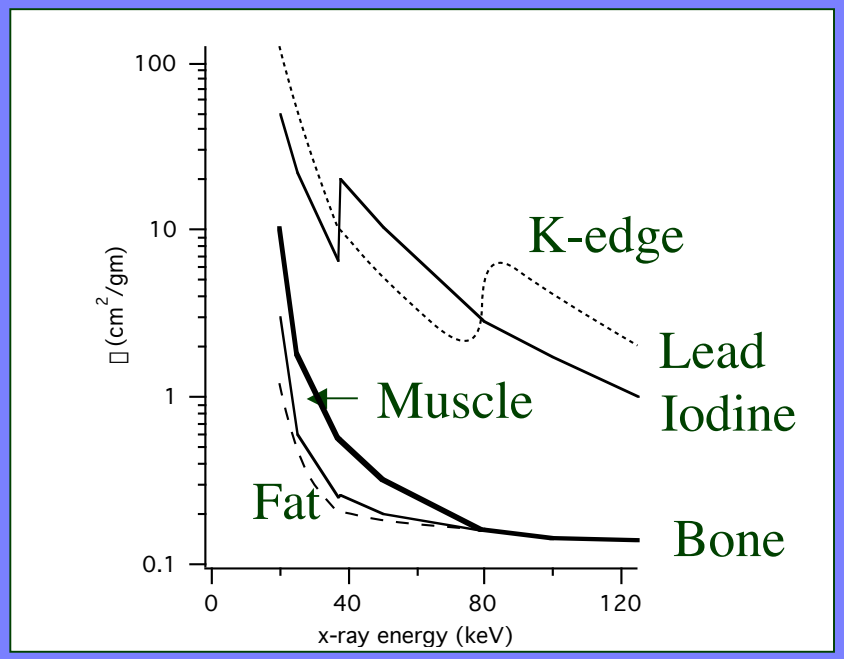
Lecture 6: X-ray Imaging

- Film Radiography
- Fluoroscopy
- Angiography
- Tomography
- Computed Tomography

www-personal.umich.edu/
~agrxray/index.html

Review of X-ray Properties

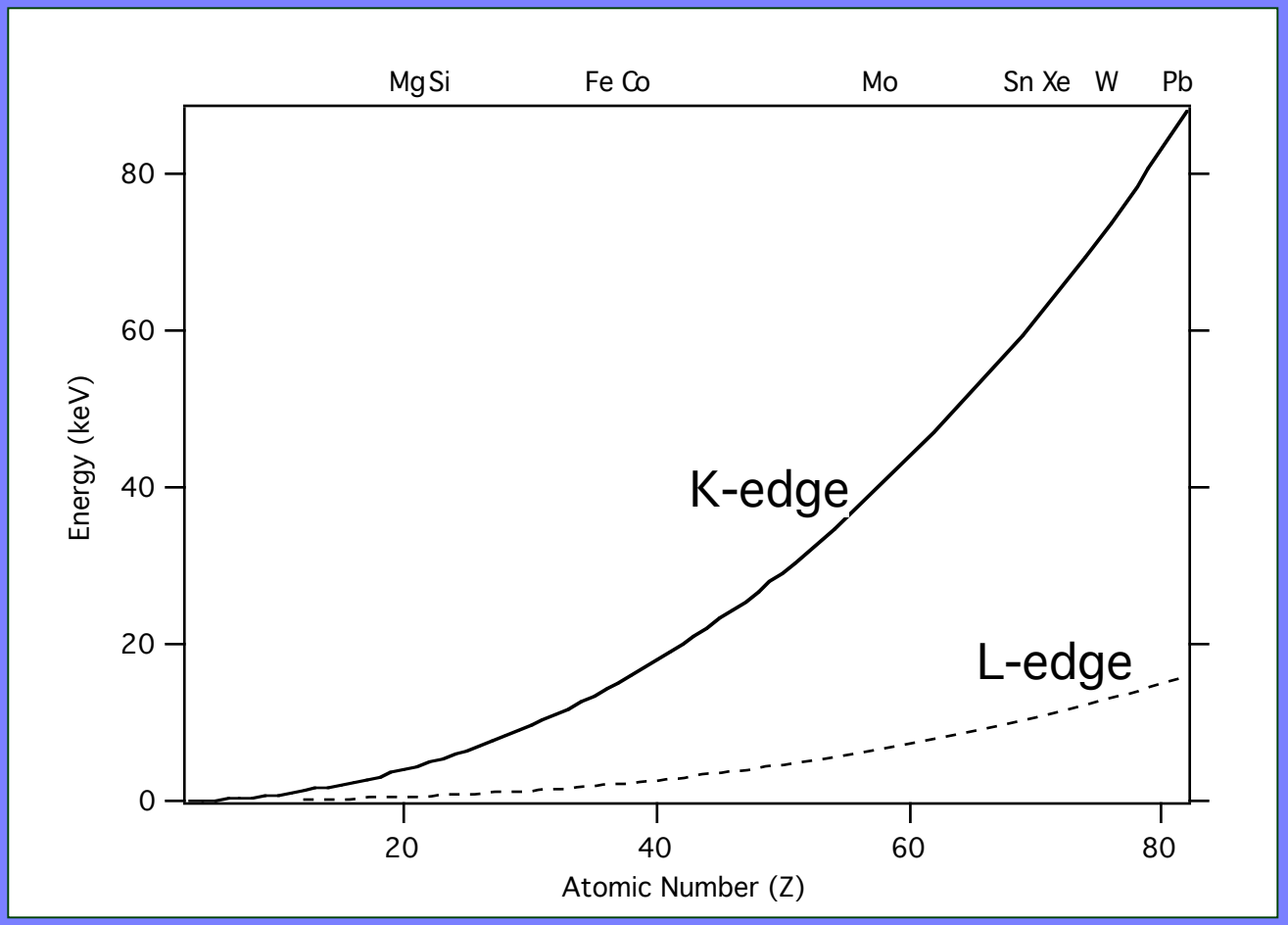
- X-rays are penetrating: $I=I_0e^{-\mu t}$
- X-ray attenuation grows with Z (atomic number) ~Z^3
- X-ray attenuation falls with E (Energy)~$1/E^3$
-



