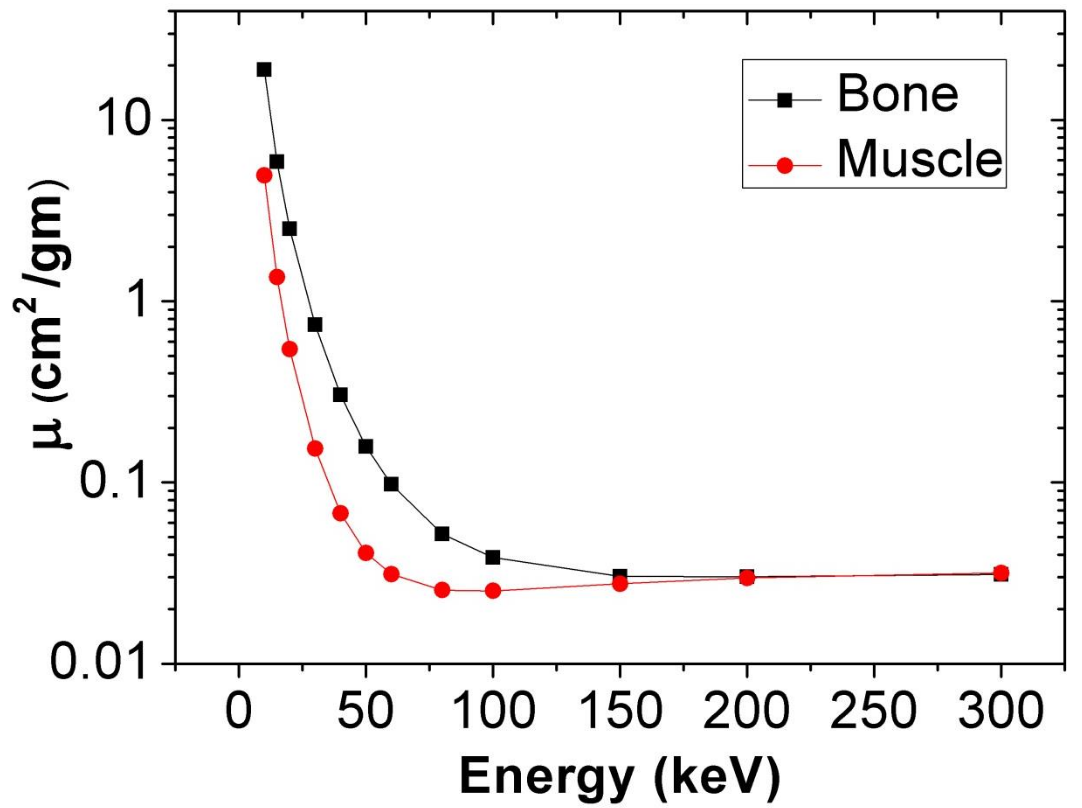
Lec 7: photoelectric and Compton effects; contrast agents

