Bioengineering 280A
Principles of Biomedical Imaging

Fall Quarter 2007
X-Rays Lecture 1

EM spectrum

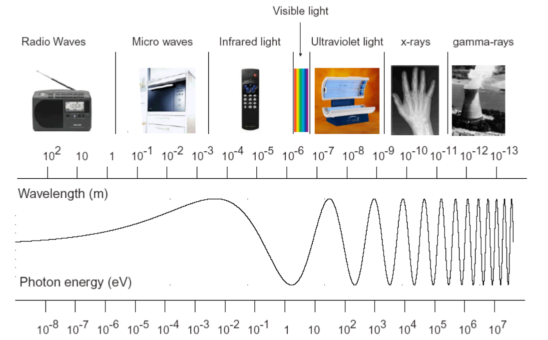
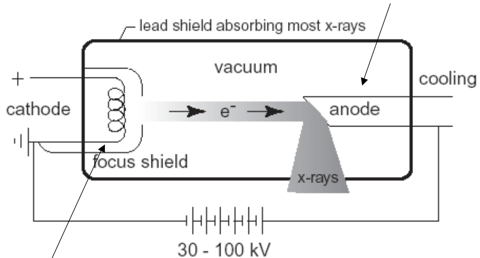


Figure 4.1: *The electromagnetic spectrum.*

Suetens 2002

X-Ray Tube

Usually tungsten is used for anode
Molybdenum for mammography



(a)

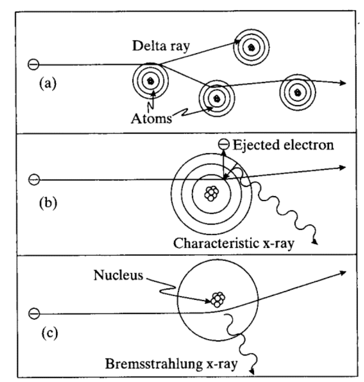
Tungsten filament heated to about 2200 C leading to thermionic emission of electrons.

Suetens 2002

X-Ray Production

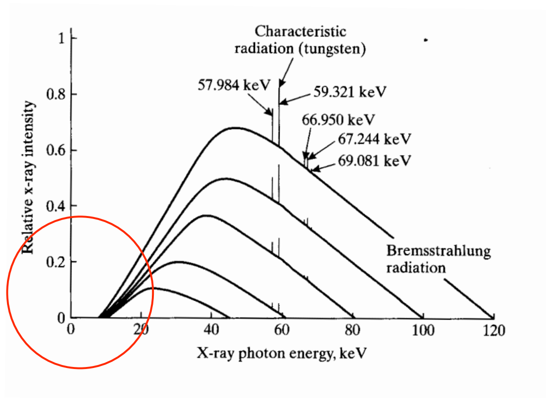
Collisional transfers

Radiative transfers



Prince and Links 2005

X-Ray Spectrum



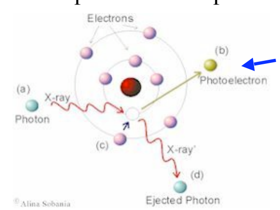
Lower energy photons are absorbed by anode, tube, and other filters

Prince and Links 2005

Interaction with Matter

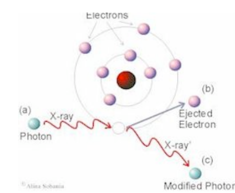
Typical energy range for diagnostic x-rays is below 200 keV.

The two most important types of interaction are photoeletric absorption and Compton scattering.



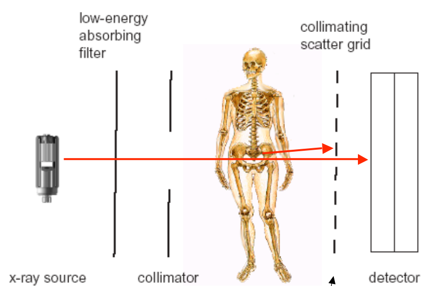
Photoelectric effect dominates at low x-ray energies and high atomic numbers.