	μ	ρ
Water	0.21 cm^2/gm	1 gm/cm^3
Muscle	0.20 cm^2/gm	~1 gm/cm^3
Fat	0.17 cm^2/gm	~0.9 gm/cm^3
Bone	0.30 cm^2/gm	1.9 gm/cm^3
Pb	6 cm^2/gm	11.3 gm/cm^3

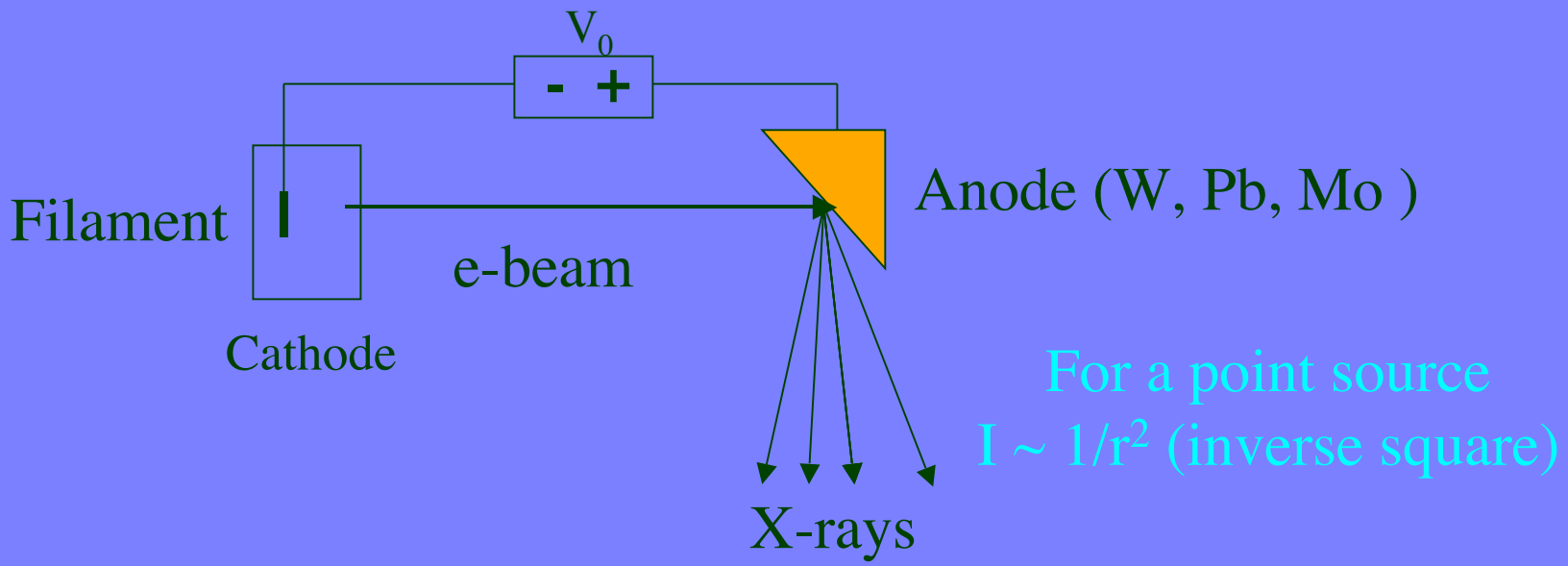
$\mu^{-1} = \rho$

K and L Edges


Mg Si
Fe Co
Mo
Sn Xe
W
Pb
80
60
40
20
0
Energy (keV)
K-edge
L-edge
20
40
60
80
Atomic Number (Z)