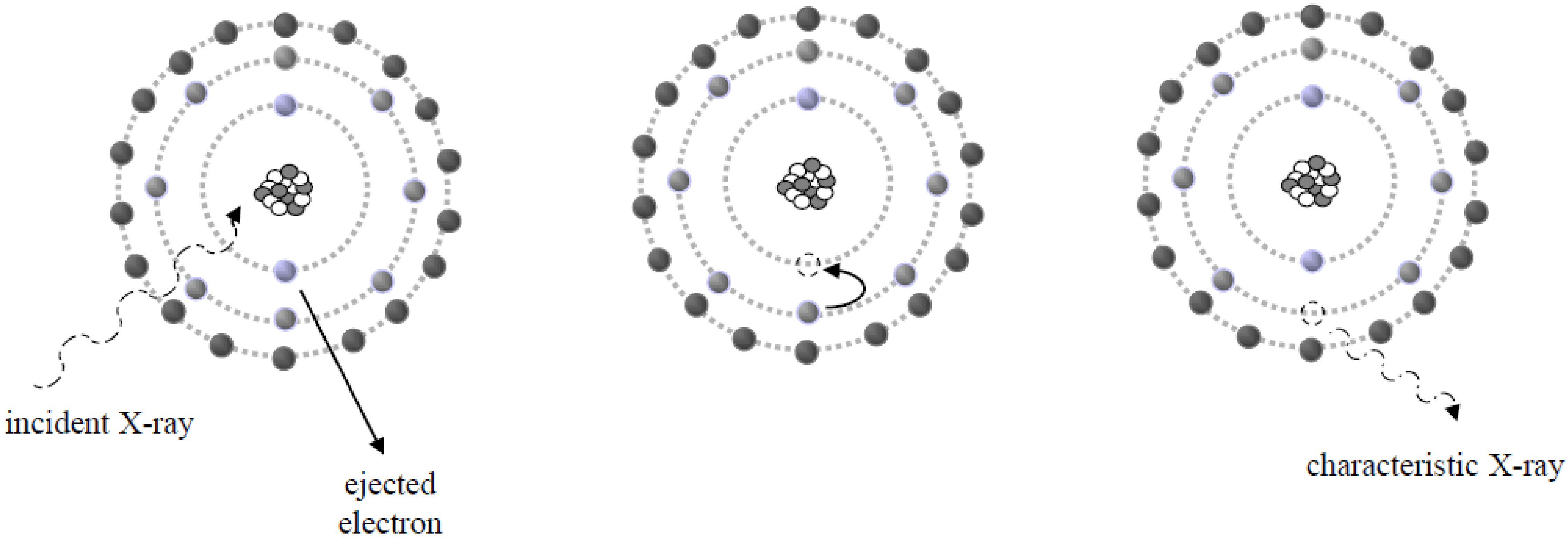
Recap: Value of μ depends on x-ray energy

X-ray photon energy (keV)	Mass attenuation coefficient (cm^2/g)	
	Compact bone	Muscle
10	19.0	4.96
15	5.89	1.36
20	2.51	0.544
30	0.743	0.154
40	0.305	0.0677
50	0.158	0.0409
60	0.0979	0.0312
80	0.0520	0.0255
100	0.0386	0.0252
150	0.0304	0.0276
200	0.0302	0.0297
300	0.0311	0.0317



Which energy range should we choose for better contrast?

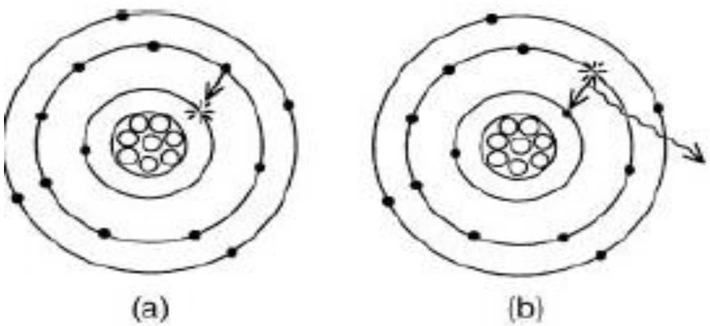
Photoelectric effect



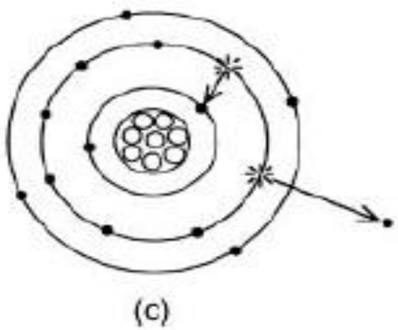
- Photon loses all its energy in one interaction with the tissue
- Watch out- the schematic diagram looks very similar to generation of characteristic x-rays.
- Inner shells