Compton scattering dominates at high x-ray energies and low atomic numbers, not much contrast



http://www.eee.ntu.ac.uk/research/vision/asobania

X-Ray Imaging Chain

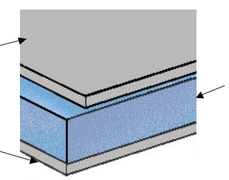


Reduces effects of Compton scattering

Suetens 2002

X-ray film

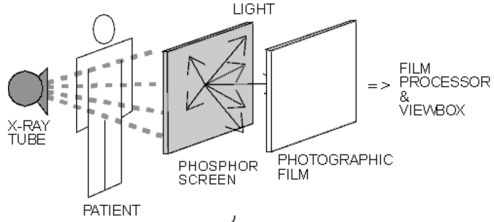
Emulsion with silver halide crystals
Each layer ~ 10 µm

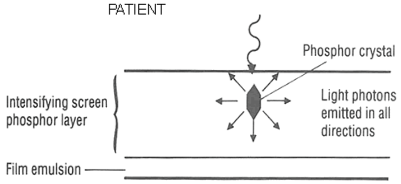


Flexible base ~ 150 µm

Silver halide crystals absorb optical energy. After development, crystals that have absorbed enough energy are converted to metallic silver and look dark on the screen. Thus, parts in the object that attenuate the x-rays will look brighter.

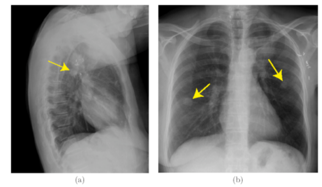
Intensifying Screen

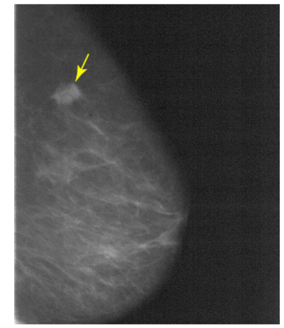




http://learntech.uwe.ac.uk/radiography/RScience/imaging_principles_d/diagimage11.htm
http://www.sunnybrook.utoronto.ca:8080/~selenium/xray.html#Film

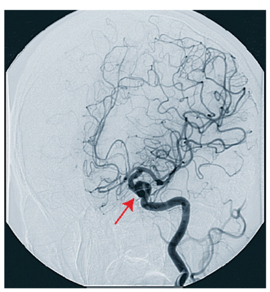
X-Ray Examples



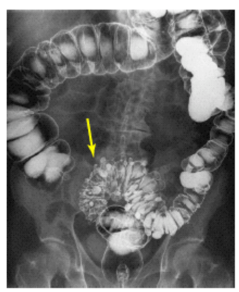


Suetens 2002

X-Ray w/ Contrast Agents



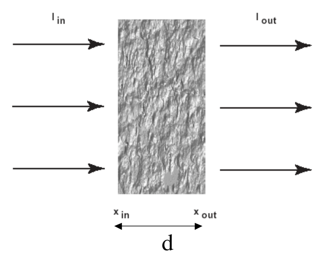
Angiogram using an iodine-based contrast agent.
K-edge of iodine is 33.2 keV



Barium Sulfate
K-edge of Barium is 37.4 keV

Suetens 2002

Attenuation



For single-energy x-rays passing through a homogenous object:

$$I_{out} = I_{in}\exp(-\mu d)$$

Linear attenuation coefficient

Attenuation

$n = \mu N \Delta x$ photons lost per unit length

$\mu = \dfrac{n/N}{\Delta x}$ fraction of photons lost per unit length

$$\Delta N = -n \longrightarrow \frac{dN}{dx} = -\mu N \longrightarrow N(x) = N_0 e^{-\mu x}$$