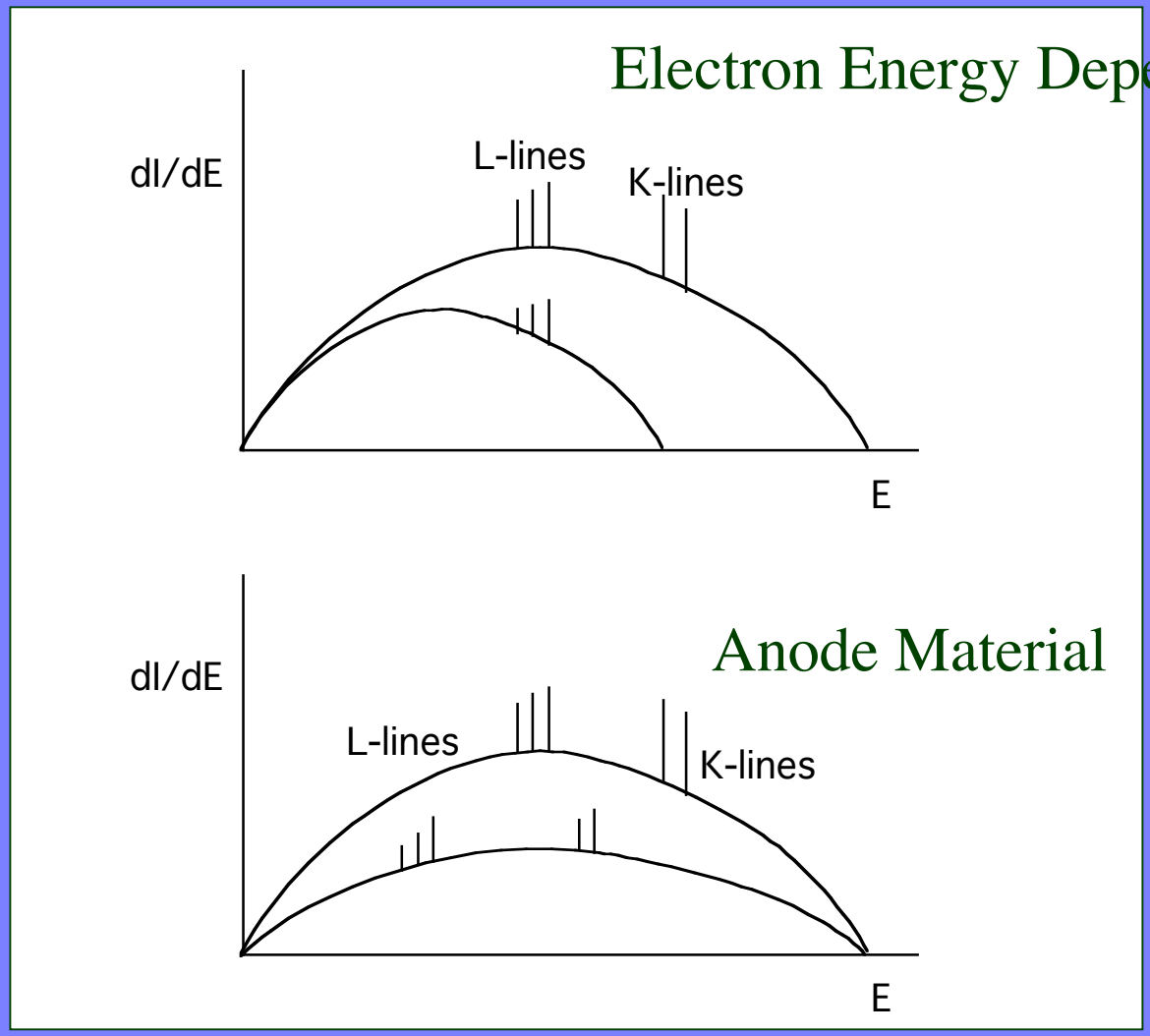
X-ray Generation

- Electron Beam Incident on Cathode



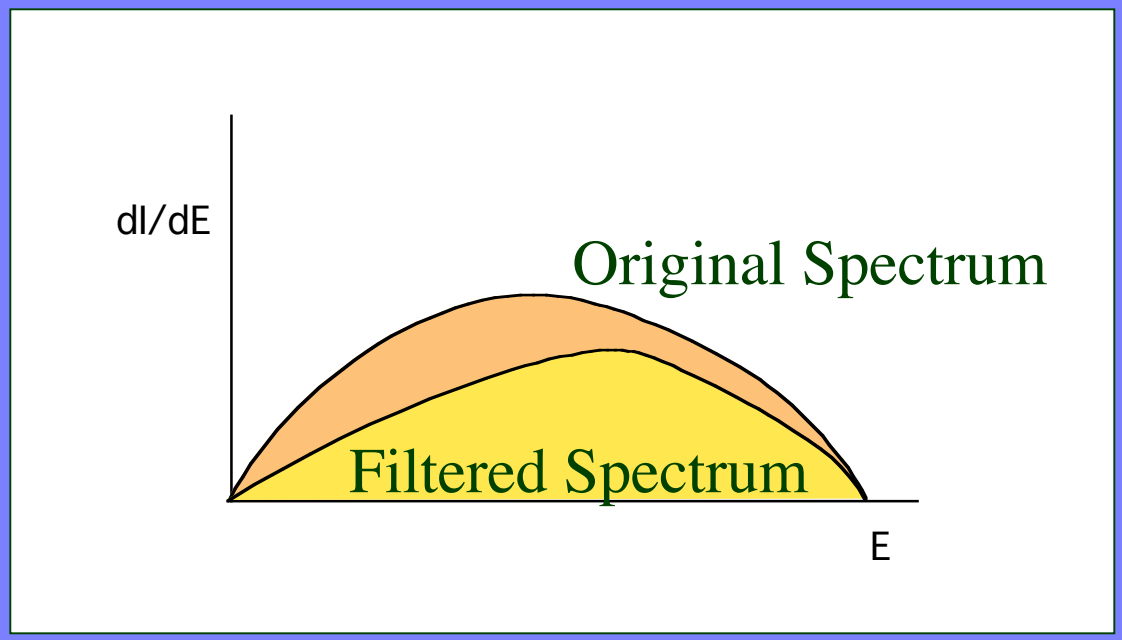
- X-fluoresence (alpha particle)
  - Emits K,L,M lines only