Auger electrons in photoelectric effect

X-ray photon ejects electron



Transition of electron from higher to lower level emits another photon



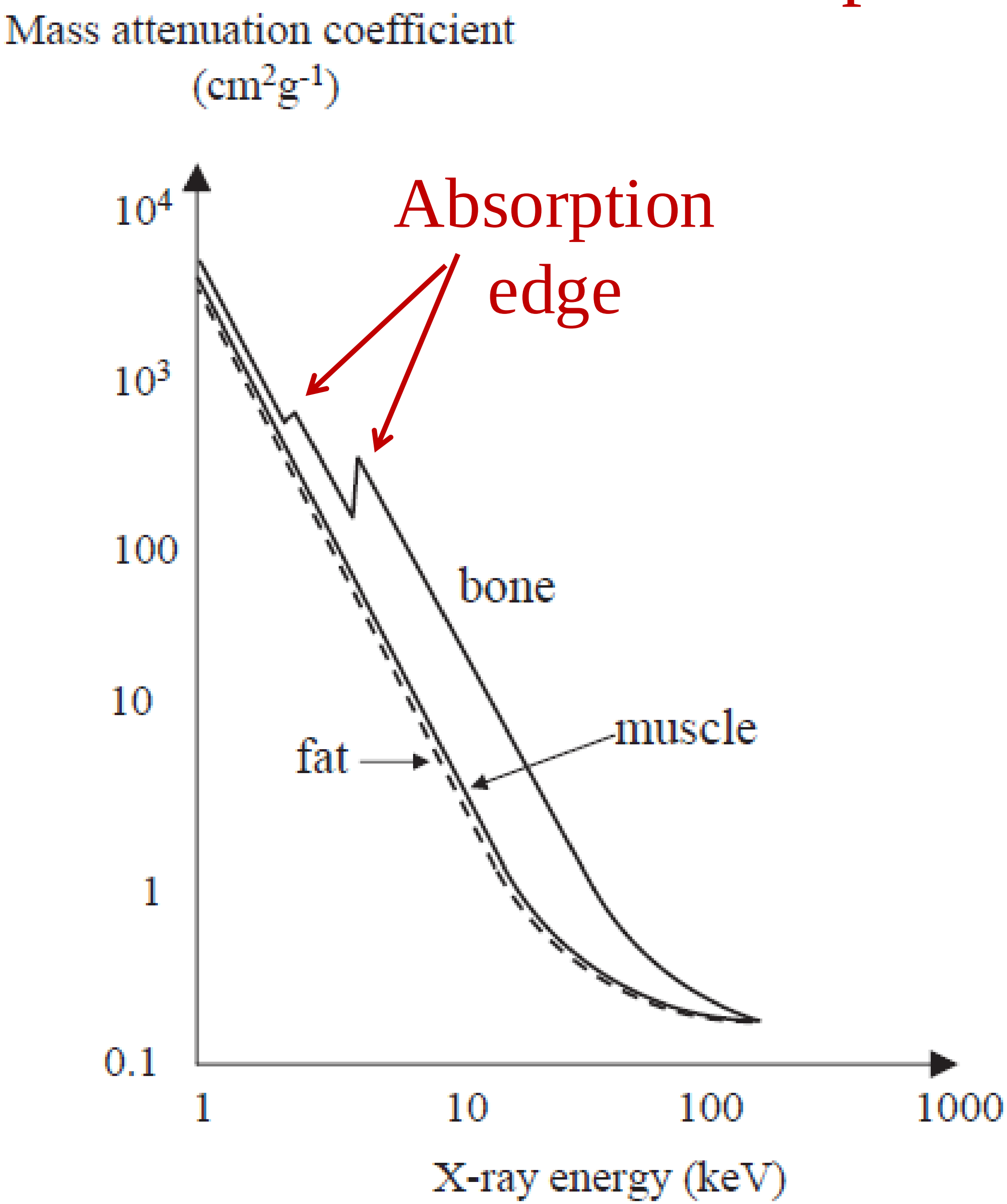
Auger transition ejects another electron instead of photon

