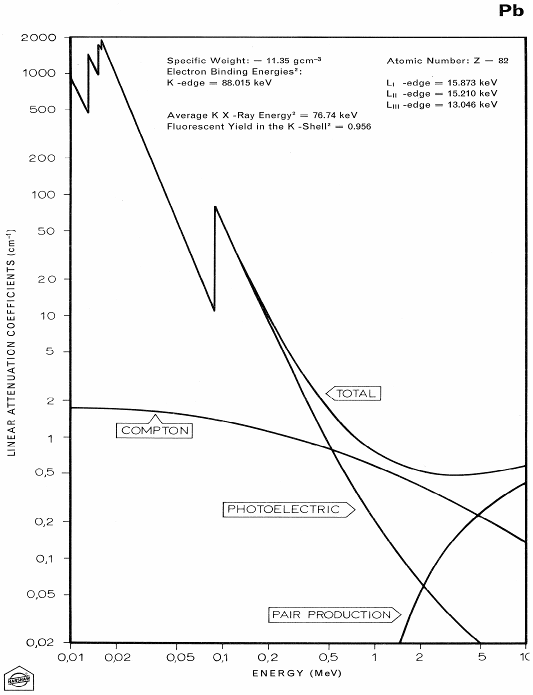


Stopping of X rays

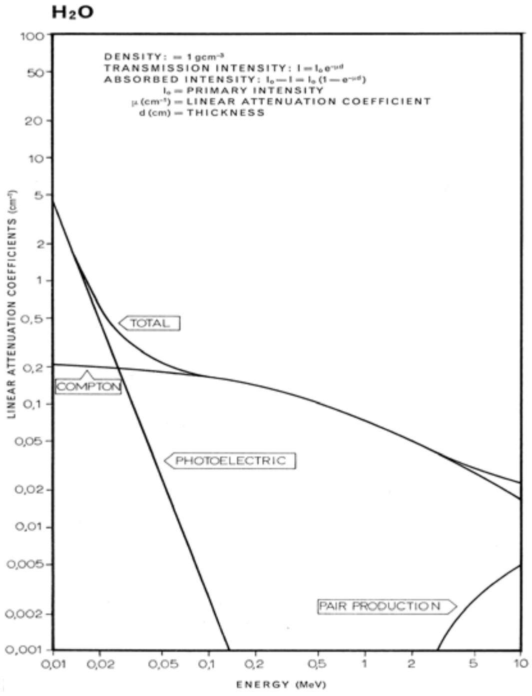
- Photo proces
- Compton proces
- (Pair effect)



Lead



water



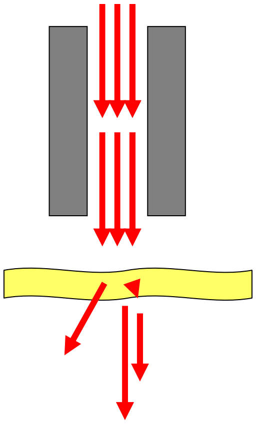
Mass attenuation coefficient μ/ρ

	50 keV	100 keV	200 keV
Air	0,208	0,154	0,122
Water	0,227	0,171	0,137
Fat	0,212	0,169	0,136
Musle	0,226	0,169	0,136
Bone	0,424	0,186	0,131
Lead	8,041	5,549	0,999

Data from http://physics.nist.gov/PhysRefData/XrayMassCoef/cover.html

Why pay interest in these interactions ?

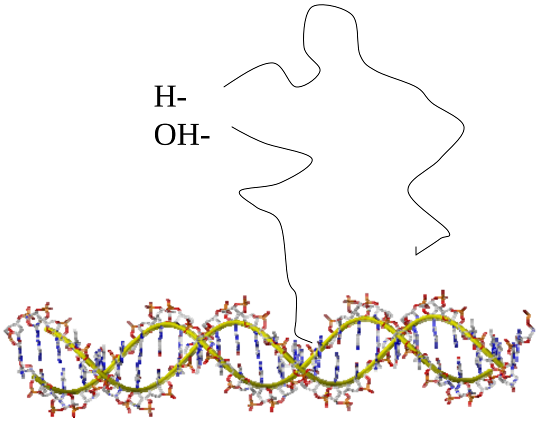
- Some of the photons should pass the sample
- Some should be stopped in the sample.
- The radiation should be stopped in the detector (film, plate, screen….)
- The radiation should be be collimated



Biological damage from ionisation

4 steps:

1. Ionisation
2. Free radicals
3. DNA change
4. Lack of repair



Consequence of DNA damage

- Single events: Most likely DNA repair
- No repair ? Cell death
- No repair, cell survives ? Small chance it is chenged to a cancer cell.

