Northeastern University
College *of* Engineering

Optical Science
Northeastern University
Laboratory

Biomedical Imaging
X–Rays

Charles A. DiMarzio
EECE–4649
Northeastern University

May 2018

History

- Röntgen, 1895
- Wide Use by 1930s
  - Military Early Adoptors
  - Bullets *etc.*
  - Commercial Uses in 1950s
- Diagnostic X–Rays
- Therapeutic X–Rays

Sources

- X–Ray Tube
  - Cathode (high negative voltage, V_{tube} Typically Many kV)
  - Anode (ground or positive)
  - Electrons Accelerated to Anode
  - Ionization
- Output
  - Characteristic X–Rays (Narrow Band, Depend on Material)
  - Brestrahlung (Broad Band, Centered near $V_{Tube}/3$)

Contrast

- Mostly Absorption by Electrons in Atoms
- Ionization
- Incoherent Addition

$$\mu_a = \sum_{n=0}^{N} C_n \kappa_n$$

- Little Soft Tissue Contrast (H, C, O)
- Good Contrast for Bone (Ca)
- Also Breast Calcifications
- Safety Issues (Joules/kg = Sieverts)

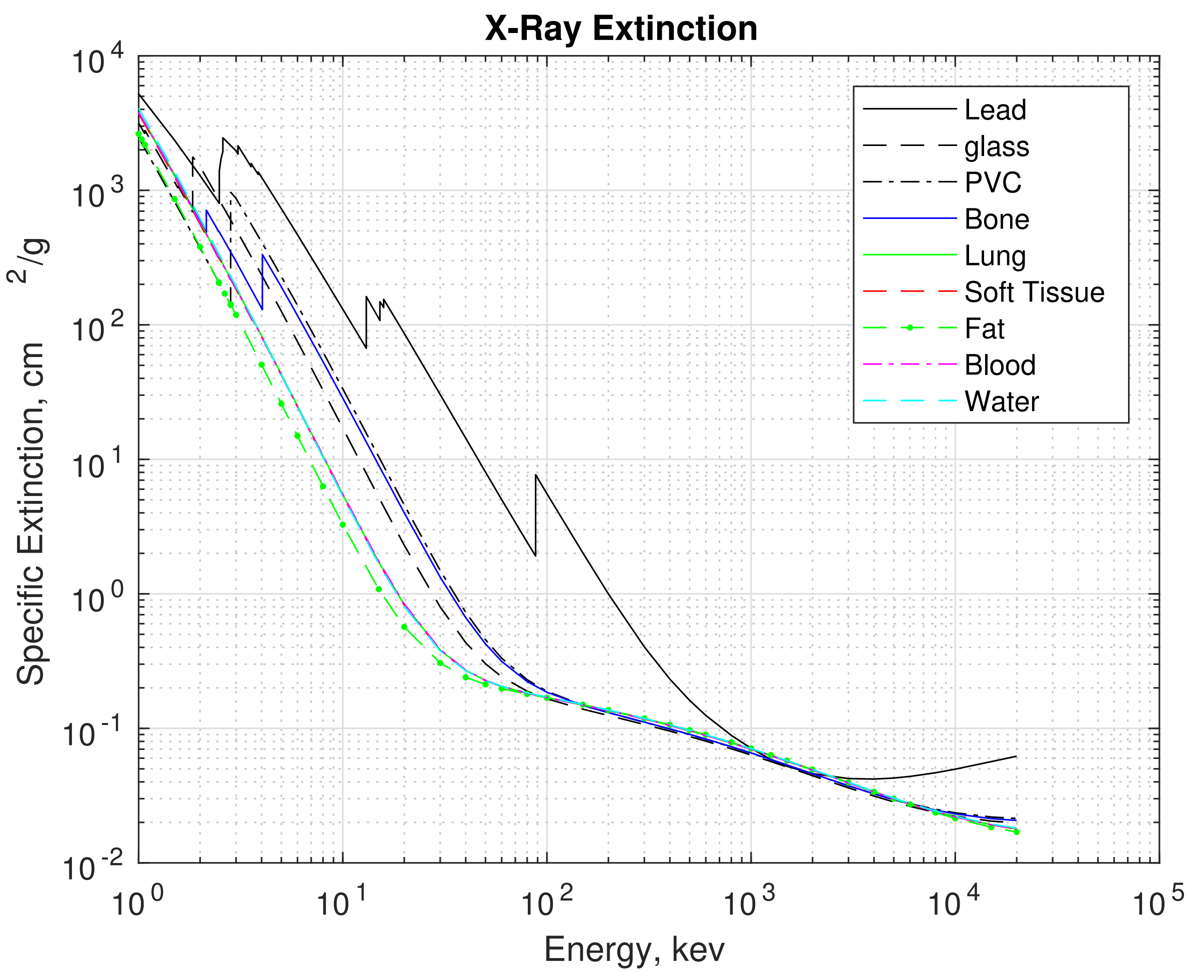
Scattering

- Compton Scattering
  - Input Photon Energy (hf) and Momentum (hk)
  - Output Electron Energy and Momentum
  - Output Photon Energy (hf) and Momentum (hk)
- Scattering Contributes to Background and Reduces Contrast

Detectors

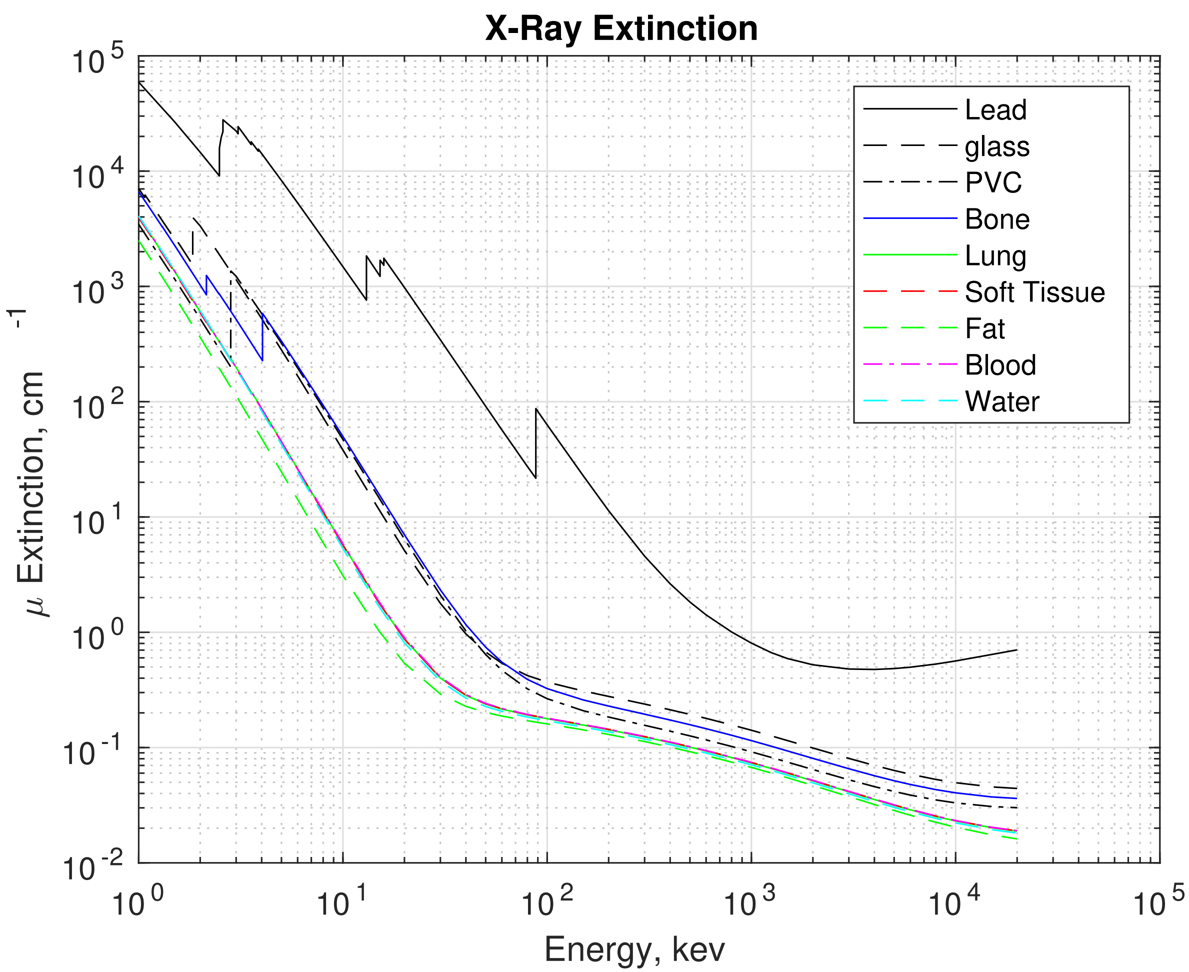
- Film
- Phosphors
- Image Intensifiers
- Arrays
- Fluoroscopy