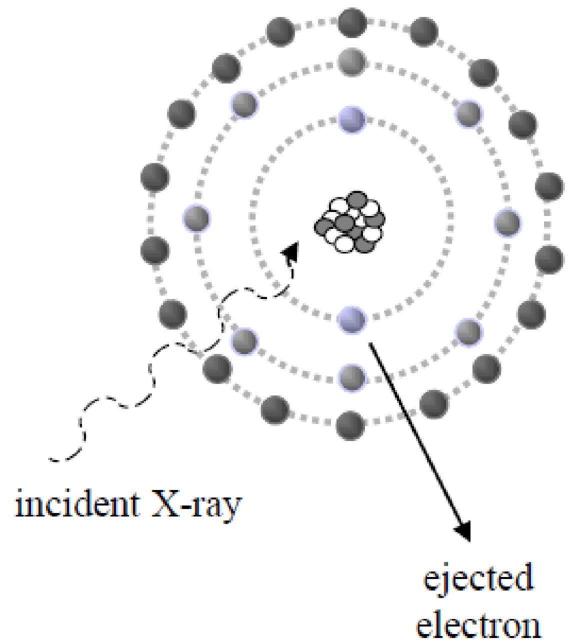
- Transition from higher (say, L) to lower energy shell (say, K) ejects another electron (usually from the same higher energy shell).
- Causes ionization of tissue.

