Week 13, Lecture 2 – Interaction of Radiation

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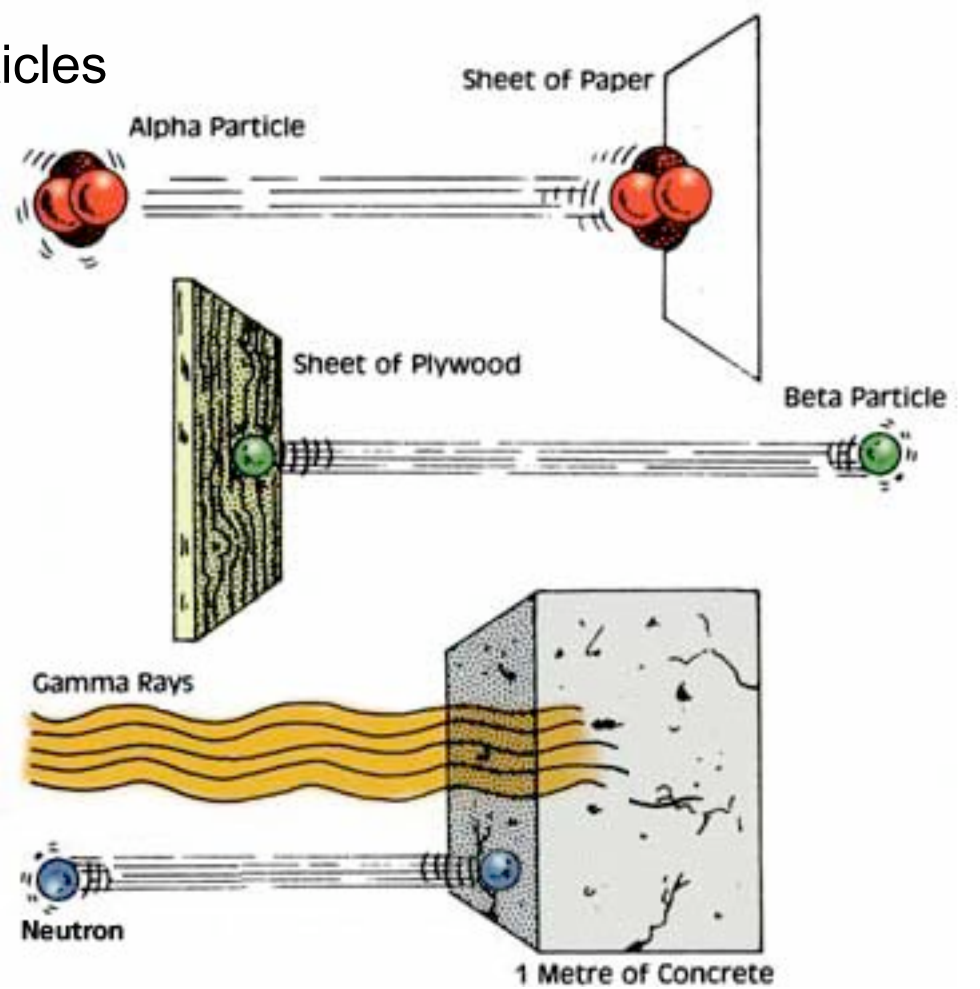
Interaction of Radiation with Matter

- Penetration/absorption of charged particles
-- heavy ions
-- electrons
- Penetration/absorption of neutral particles
-- gamma rays
-- neutrons



9th Homework due Monday

http://www.cameco.com/uranium_101/uranium_science/radiation/

Interaction of Photons with Matter –1–

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A beam of photons passes through material until each undergoes a collision, at random, and is removed from the beam. Thus, the intensity of the beam will continuously drop as the beam propagates through the medium but the energy of the photons will remain constant. This degradation of the beam follows the Beer-Lambert exponential attenuation law:

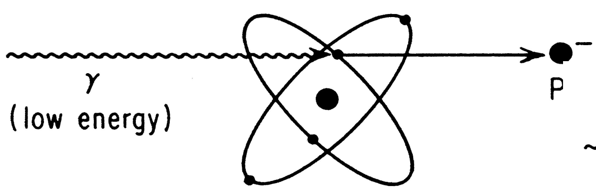
$$I = I_0\, e^{-\mu x} \qquad \mu = 1/\lambda$$

