Medical Imaging Physics

Spring Quarter

Week 7-1

X-Rays

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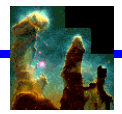
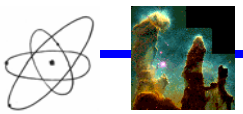


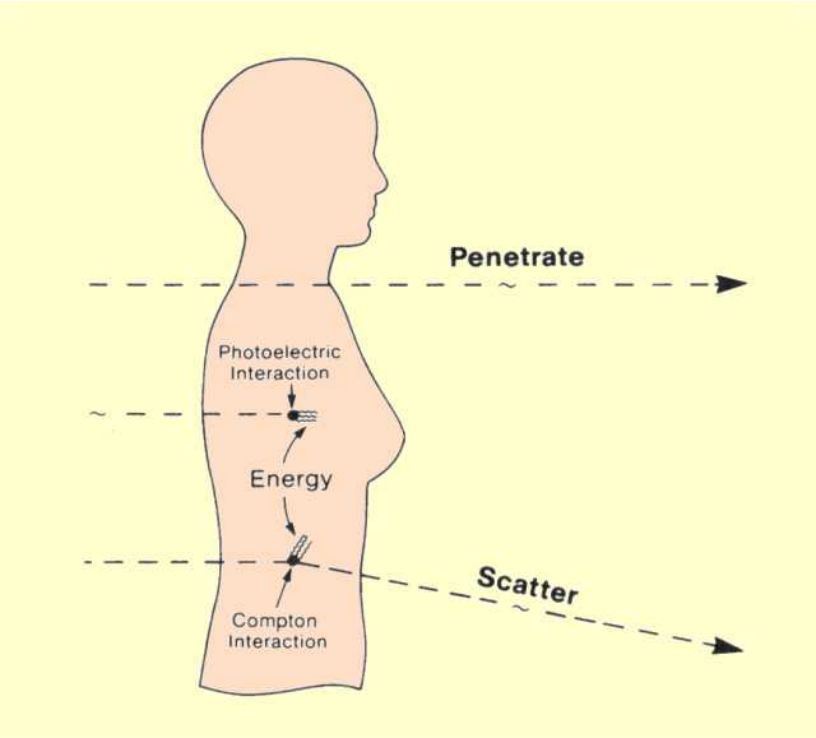
Outline

- Midterm
- Radiology, CT
- Reading assignment:
  - CSG D 16; http://www.sprawls.org/ppmi2/
- Homework
  - Essay questions
  - Due Thursday, May 8



Radiation Interaction with Matter

- X or Gamma rays (photons) can interact with matter:
  - Penetration w/o interaction
  - Absorption and deposition of all energy
    - Photoelectric effect
  - Scattering and partial deposition of energy
    - Compton scattering