$$K.E._{Auger} = E_{Bi} - 2E_{Bo}$$

Hendee, Pg. 16

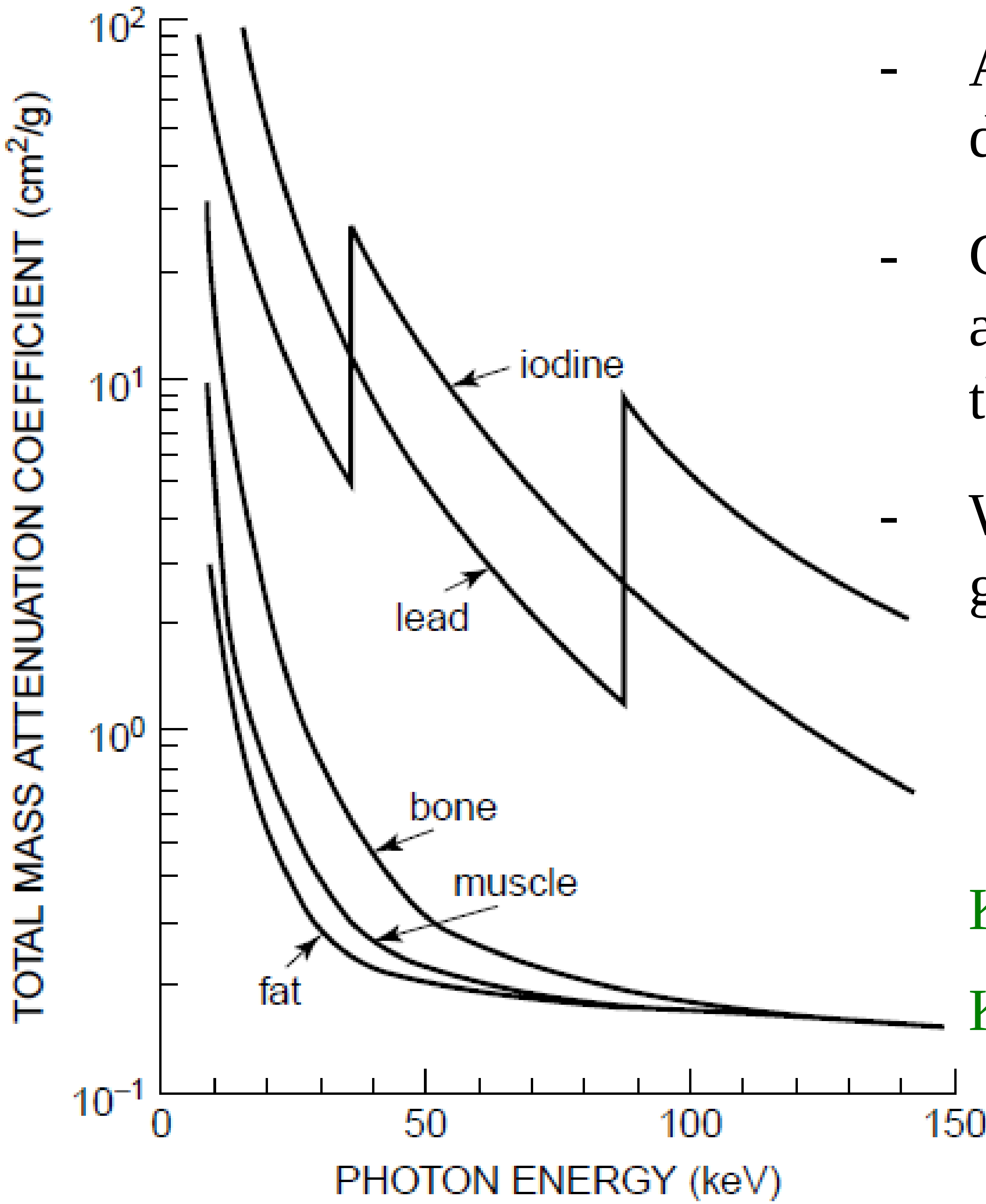
Absorption edge





Without absorption edges, attenuation coefficient of bone would have been similar to soft tissues.

Contrast agents



- Absorption edge helps in design of contrast agents
- Can we use lead as a contrast agent? Ignore its toxicity for the moment.
- Why are barium and iodine good contrast agents?

K-edge of iodine: 33keV

K-edge of lead: 88 keV

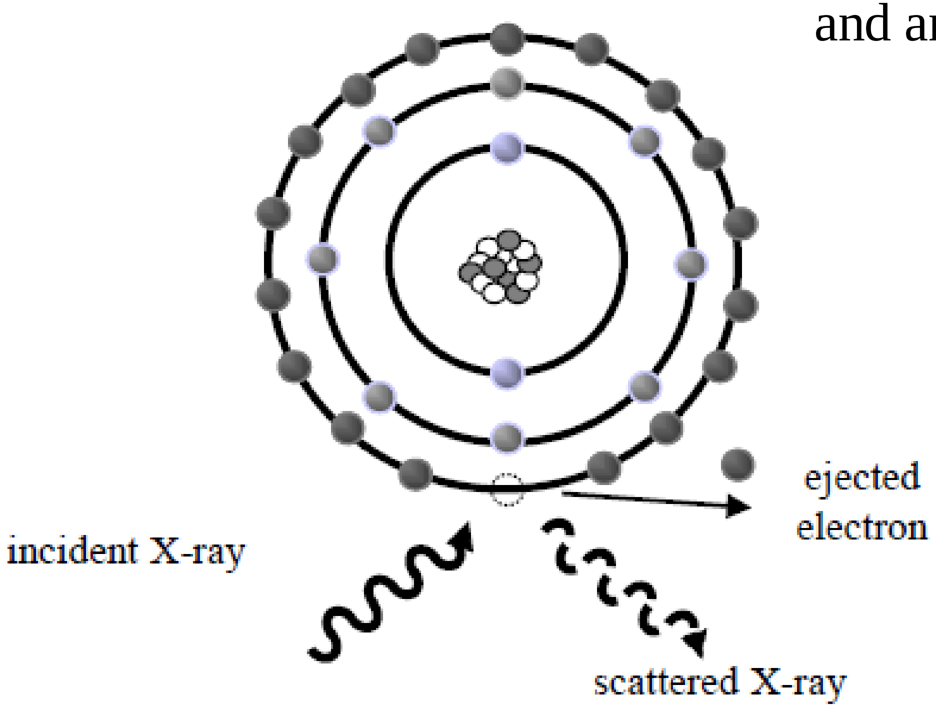
Angiograms with and without a contrast agent.

Effective atomic numbers of air (Z_{eff} = 7.65) and muscle (Z_{eff} = 7.4) are very similar. Air is often used to displace fluids that interfere with imaging. Why?