X-ray Emission Spectra



Power=$\int E(dI/dE)\, dE = IV_0$-Heat

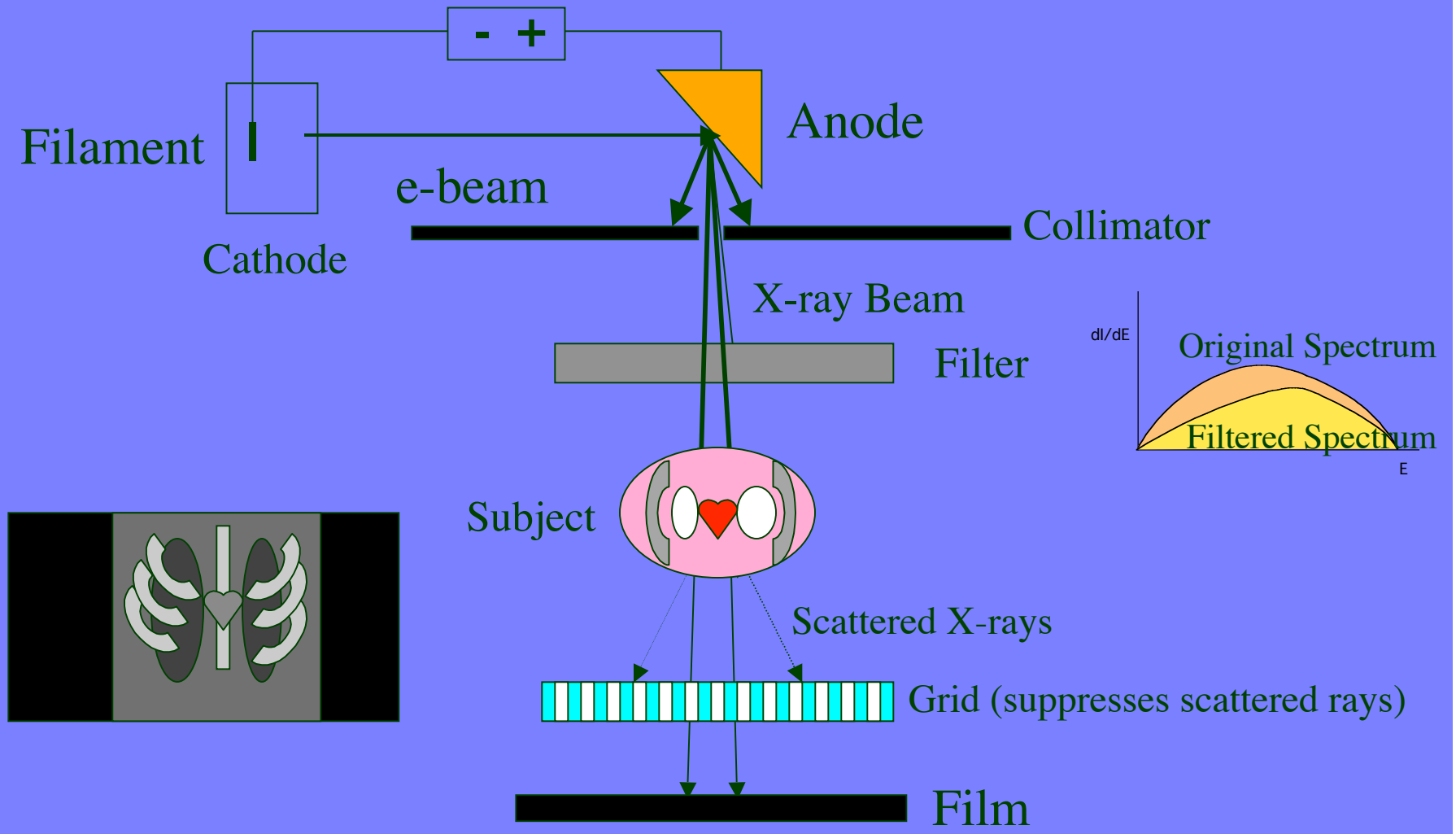
X-ray Filters



Lower Energy X-rays completely absorbed in the patient:

- **Dose**
- **No film exposure**

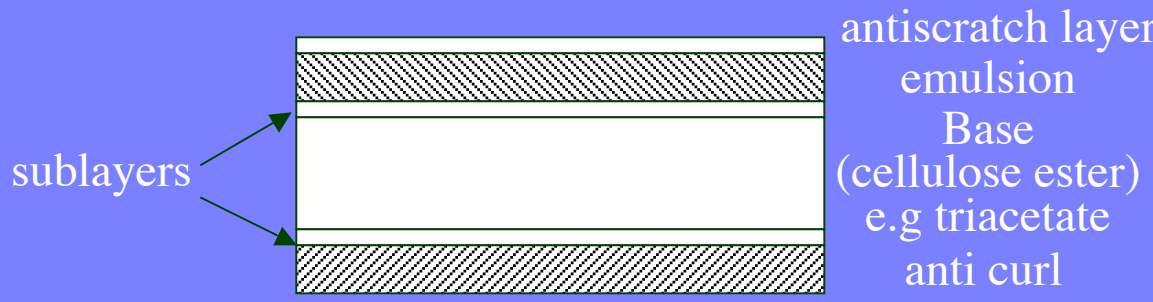
X-radiography



X-ray Detectors

- Film silver bromide -> silver atoms
  - Silver density (D) is linear with $E=\int Idt$ (exposure)
    - $\gamma = \text{Log } D / \text{Log } E \sim 1$
  - Saturation at high exposure
- Digital still and video