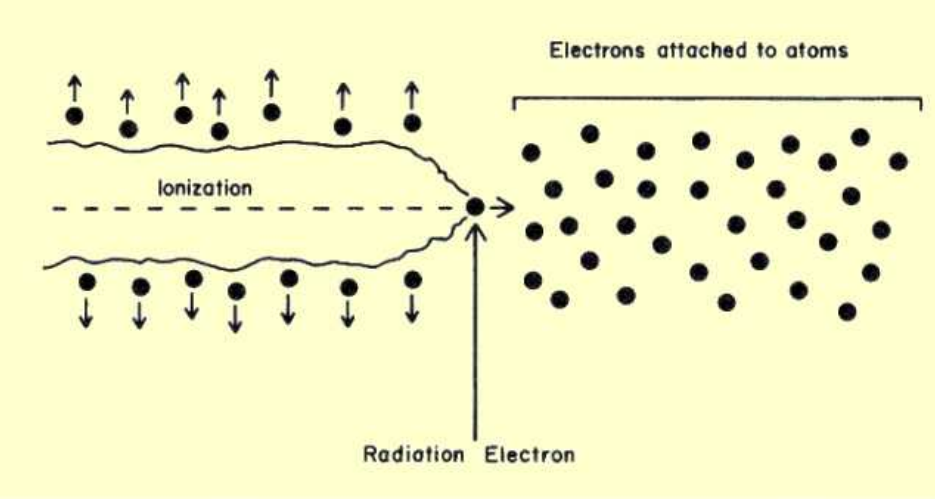


Interactions

- Photoelectric (photon-electron) effect:
  - Photon transfers all its energy to a bound electron (K or L)
  - Electron is ejected from the atom and gets quickly absorbed close to the origination point
  - The vacancy is filled with another electron
    - Characteristic radiation (x-rays or visible light)
    - It's called Fluorescent Radiation
- Compton scattering
  - Photon bounces off an electron and changes its direction
  - Similar to partially inelastic collision of billiard balls
  - Part of the photon energy transfers to the electron

Secondary Interactions

- Electron interactions
  - Ejected electron interacts with matter and loses its energy
    - Elevated energy state of atoms
    - Ionization of atoms (33.4 eV per ionization of one “atom” of air)
    - Very important: 50-keV x-ray photon undergoing a photoelectric interaction
      - The initial interaction of the photon ionizes one atom
      - The resulting energetic electron ionizes approximately 1,500 additional atoms



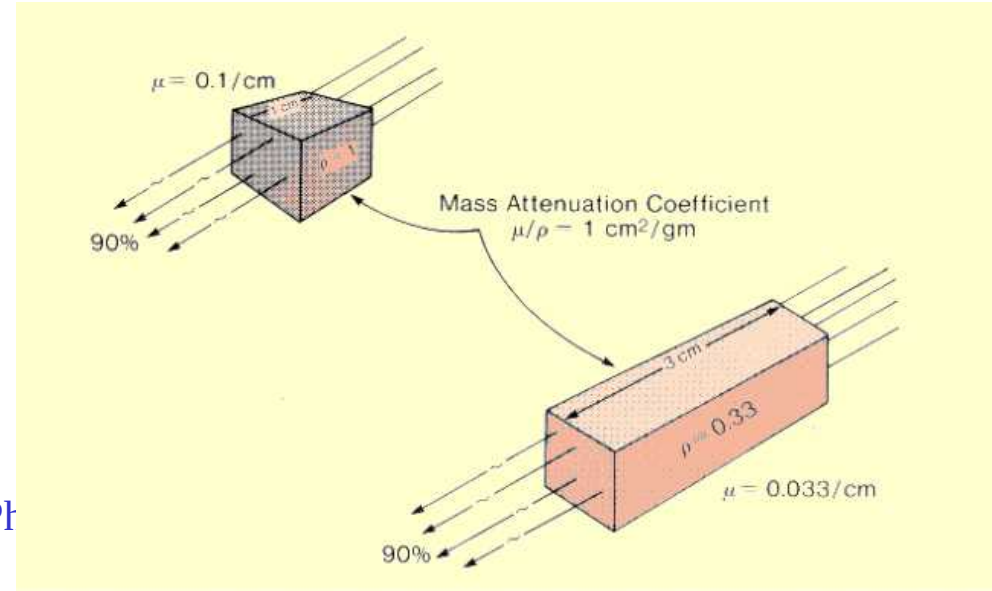
Attenuation

- Linear attenuation coefficient
  - The fraction of photons interacting per 1-unit thickness of material
- Mass attenuation coefficient

Mass Attenuation Coefficient (μ/ρ) = Linear Attenuation Coefficient (μ) / Density (ρ)

