Lecture 5: X rays

X-rays

- Electromagnetic radiation with "short" wavelength (~ 1 Å - atomic spacing in a solid)
- X-ray **photons**
  - Photons are Quanta of E.M. radiation

Duality

Wave Property

Frequency-wavelength

$c=\lambda f$

$c=2.97\times10^{8}$ m/s

Particle Property

Energy-momentum

$E=hf$

$p=h/\lambda=E/c$

$h=6.63\times10^{-34}$ J/Hz

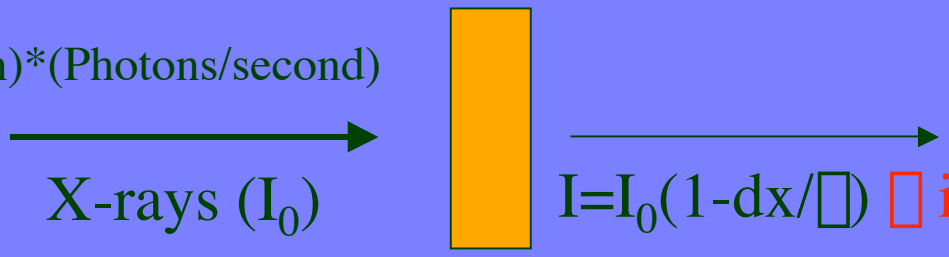
1 Å ~ 120 eV

X-rays are Penetrating

- X-ray attenuation depends on material
  - Density and thickness

I (power/area)

P = (Energy/Photon)*(Photons/second)

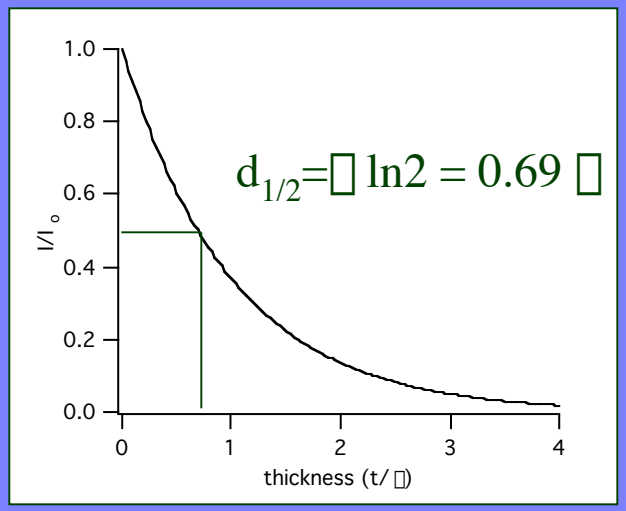


Note: (Energy/Photon) is often dropped

I ~ (Photons/second)

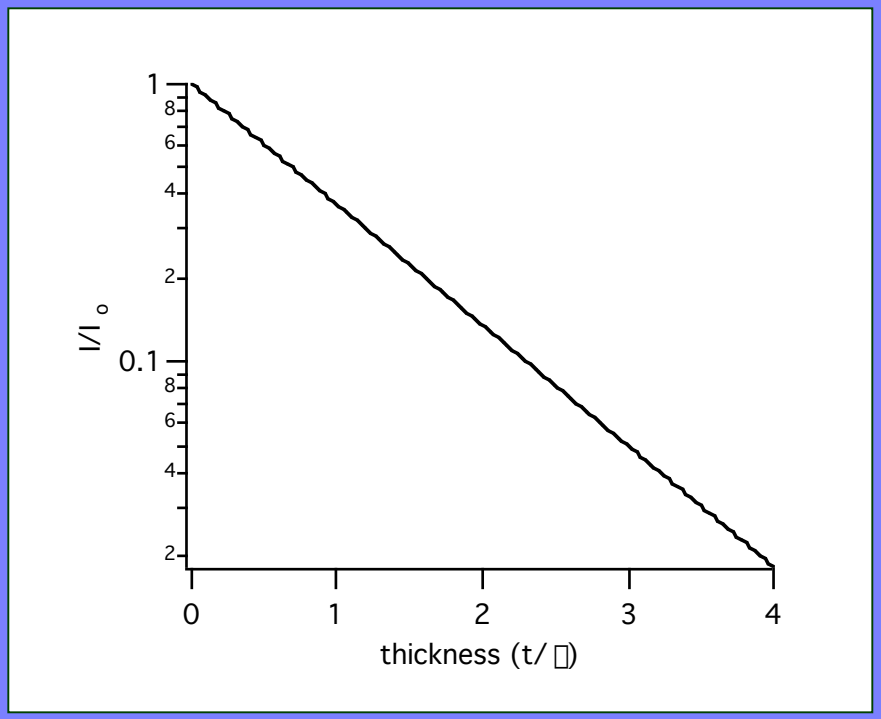
$$\frac{dI}{dx} = -I_0/\mu$$

$$I = I_0 e^{-t/\mu} = I_0 e^{-\mu t}$$



t is material thickness; μ (μ) depends on material

Life is Logarithmic!