Specific Extinction (per unit density)



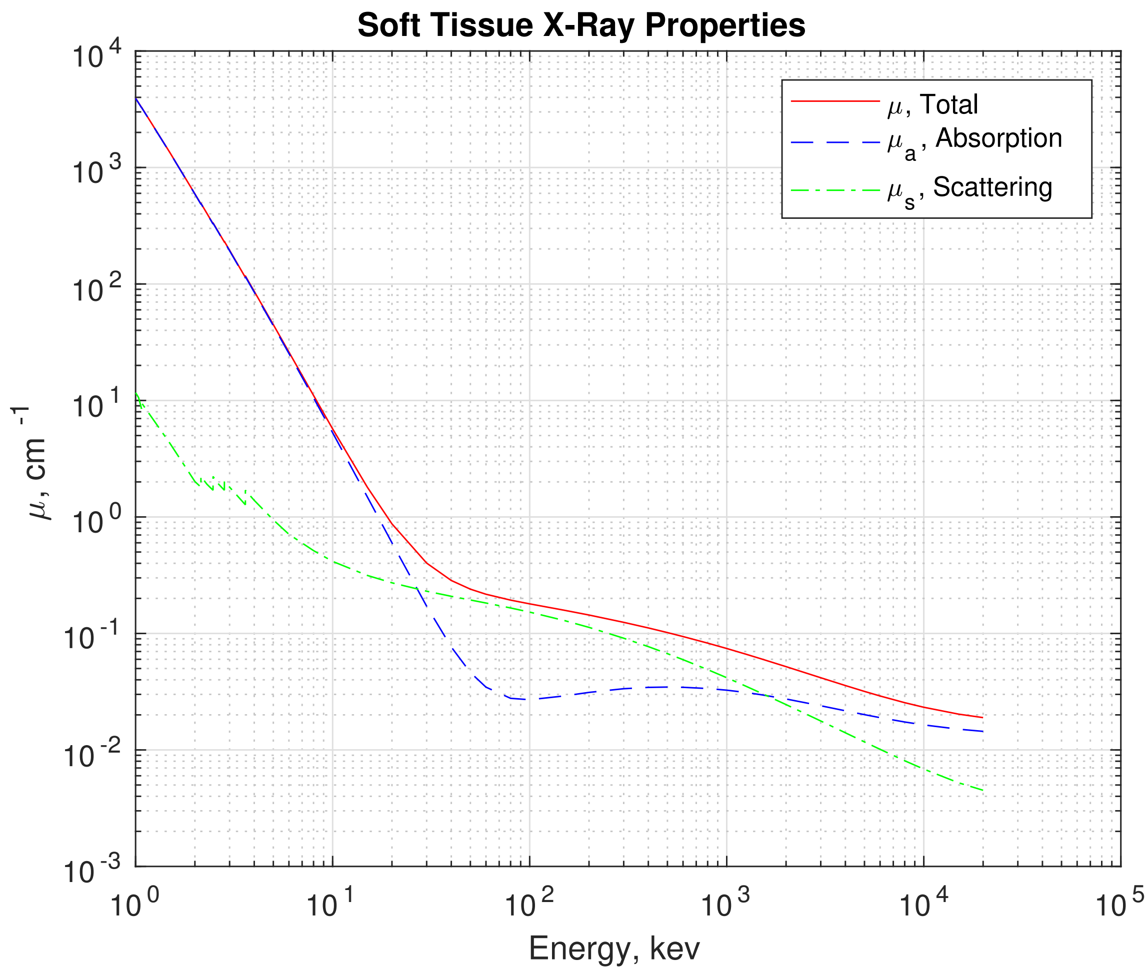
https://www.nist.gov/pml/x-ray-and-gamma-ray-data
http://physics.nist.gov/PhysRefData/XrayMassCoef/tab4.html