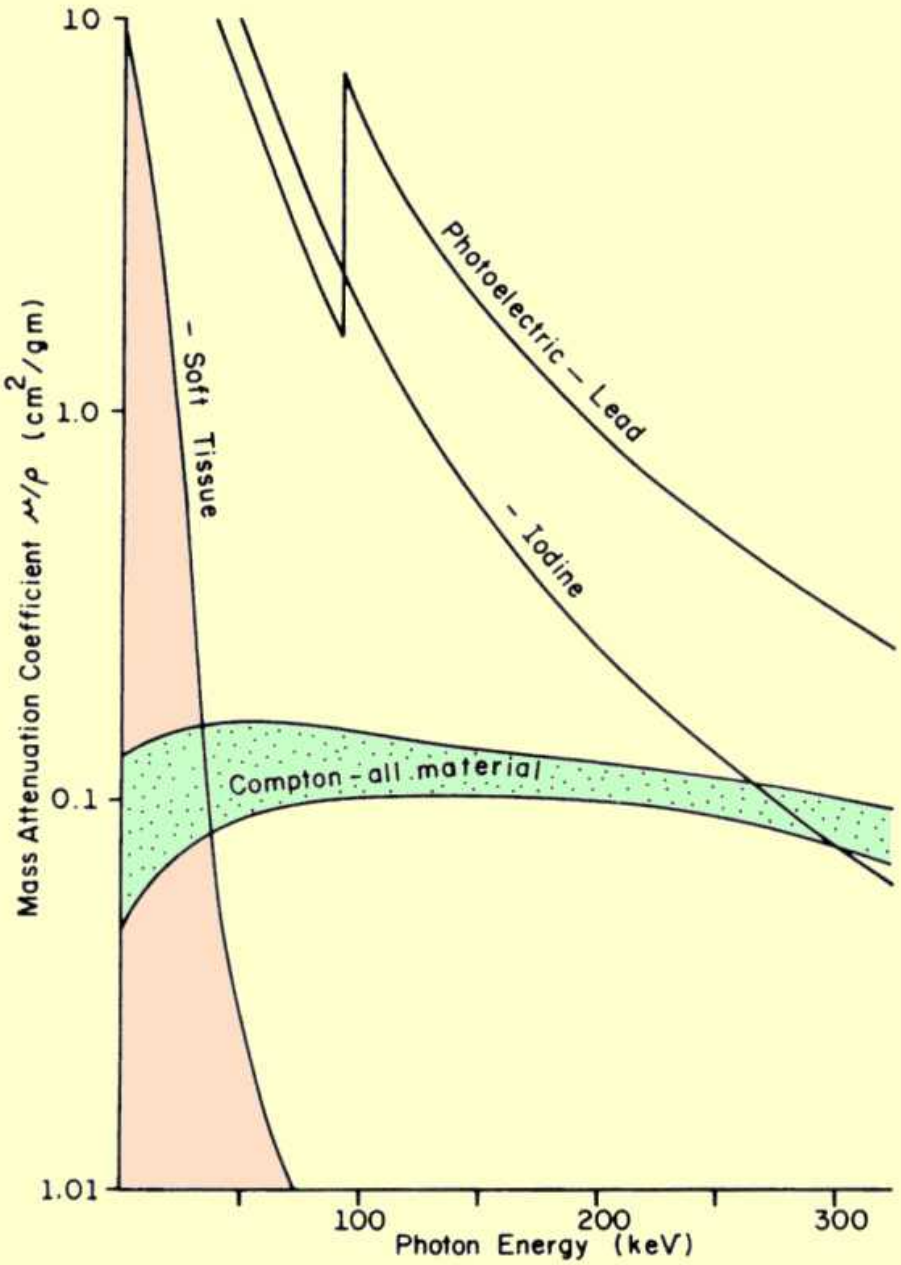
  - Area mass is the amount of material behind a 1-unit surface area

Area Mass (g/cm^2) = Thickness (cm) x Density (g/cm^3)



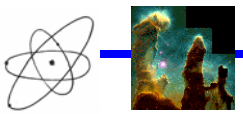
Overall Picture

- PE effect attenuates much stronger because all photon energy si deposited
- Compton
  - Predominant at higher energies
  - In tissue: above 30 keV



X-Ray Imaging

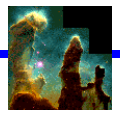
- Two different ways:
  - Projecting a (large) shadow image on the receptor
    - Radiography and fluoroscopy
  - Scanning with a thin x-ray beam and reconstructing 3-D image
    - Computed Tomography (CT)
- In general, larger penetration requires higher energies
- Different issues define image quality (contrast)
  - Scattered radiation
  - Characteristics of the receptor and display system
  - Characteristics of body parts and radiation