  - CCD (Charged coupled devices)

Film: Light Sensitivity

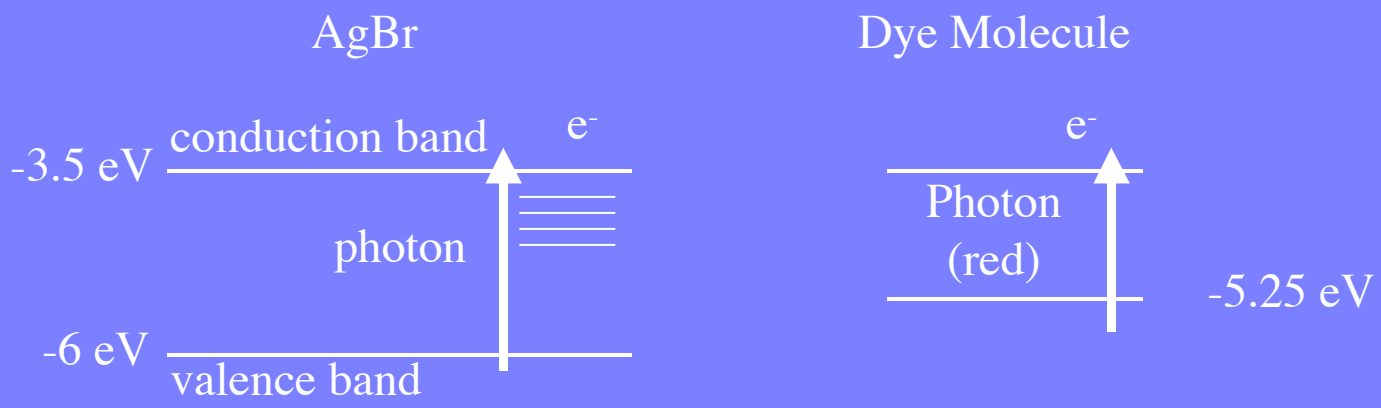


- Emulsion: silver halides AgBr (AgCl, AgI)
  - $AgBr + photon \rightarrow Br^{*} + Ag$
  - $Br^{-} + photon \rightarrow Br^{*} + e^{-}$
  - $Ag^{+} + e^{-} \rightarrow Ag$ (binds to sublayer)
- Development: Reduction of AgBr
  - $AgBr + R \rightarrow Ag + R_{O} + Br^{-}$

Spectral Sensitivity

- Normally silver halides are BLUE sensitive
- Dyes extend sensitivity to green/red