Extinction

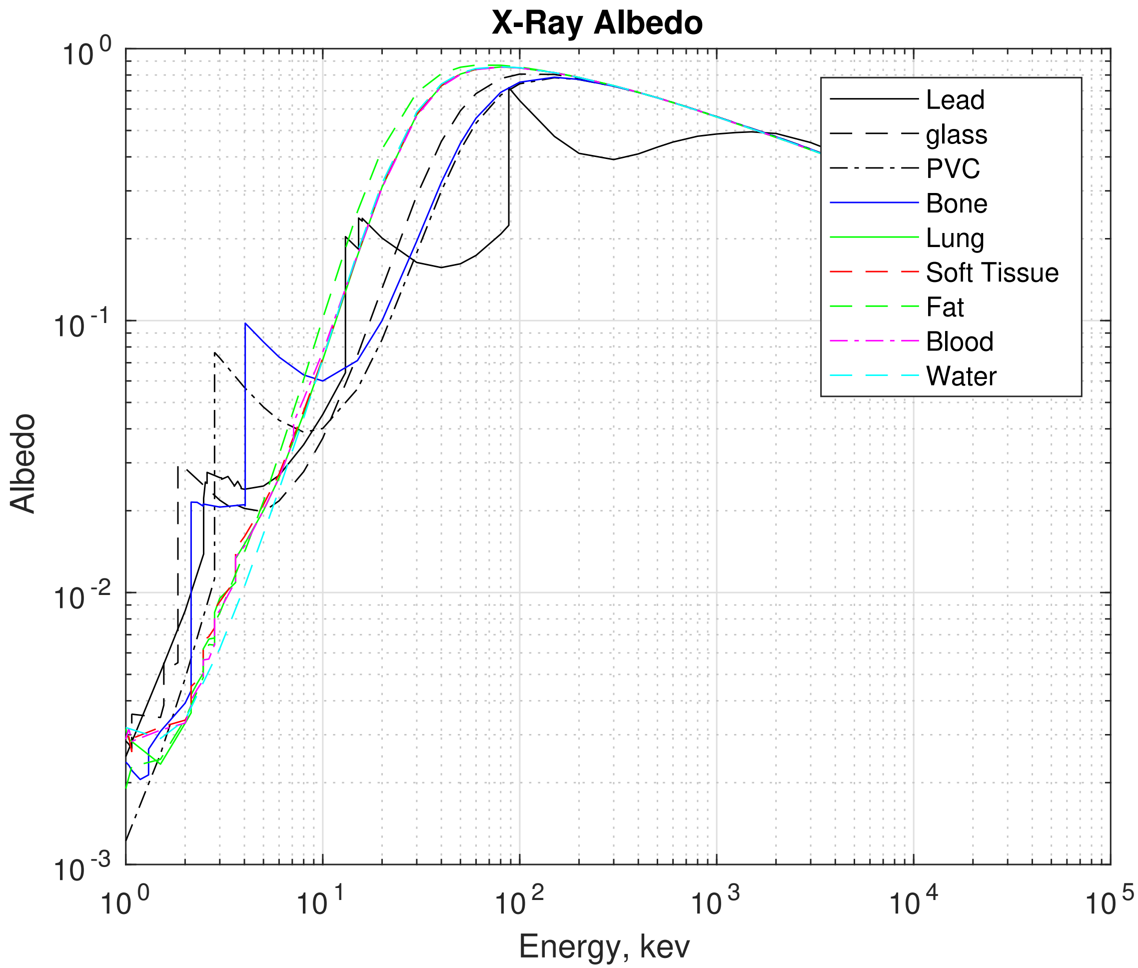


https://www.nist.gov/pml/x-ray-and-gamma-ray-data
http://physics.nist.gov/PhysRefData/XrayMassCoef/tab4.html