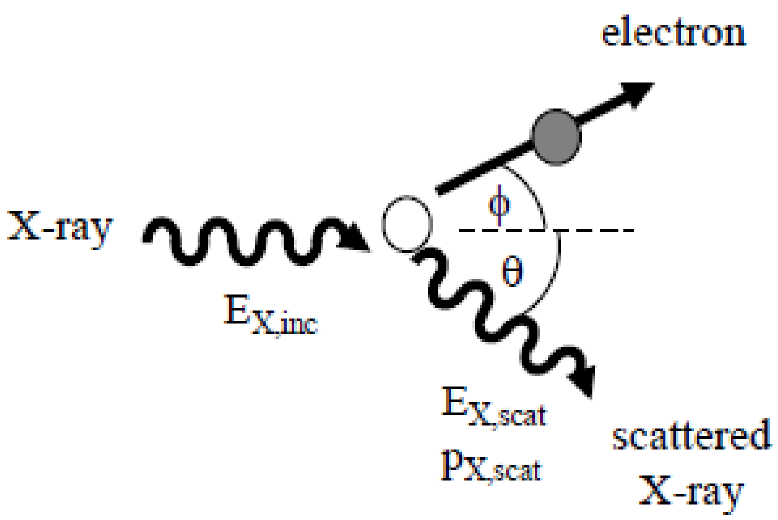
Compton scatter

- X-ray photon loses a part of its energy in one interaction
- Outer shells

- Leads to a scattered x-ray photon and an ejected electron.



Scattered x-ray wavelength



- Initial: incident x-ray photon + electron at rest
- Final: scattered x-ray photon + ejected electron
- Solve both energy balance and momentum balance equations.

$$\mathbf{\Delta\lambda = h/m_o c\,(1 - Cos\theta)}$$

Electron rest mass (m_o) = 9.11×10^{-31} kg

θ = x-ray scatter angle

Compton wavelength

$$\lambda c = h/m_o c$$

Compton wavelength ~ 2.5 pm

Change in wavelength

$$\boldsymbol{\Delta\lambda = (h/m_o c)\,(1 - \mathrm{Cos}\theta)}$$

When does the maximum change in wavelength occur?

Change in energy in Compton scatter

$\Delta\lambda = h/m_o c\ (1 - \text{Cos}\theta)$ ––––– (1)

$1/E_1 = 1/E_o + (1/\ 0.5\ \text{MeV})(1 - \text{Cos}\theta)$ ––––– (2)

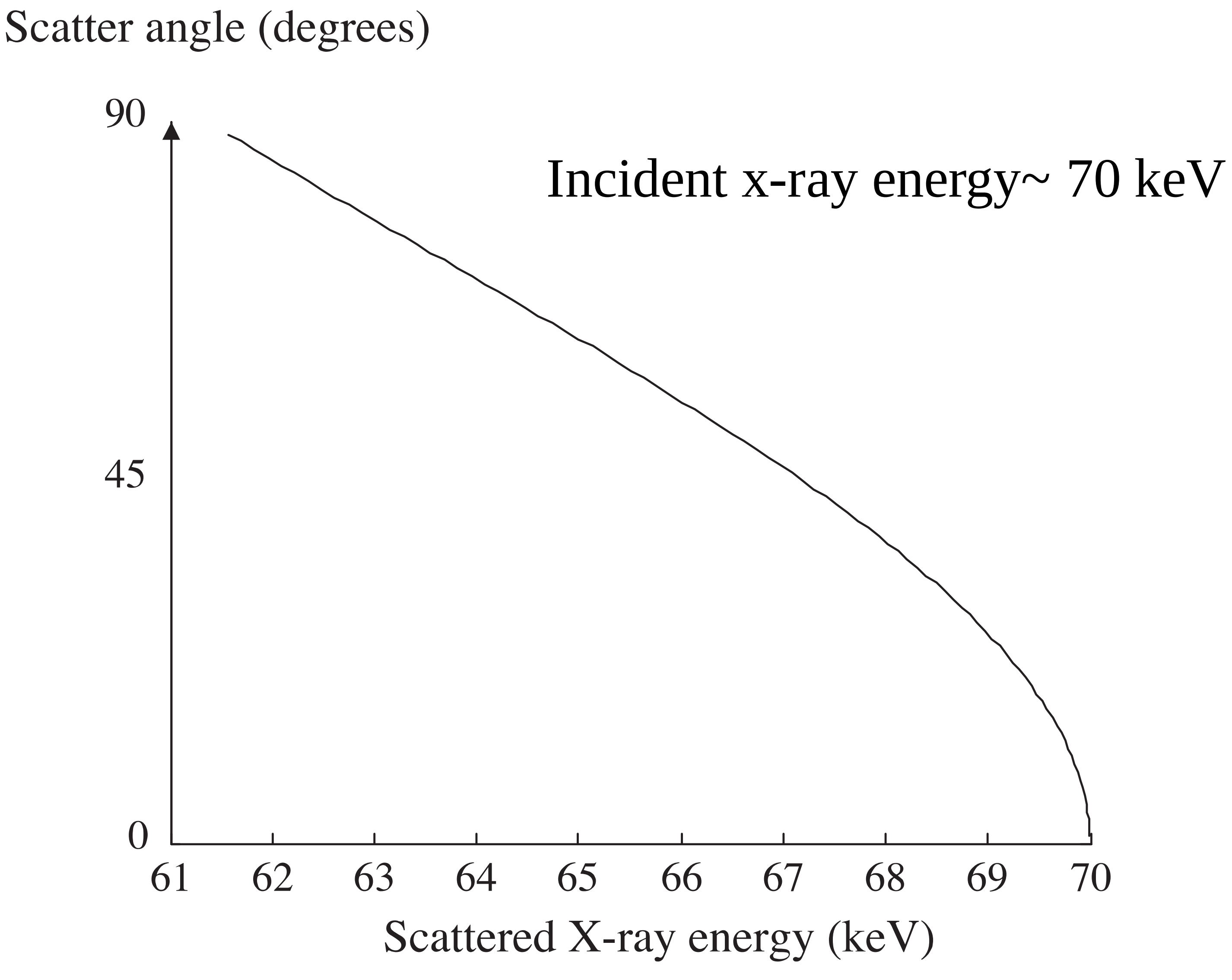
(Put $\lambda = hc/E$ and use rest mass of electron as 0.5 MeV)