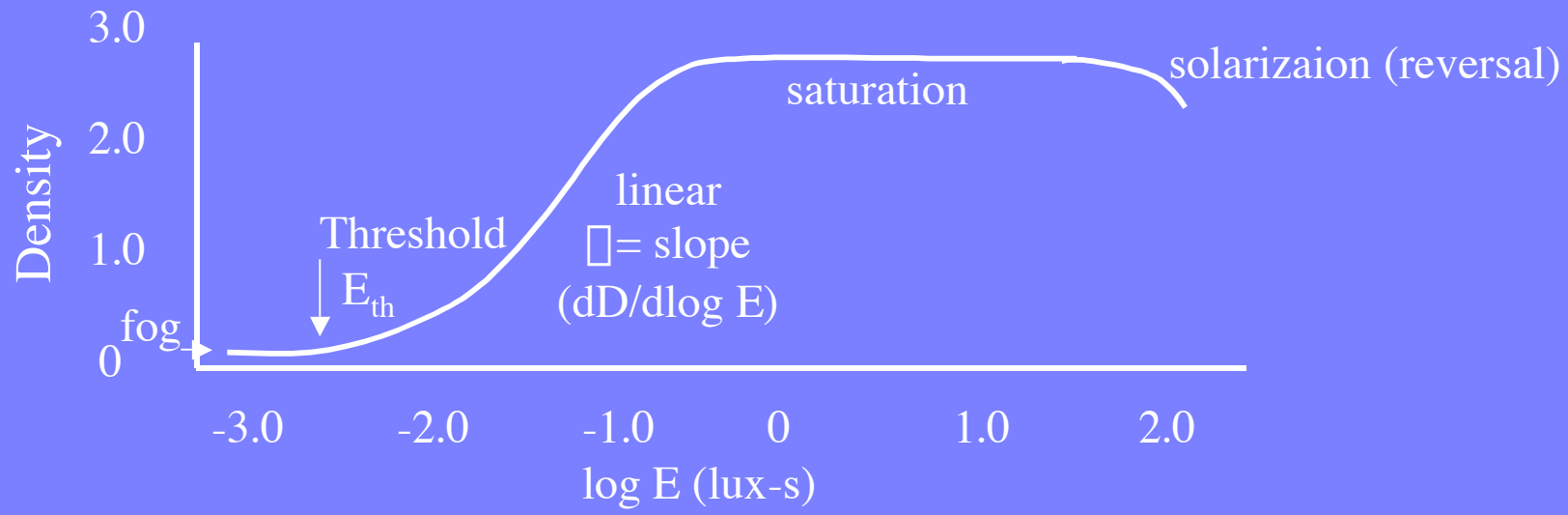
(for visible light photography)



$$\frac{2.5\ \text{eV} * 1.6\text{x}10^{-19}\ \text{J/eV}}{6.63\text{x}10^{-34}\ \text{J/Hz}} = 6 \text{ x } 10^{14}\ \text{Hz} \sim 492\ \text{nm}$$