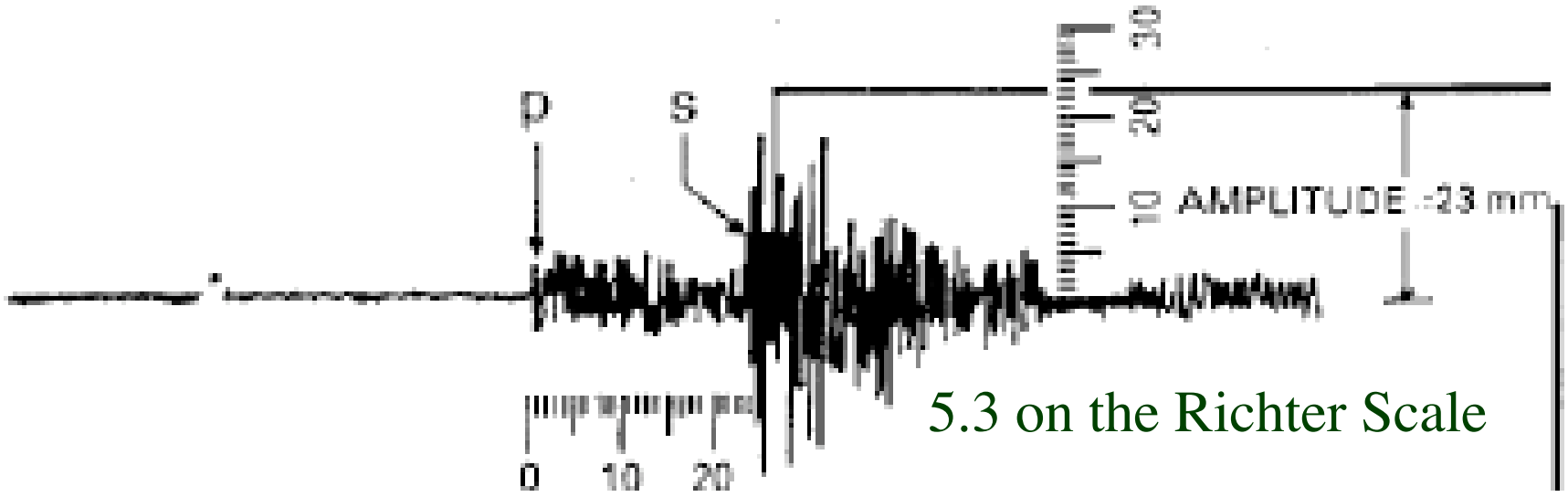
Other Logarithmic Scales:
Decibel Scale for sound
Richter Scale for earthquakes (e.g. 7.6)
Visual Magnitude for stars (astronomy)

Dr. Charles F. Richter showed that, the larger the intrinsic energy of the earthquake, the larger the amplitude of ground motion at a given distance. He calibrated his scale of magnitudes using maximum amplitudes measaured on seismometers particularly sensitive to shear waves with periods of about one second. The records had to be obtained from a specific kind of instrument, called a Wood-Anderson seismograph. Although his work was originally calibrated only for these specific seismometers, and only for earthquakes in southern California, seismologists have developed scale factors to extend Richter's magnitude scale to many other types of measurements on all types of seismometers, all over the world. In fact, magnitude estimates have been made for thousands of Moon-quakes and for two quakes on Mars.

The equation for Richter Magnitude is: **$M = \log A + 3 \log \Delta t - 0.21$**

A is the amplitude, in millimeters, measured directly from the photographic paper record of the Wood-Anderson seismometer, a special type of instrument. The duration Δt is determined from seismic data collected at several stations.