μ attenuation coefficient; λ mean free-path

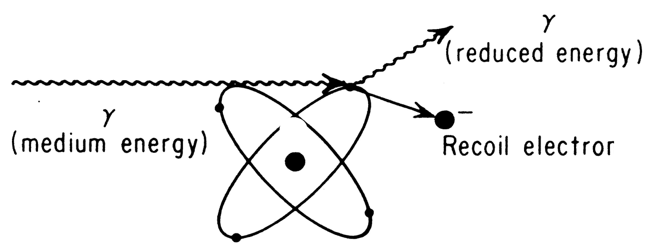
http://physics.nist.gov/PhysRefData/XrayMassCoef/cover.html

Three interaction processes:

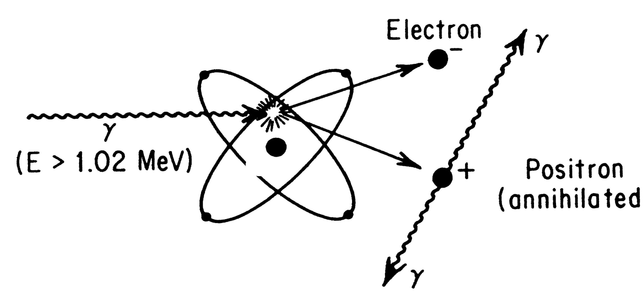
Photoelectric Effect



Compton Scattering



Pair-production



Interaction of Photons with Matter –2–

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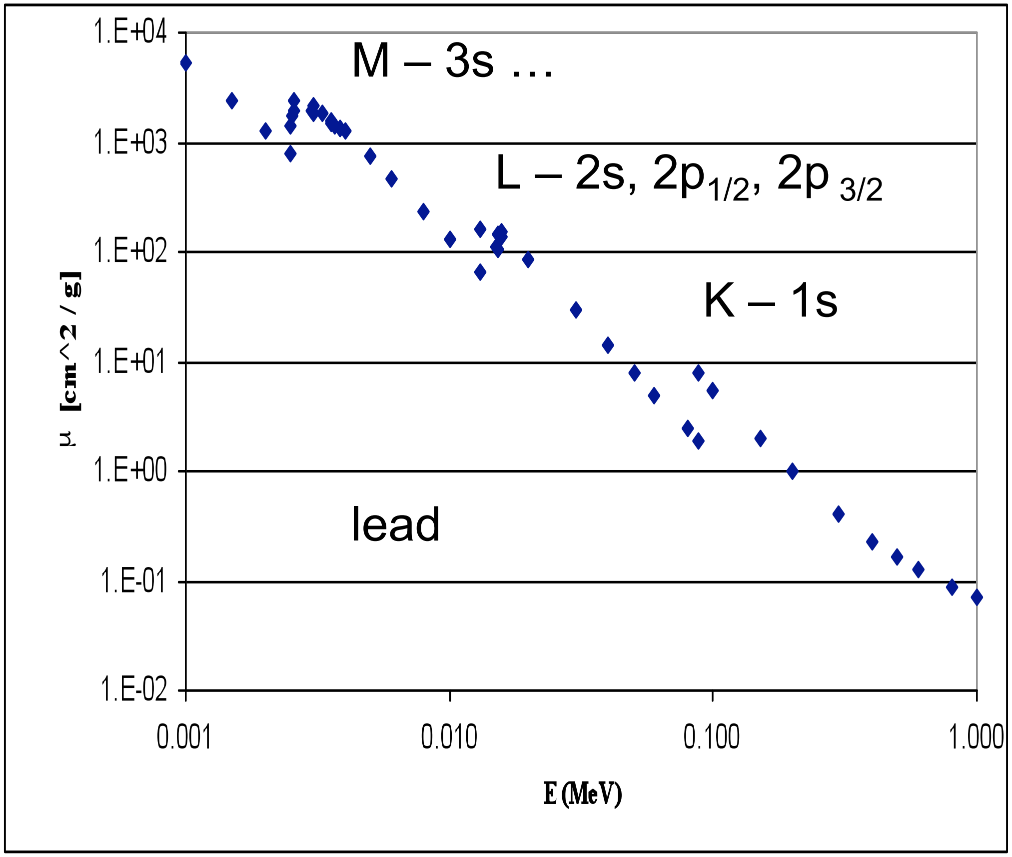
Photoelectric Effect: process originally described by Einstein, most efficient conversion of photon into a moving electron. [Electron then goes on to ionize the medium as just discussed.] Atomic scale (square angstrom) cross sections that decrease sharply with photon energy with steps at the electron shell energies.