Cells and tissue under rapid cell division most radiation sensitive

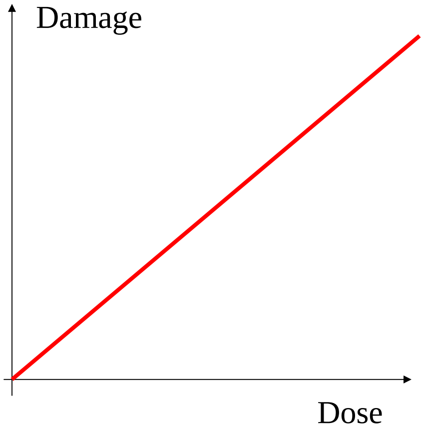
---

Stochastical effect

Damage risk proportional to dose

No known lower limit

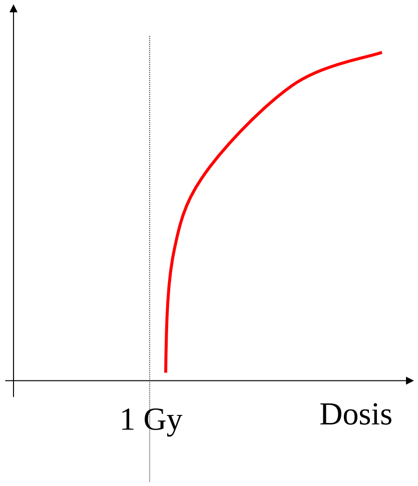
Effect can show up late



Deterministic effect

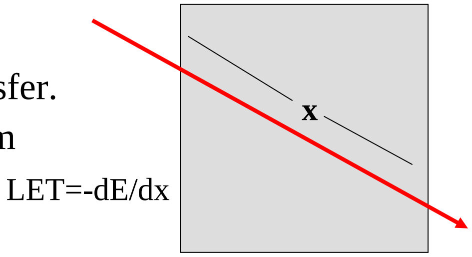
- Threshold value
- Rapid onset
- Often local
- Cell death

LD$_{50}$ humans: 5 Gy

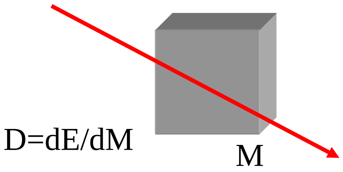


A biological relevant measure for energy transfer

- LET =
  Linear Energy Transfer.
  Measured in keV/µm



- Dose =
  Energy deposited per unit mass
  Measured in Gray (Gy)= J/Kg

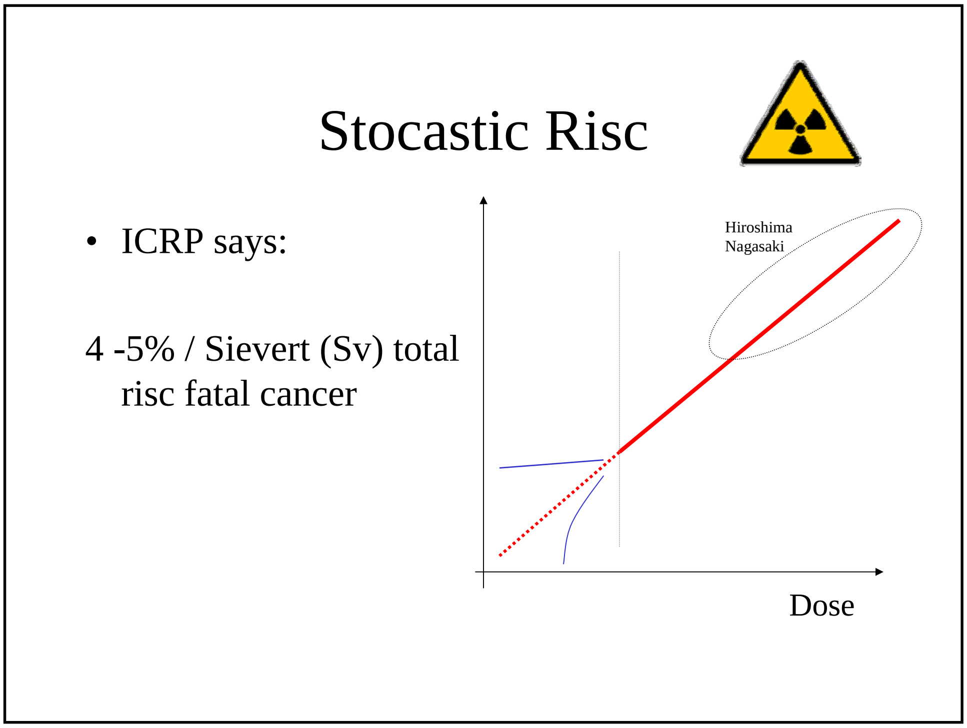


Unit of dose

- Gray (J/kg)
- With important ”biological” weight factors linked to Sievert (Sv) (still J/kg)

X ray doses

- Single exposure, small area, short path
- -limb, teeth, chest
- few micro Sievert
- Multiple exposures whole body, low energy to enhance contrast (CT….)
- several milli Sievert



Stocastic Risc

- ICRP says:

4 -5% / Sievert (Sv) total risc fatal cancer