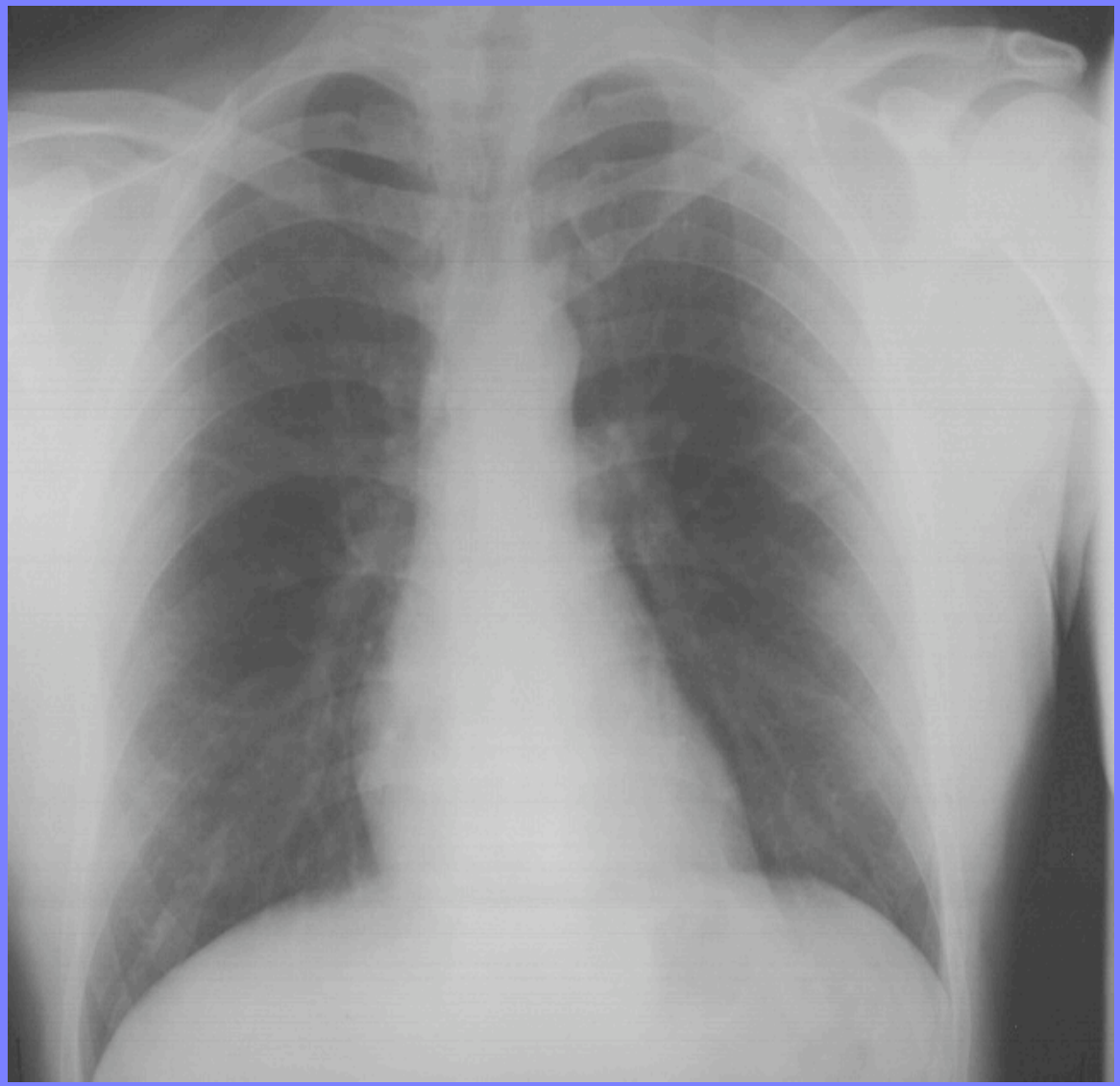
Film Sensitivity

- Transmission through negative $t=I/I_0$
- Opacity $O=1/t = I_0/I$
- Density $D = \log_{10} O$