Power is proportional to A^2 and total quake energy is proportional **to $A^2 \Delta t$.**

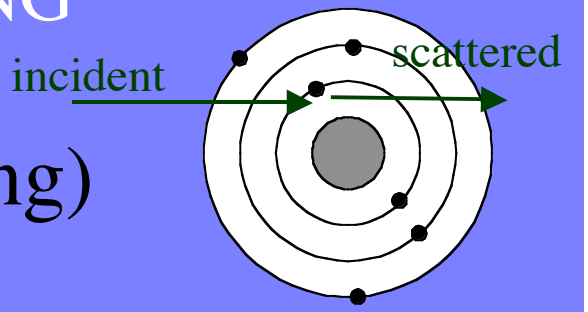


5.3 on the Richter Scale

X-ray Interactions

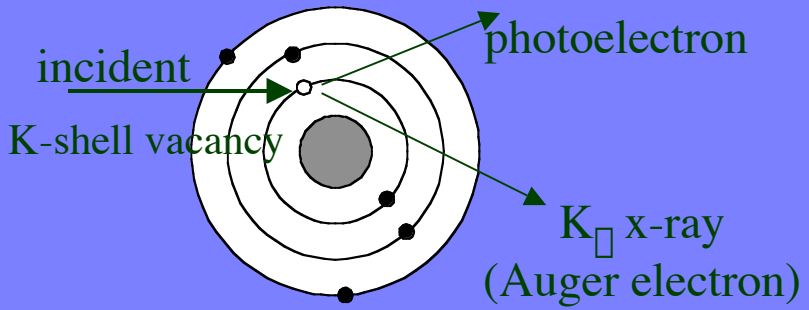
x-rays interact with atomic electrons

Energy >> 1 eV : IONIZING



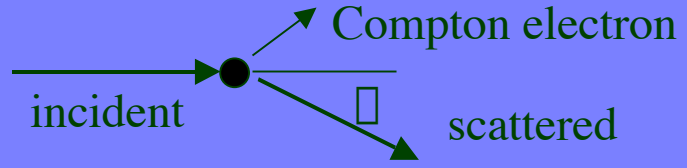
- Coherent Scattering (non-ionizing)