Compton scatter is a problem in diagnostic imaging

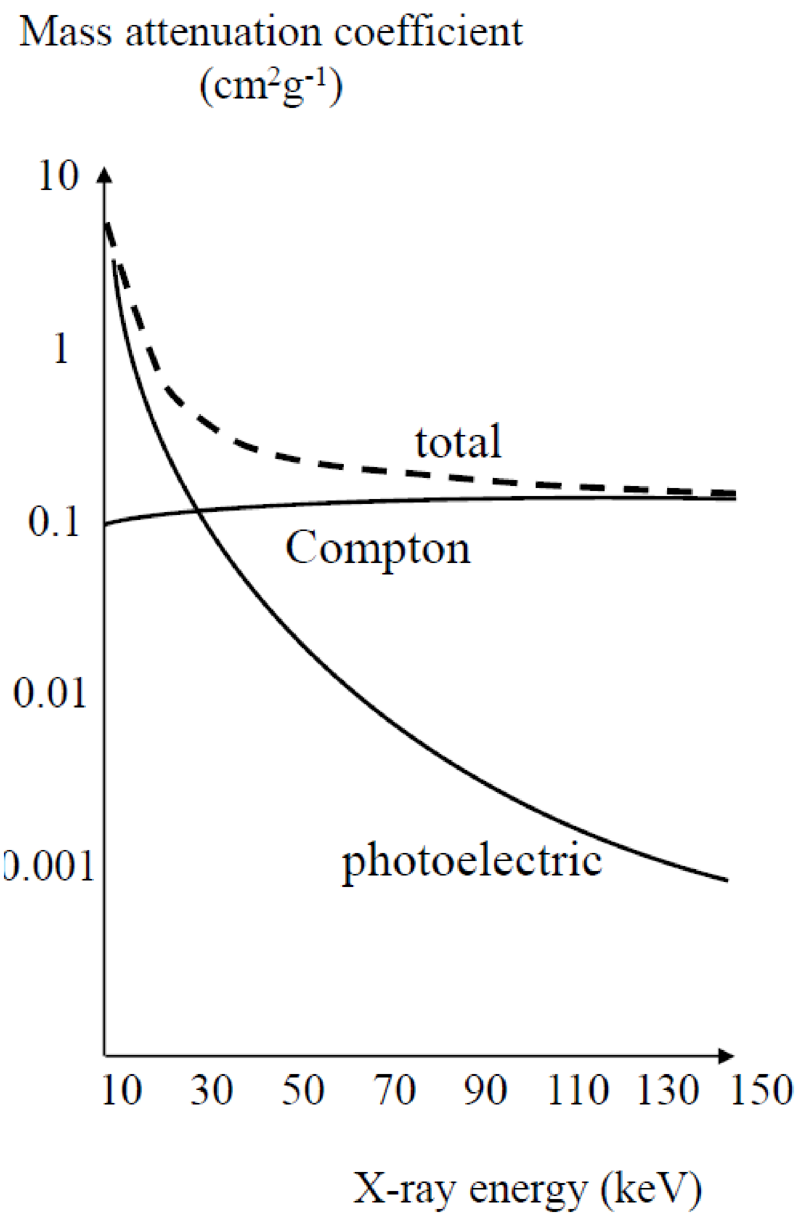
- Scattered x-ray photons have the same energy range as incident photons (for diagnostic x-ray energies)