X-radiographs

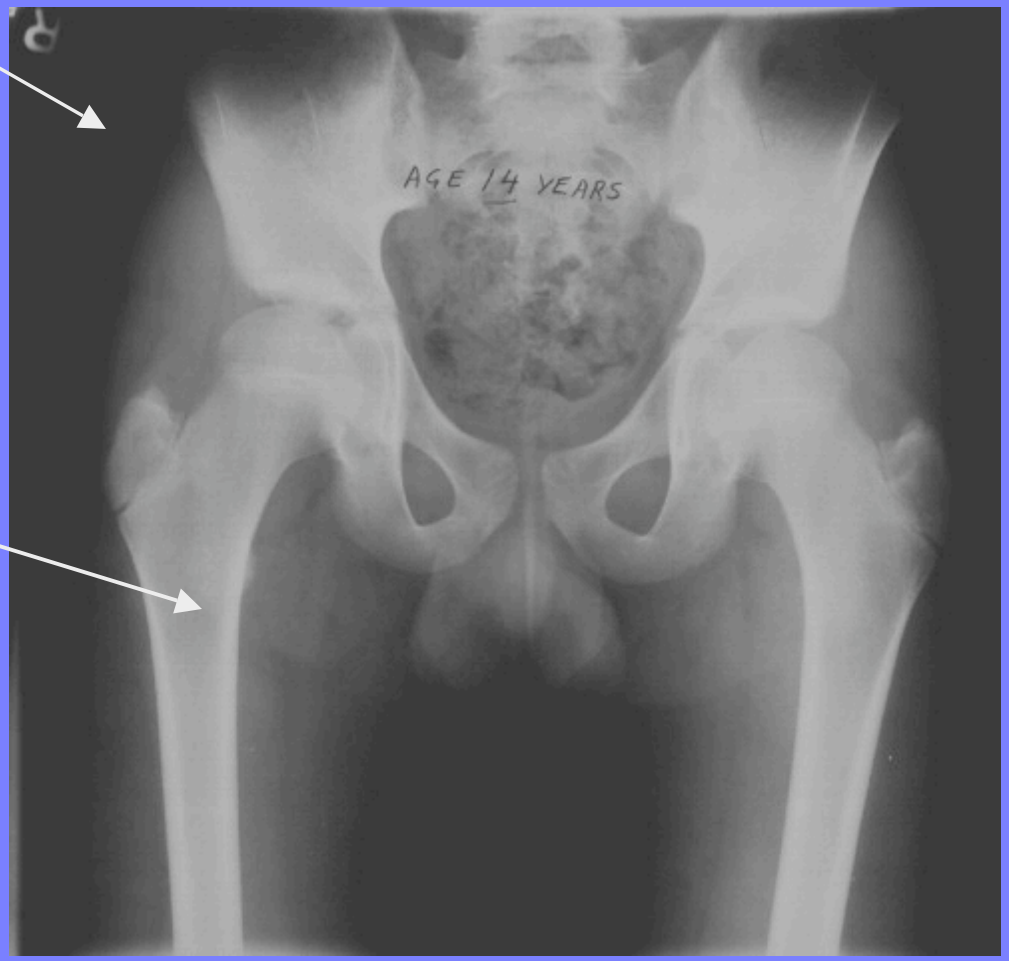
Chest X-ray



Pelvic X-ray

More Exposed

Less Exposed



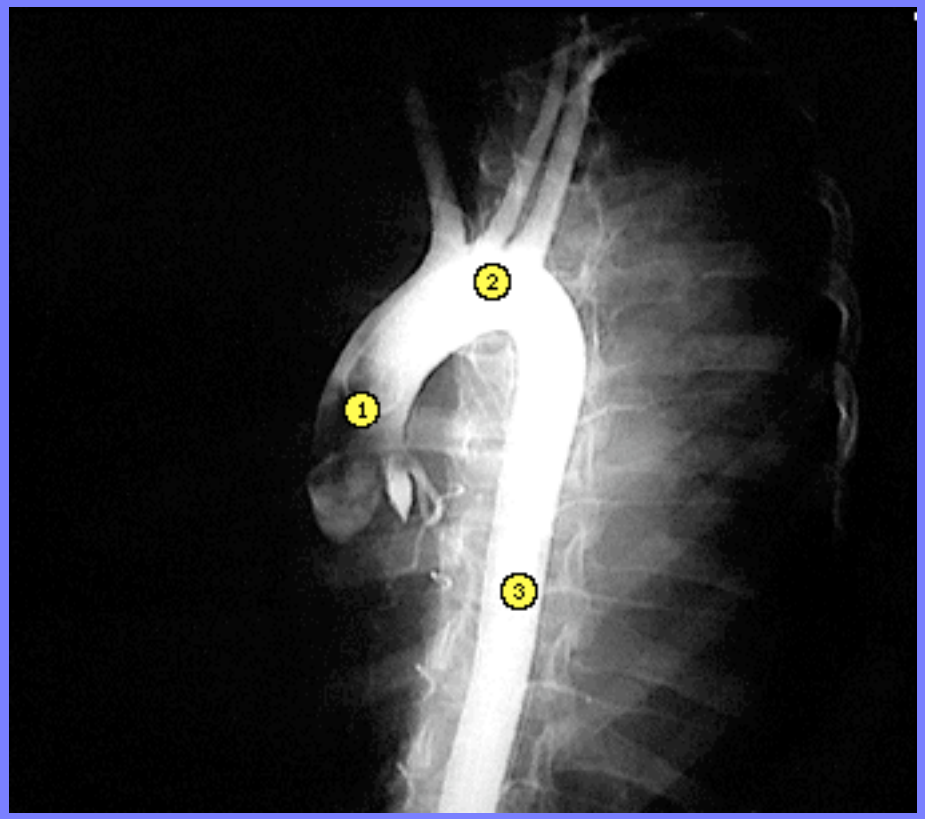
X-ray contrast

$C = O_{max}/O_{min}$

- Heavy elements (high Z) have higher attenuation
  - 3 cm bone (Ca,P) $I=0.18\ I_0$; 3 cm H_2O $I=0.54\ I_0$
- Injectable contrast agents
  - Barium (Z=56): used for colon and bowel
  - Iodine (Z=53): used for angiography (blood stream)
  - Xenon (Z=54): used for lungs and brain
- Subtraction:
  - Make images before and after injection

Angiogram

1-ascending aorta
2-aortic arch
3-descending aorta



- Catheter injects iodine contrast agent into the ascending aorta and while x-rays are made.
- Patient Position adjusted

Harmful Effects of X-rays

- Ionizing Radiation: dislocates electrons/atoms
  - H_2O + radiation -> $H_2O^+ + e^-$: OH, H^+, H, OH^-, H_2O_2
    - Early cell death
    - Inhibited cell division
    - Genetic modification of chromosomes
- Units of exposure:
  - Curie (activity) 1 Cu = 3.7×10^{10} disintegrations/s
  - Rad (absorbed dose) 1 rad = 0.01 J/kg (water) 100 R=1Gr
  - Rem(includes biological effectiveness - RBE)
    - 1 for x-rays
    - 5 slow neutrons
    - 20 for alpha particles, fast neutrons, protons

Typical Dose

• Chest Xray	20 mR
• Brain Xray	250 mR
• Abdomen	550 mR
• Dental	10 mR
• Mammography	50 mR
• CT slice	1000 mR