Properties of Soft Tissue

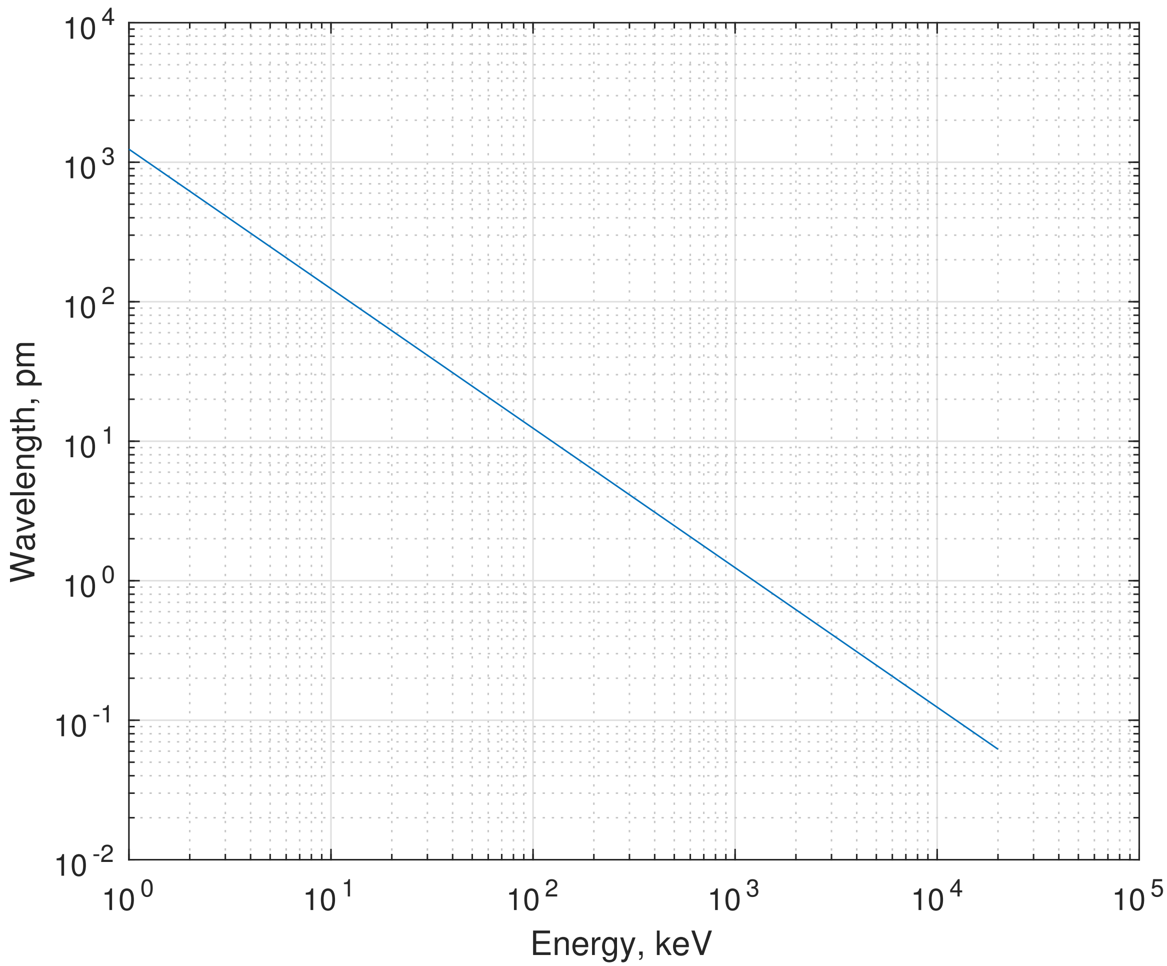


Albedo



Not Normally Used in Medical Imaging

Wavelength *vs.* Energy



Resolution

- Spot Size, d

$$d = \frac{\lambda}{D} z$$

- Match $d = D$

$$D = \frac{\lambda}{D} z$$

- Solution: Almost no Diffraction Issues

$$D = \sqrt{z\lambda} \approx \sqrt{1 \text{ m} \times 10^{-10} \text{ m}} = 10 \ \mu\text{m}$$

- Resolution Often Determined by Sampling

X–Ray Computed Tomography (1)

- Concept
  - Multiple 2–Dimensional Projections
  - Reconstructions (2–Dimensional)
  - Slices for 3 Dimensions

- Hard to Do
  - Detector Issues
  - Time Issues
  - Exposure Issues

X–Ray Computed Tomography (2)

- Generation 1
  - Before Arrays; One Detector
  - Translate and Rotate (Slow)
- Generation 2
  - Multiple Detectors (Faster)
- Generations 3–4
  - Fan Beams
  - More Sources and Detectors (Inverse Fan)
- Move Patient for 3 Dimensions

CT Issues

- High Exposure
- Slip Rings (low voltages)
- Limited View (Resolution Issues)
- Fluoroscopy
- Stop–and–Go Artifacts
- Helical Scan with Interpolation
- Beam Hardening: T Depends on Frequency (Energy)

$$T(f, x, y) = e^{-\int \mu(f,x,y,z)dz}$$

Forward Model

- Assume Finite Pixels

$$\log T\left(\ell dx, mdy\right) = Y_{\ell,m} = \Sigma_n X dz$$

$$X_{\ell,m,n} = \mu\left(\ell dx, mdy, ndz\right)$$

- Matrix Equation with Noise

$$Y = \mathcal{M}\mathbf{X} + \mathbf{N}$$

- Inverse

$$\hat{\mathbf{X}} = \mathcal{M}^{-1}\mathbf{Y} = \mathcal{M}^{-1}\left(\mathcal{M}\mathbf{X} + \mathbf{N}\right) = \mathbf{X} + \mathcal{M}^{-1}\mathbf{N}$$