- Photoelectric absorption



- Compton Scattering

$$E_s = E_i * m_e c^2 / (m_e c^2 + E(1-\cos\square))$$

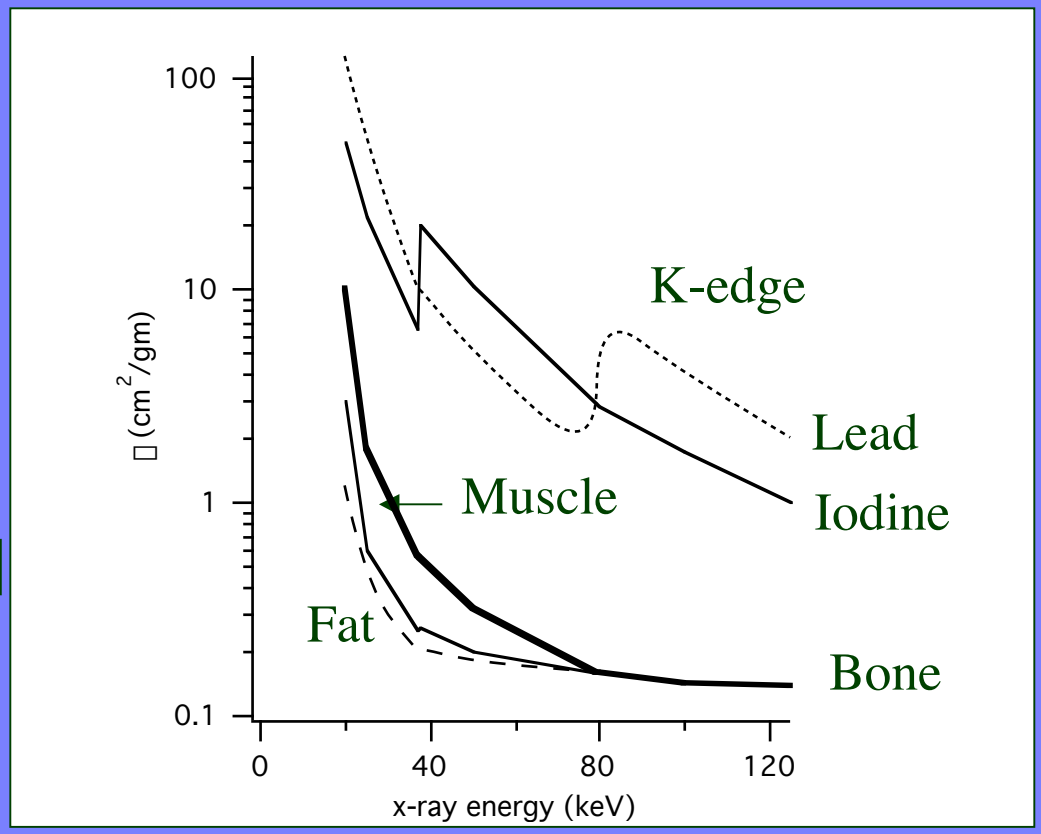


- Gamma rays (E > 1.022 MeV): e^+e^- pair production

Attenuation Coefficients

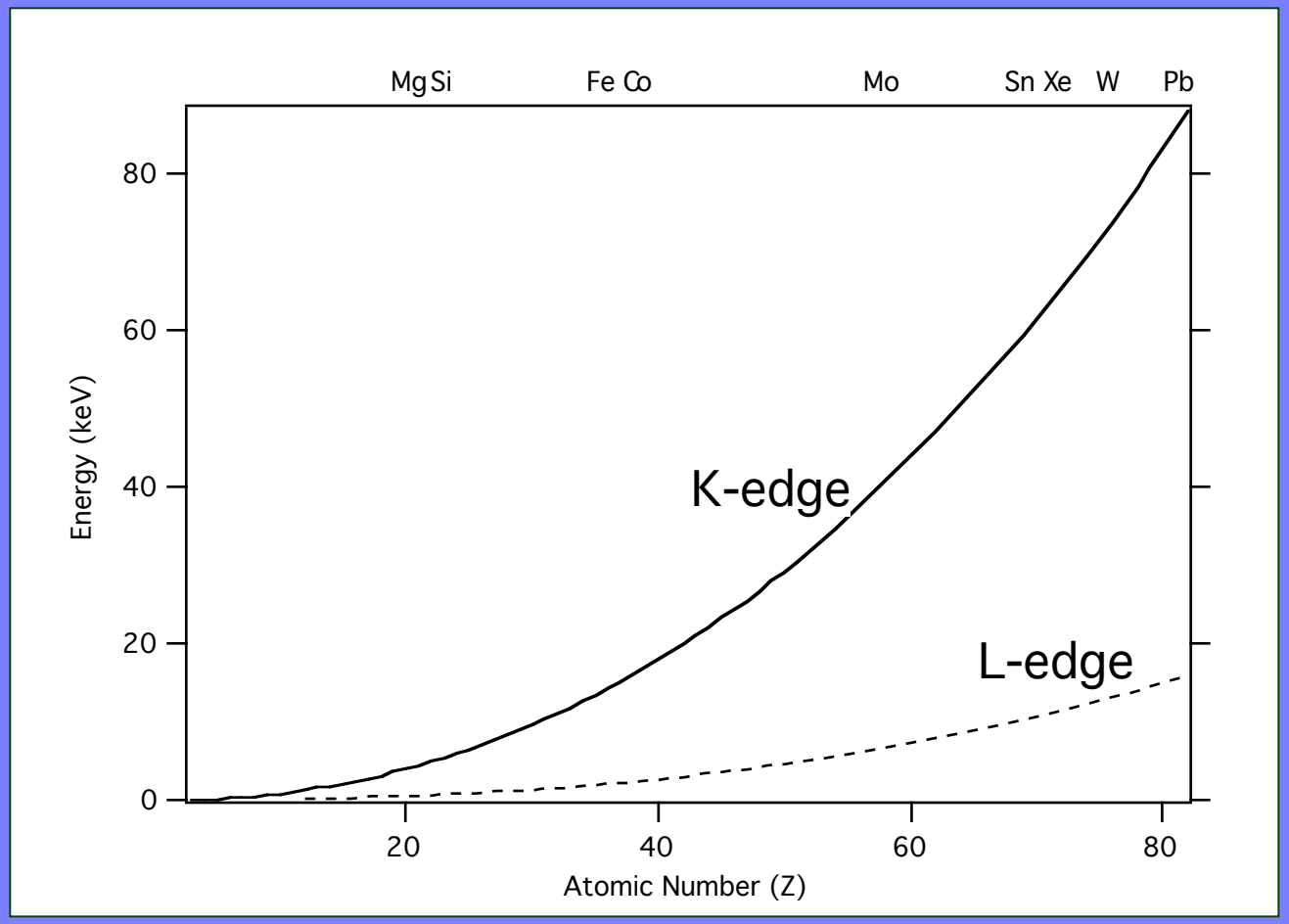
$\mu^{-1} = \rho\sigma$

Electrons/cm^3 ~ ρ