Contrast

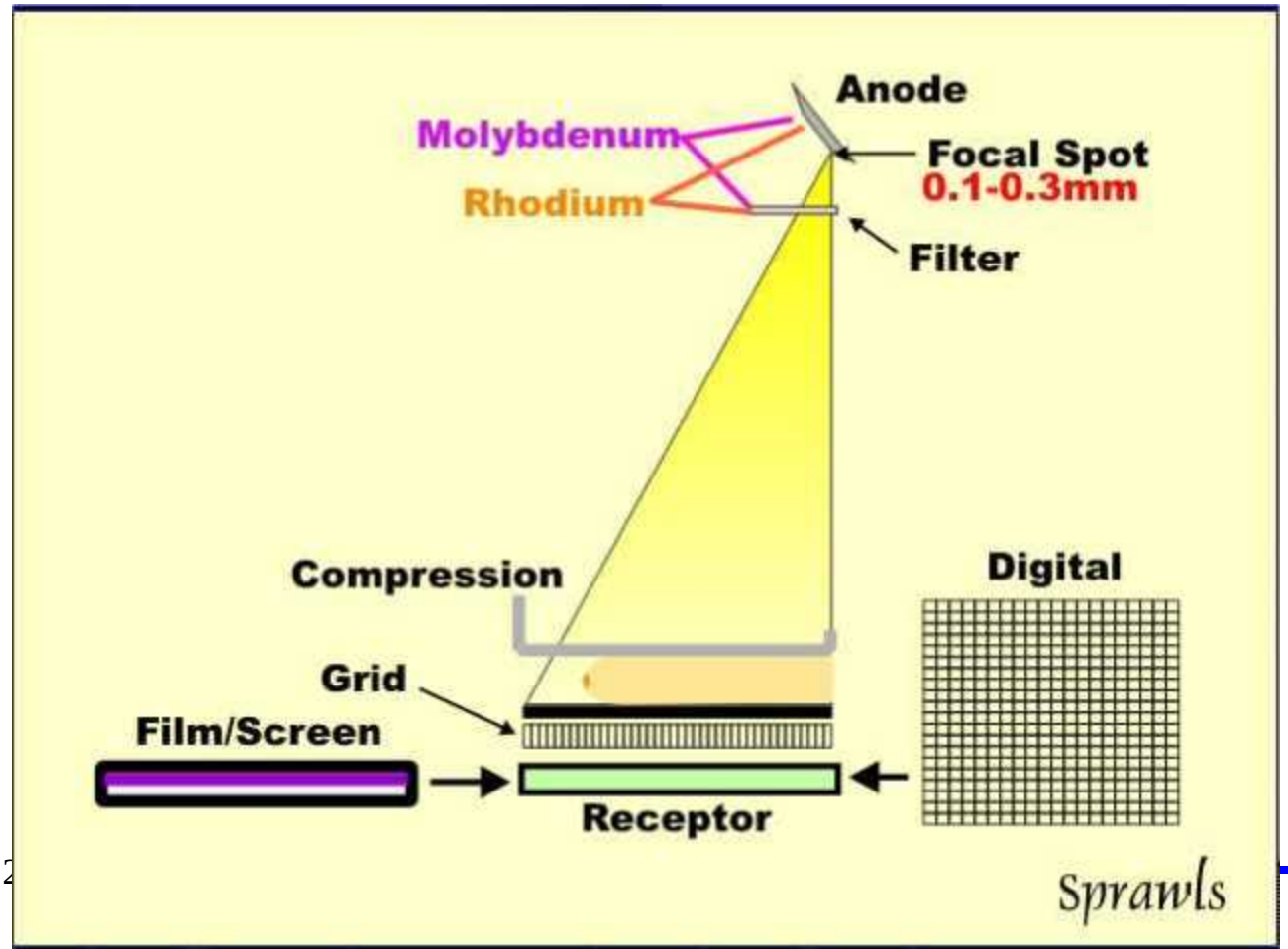
- X-ray imaging contrast:
  - Either atomic number (Z) or density difference

Material	*Effective Atomic Number (Z)*	*Density (g/cm^3)*
Water	7.42	1.0
Muscle	7.46	1.0
Fat	5.92	0.91
Air	7.64	0.00129
Calcium	20.0	1.55
Iodine	53.0	4.94
Barium	56.0	3.5