For mono-energetic case, intensity is

$$I(\Delta x) = I_0 e^{-\mu \Delta x}$$

Attenuation

Inhomogeneous Slab

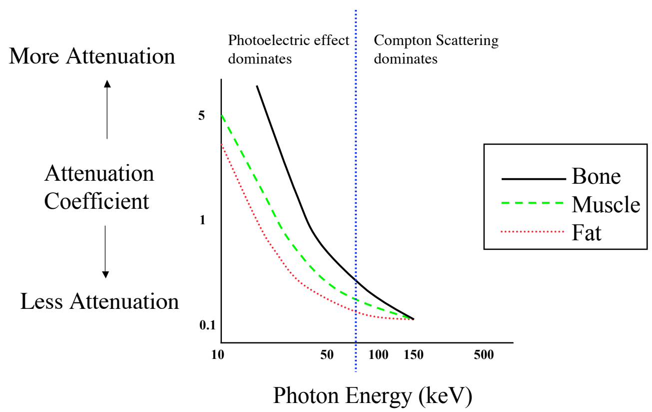
$$\frac{dN}{dx} = -\mu(x)N \longrightarrow N(x) = N_0 \exp\left(-\int_0^x \mu(x')dx'\right)$$

$$I(x) = I_0 \exp\left(-\int_0^x \mu(x')dx'\right)$$

Attenuation depends on energy, so also need to integrate over energies

$$I(x) = \int_0^\infty S_0(E')E' \exp\left(-\int_0^x \mu(x';E')dx'\right)dE'$$

Attenuation



Adapted from www.cis.rit.edu/class/simg215/xrays.ppt

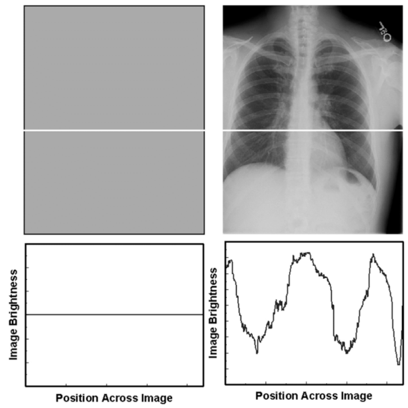
Half Value Layer

X-ray energy (keV)	HVL, muscle (cm)	HVL Bone (cm)
30	1.8	0.4
50	3.0	1.2
100	3.9	2.3
150	4.5	2.8

In chest radiography, about 90% of x-rays are absorbed by body. Average energy from a tungsten source is 68 keV. However, many lower energy beams are absorbed by tissue, so average energy is higher. This is referred to as beam-hardening, and reduces the contrast.

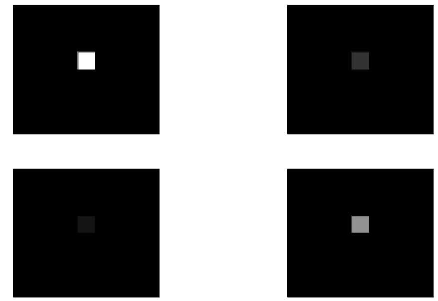
Values from Webb 2003

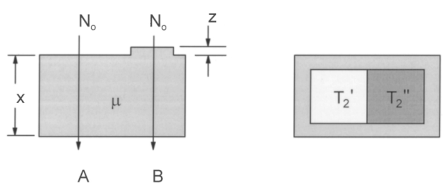
Contrast



Bushberg et al 2001

Contrast





(A) X-ray Imaging (B) MR Imaging

Bushberg et al 2001

$$A = N_0 \exp(-\mu x)$$
$$B = N_0 \exp(-\mu(x+z))$$

Subject Contrast

$$C_S = \frac{A-B}{A} = \frac{N_0 \exp(-\mu x) - N_0 \exp(-\mu(x+z))}{N_0 \exp(-\mu x)} = 1 - \exp(-\mu z)$$