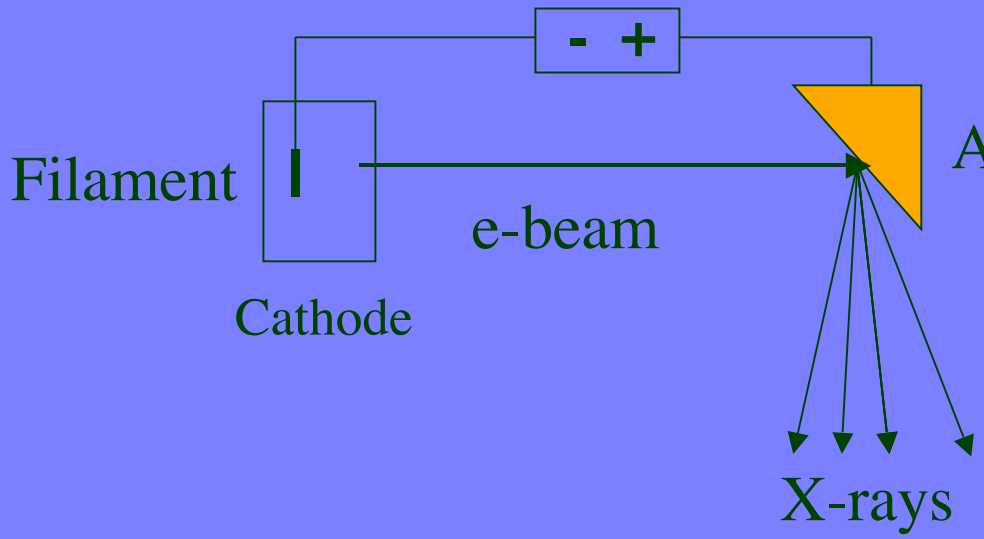
Air (N_2)	0.03 cm^2/gm (at 50 keV)	ρ=1.2x10^{-3} gm/cm^3
Water	0.21 cm^2/gm	1 gm/cm^3
Muscle	0.20 cm^2/gm	~1 gm/cm^3
Fat	0.17 cm^2/gm	~0.9 gm/cm^3
Bone	0.30 cm^2/gm	1.9 gm/cm^3
Pb	6 cm^2/gm	11.3 gm/cm^3

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



Anode (W, Pb, Mo)