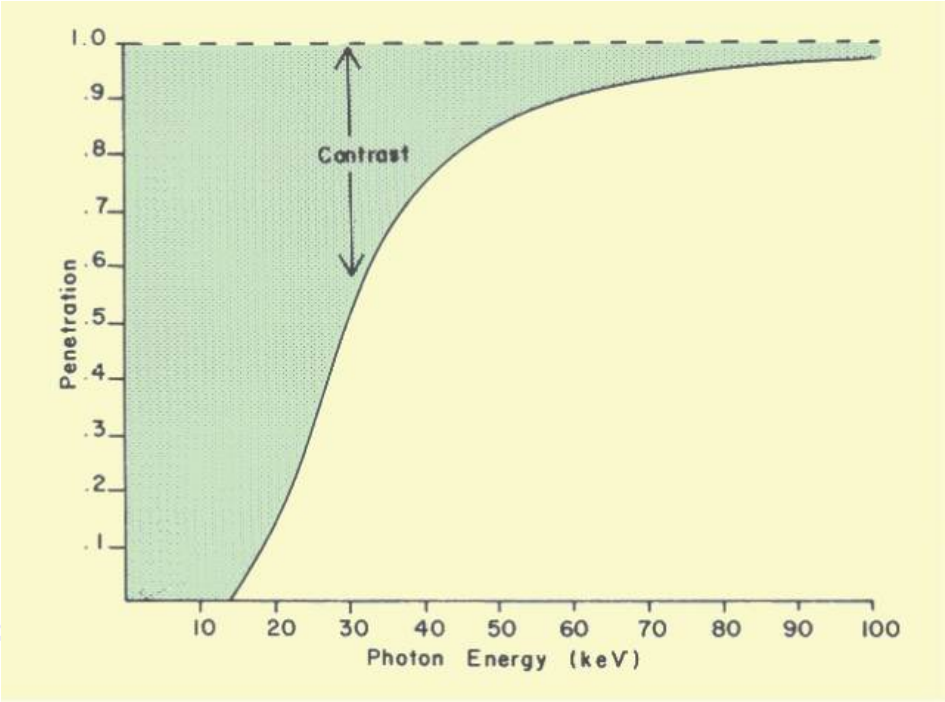
Mammography

- The setup:



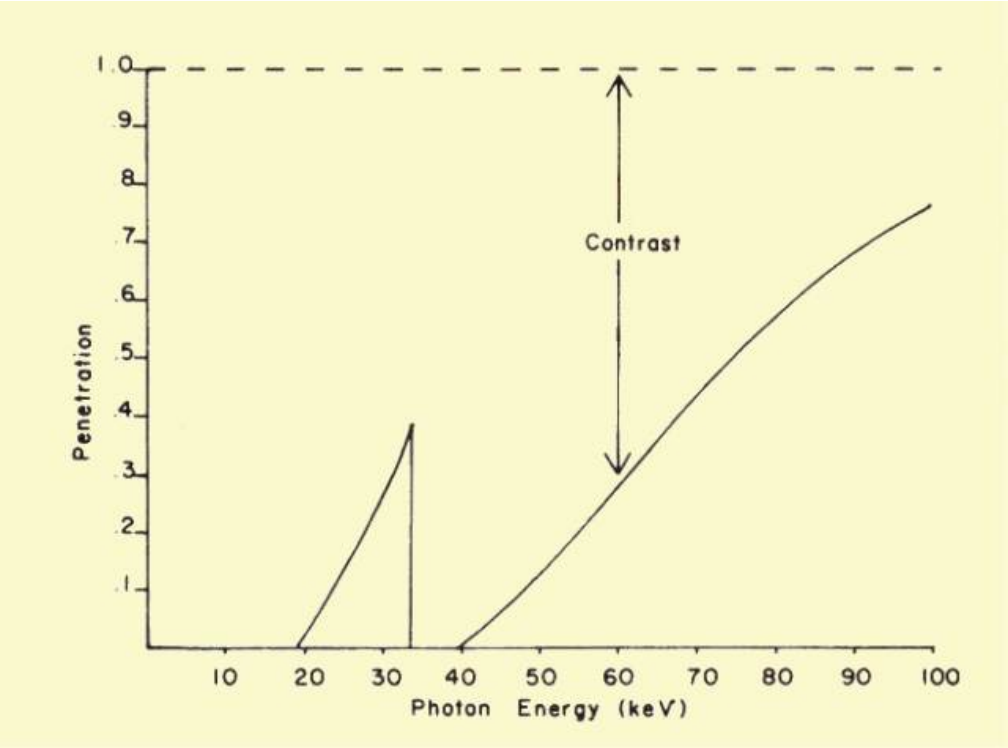
Calcium Effects

- Calcium is a source of contrast
  - Important for imaging bones
  - Even more important in calcifications that are associated with some pathological conditions
  - Used x-ray energy will depend on the size
    - Imaging bones requires high energy
    - Smaller calcifications in breasts require lower energy



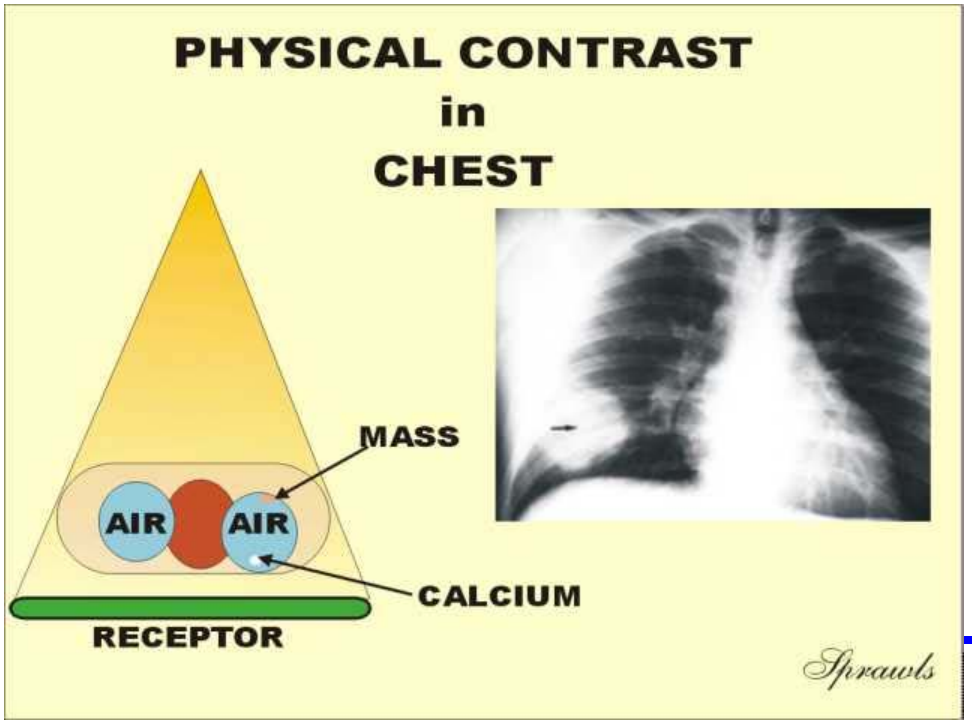
Other Contrast Media

- Iodine and Barium
  - K edge (I) = 33 keV
  - K edge (Ba) = 37 keV
- The highest contrast achieved with a slightly higher x-ray energy
  - Maximizes PE effect