- Does not contribute to good contrast

Problem with scatter



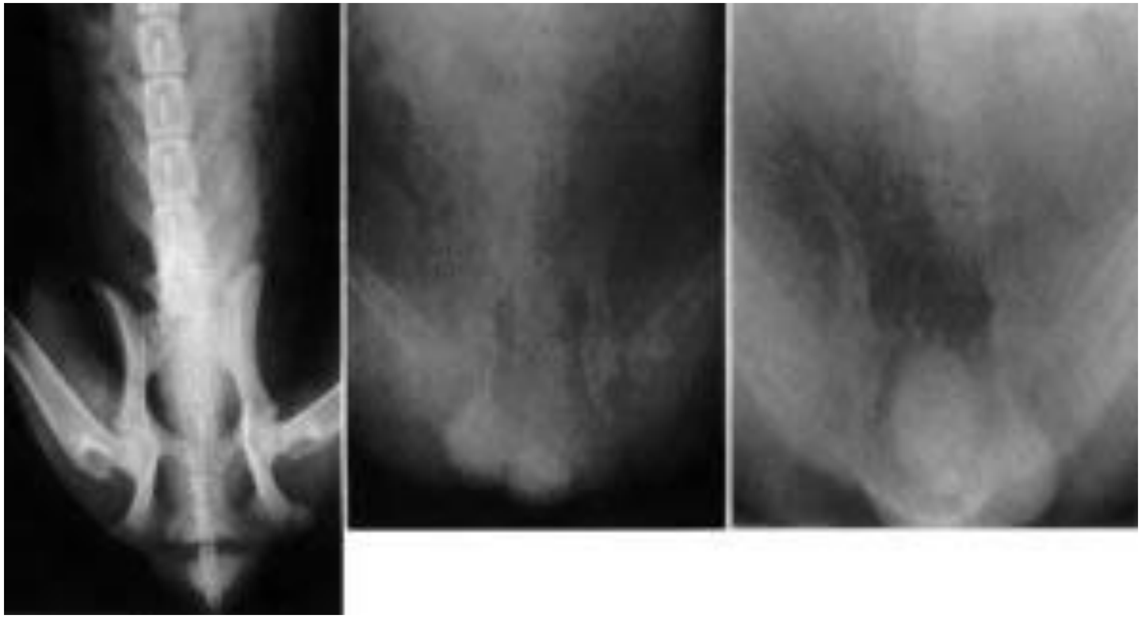
Attenuation mechanisms vs. energy



Low energies: Photoelectric interaction dominates

High energies:
Compton effect dominates

Incident energy and contrast



MARGIN FIGURE 4-19
Radiographs taken at 70 kVp, 250 kVp, and 1.25 MeV (^{60}Co). These films illustrate the loss of radiographic contrast as the energy of the incident photons increases.