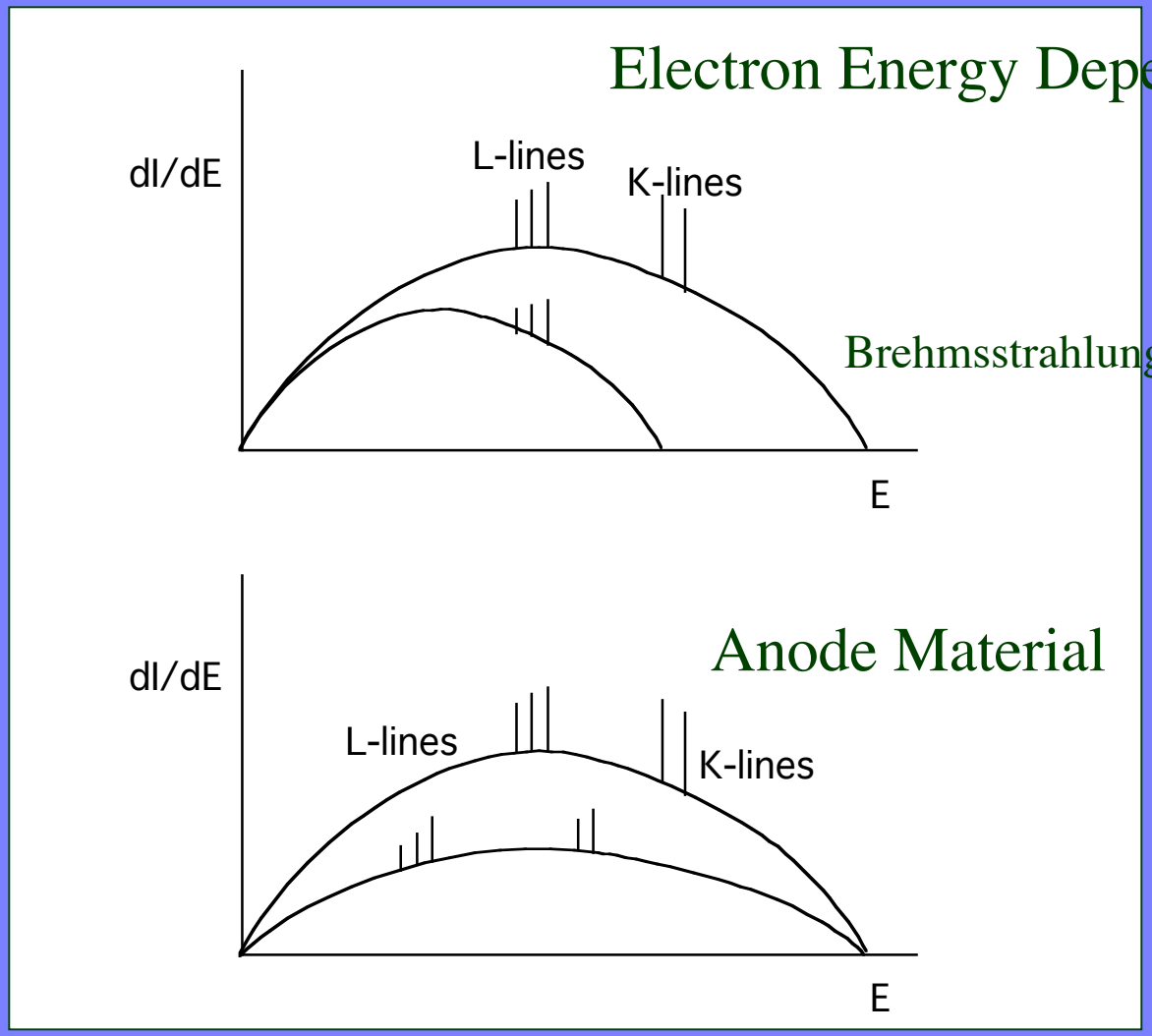
Brehmsstrahlung

For a point source

$I \sim 1/r^2$ (inverse square)

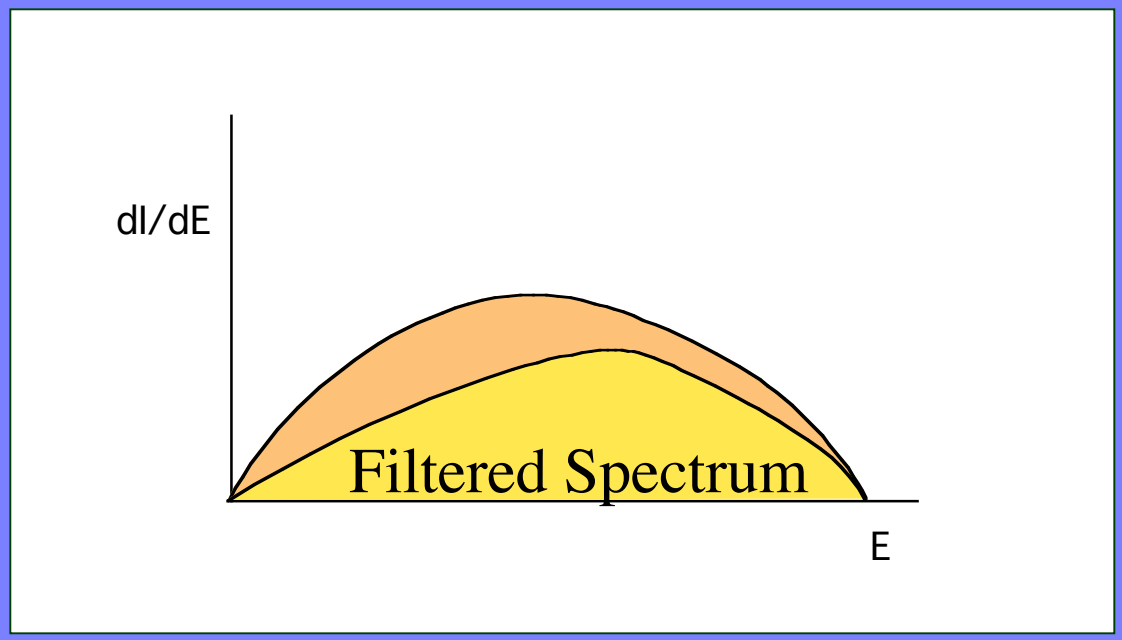
- X-fluoresence (alpha particle)
  - Emits K,L,M lines only

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 (bad)**
- **No film exposure (useless)**

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 bilogical effectiveness - RBE)
    - 1 for x-rays
    - 5 slow neutrons
    - 20 for alpha particles, fast neutrons, protons

Imaging

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