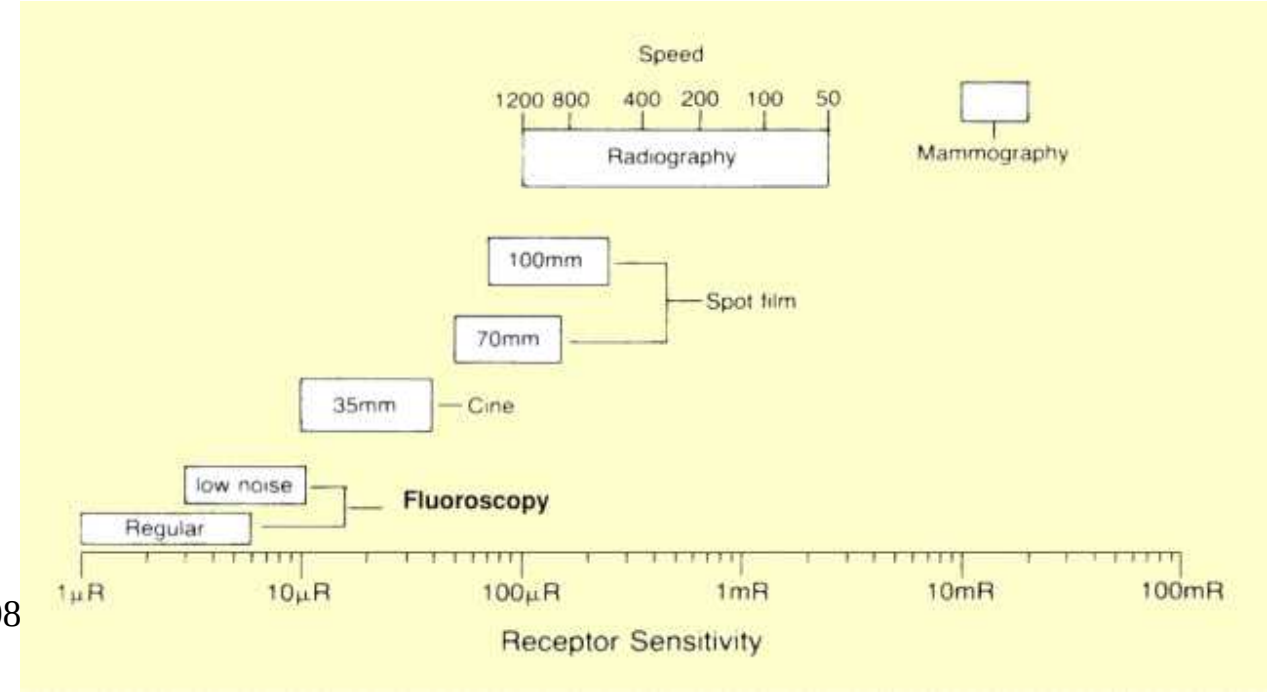
Radiography

- Chest imaging is challenging
  - High contrast between lungs and the mediastinum
  - High penetration needed
  - Some objects that need to be identified (calcifications) are very small



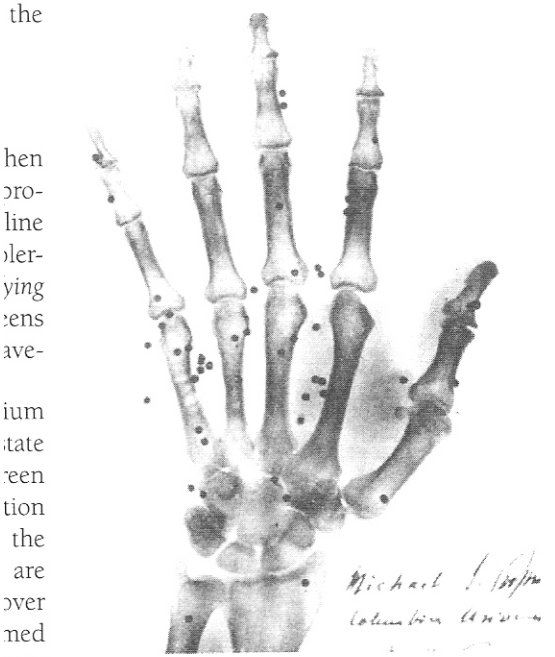
Radiography

- Different receptors used
  - Film – dynamic range has to be high
  - Digital imaging – overcomes some problems with digital processing (local enhancements of contrast,…)
- Sensitivity of different techniques

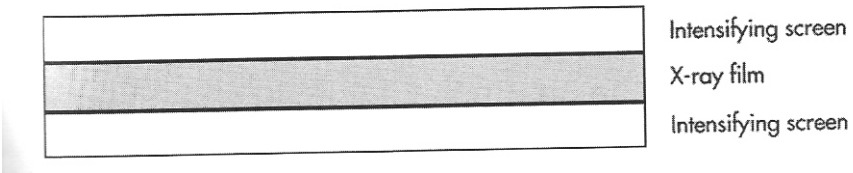


Imaging Media

- Film
  - Traditionally used
  - Proper exposure is crucial
  - Good detail – long exposures needed
  - Image has to be developed
- Intensifying screen and image intensifier
  - Increase the efficiency and shorten exposure time
  - Calcium tungstate fluoresces in blue and additionally exposes the film
  - Different materials are used lately (rare-earth elements)

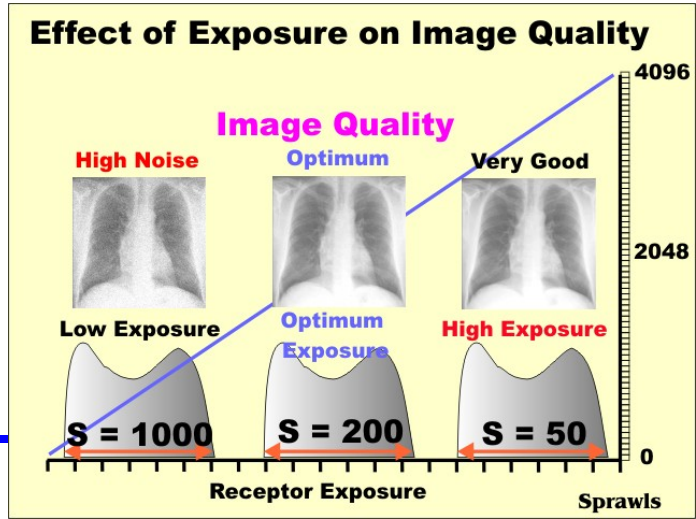


MARGIN FIGURE 9-2
First screen-film radiograph obtained by M. Pupin of Columbia University in February 1896. The radiograph demonstrates a shotgun wound to the hand.[1]



Imaging Media

- Digital detectors
  - Pixels define the image
  - Manipulation and storage simpler
  - Based on photodiodes, scintillation probes, CCDs, storage phosphors,…
- Digital systems
  - Do not have limitations on exposure time, as defined by film speed
  - Wide dynamic exposure range
  - Much more sensitive than image screen systems



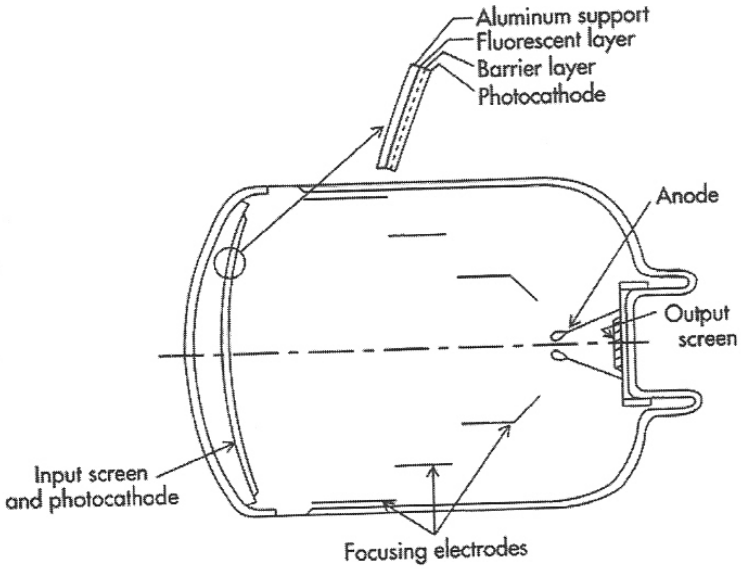
Fluoroscopy

- Radiography furnishes information at a particular point in time

- Fluoroscopy: continuous stream of images
  - Radiation passing through the patient directed to the fluorescent screen
  - Image intensifier and camera are usually used

Fluoroscopy

- Image intensifier
  - Layer of CsI emits visible light in proportion to x-ray intensity incident on the screen
  - Light ejects electrons from photocathode surface
  - Electrons are accelerated toward the anode and form an image on output screen
  - Significant brightness gain (minification and electronic gain)



RE 9-5
section of an x-ray image intensifier.

Next Time

- Computed Tomography
- Radiation Doses