PE effect generates
One electron with:
$E_e = h\nu - BE_e$

"Edges" in data due to a threshold at each electron shell.

$$\frac{I}{I_o} = e^{-\mu t} = e^{-x/x_o}$$

$$\mu\rho = \frac{1}{x_o}$$



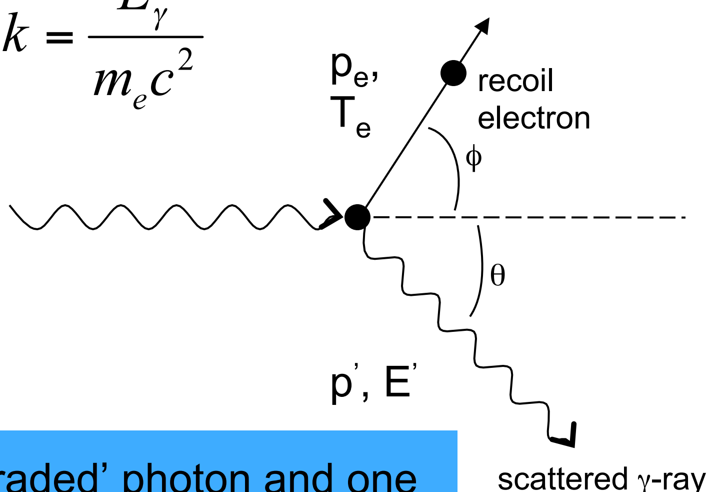
Interaction of Photons with Matter –2–

Compton Scattering: scattering of a photon by a (free) electron that leads to a moving electron *and* a lower energy photon. The two-body scattering leads to a correlation between angle and electron kinetic energy. The total cross section for the scattering is given by the Klein-Nisihna formula:

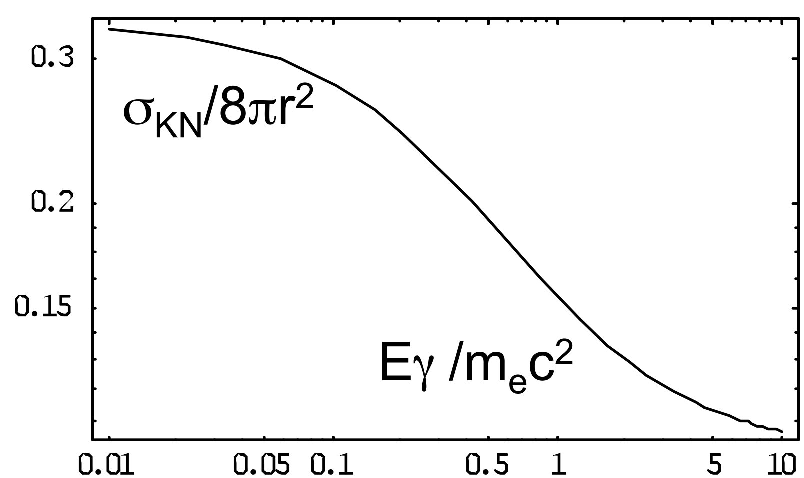
$$\sigma_{KN} \cong 8\pi r_e^2 \frac{1+2k+1.2k^2}{3(1+2k)^2}$$

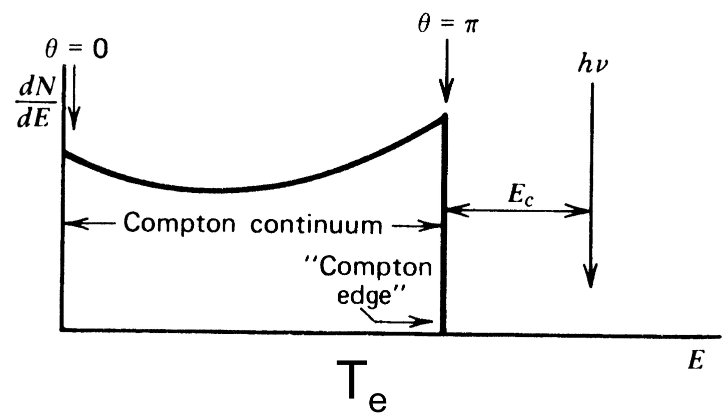
$$r_e = \frac{e^2}{m_e c^2} = 2.818x10^{-15}m$$

$$k = \frac{E_\gamma}{m_e c^2}$$



'Degraded' photon and one moving electron.

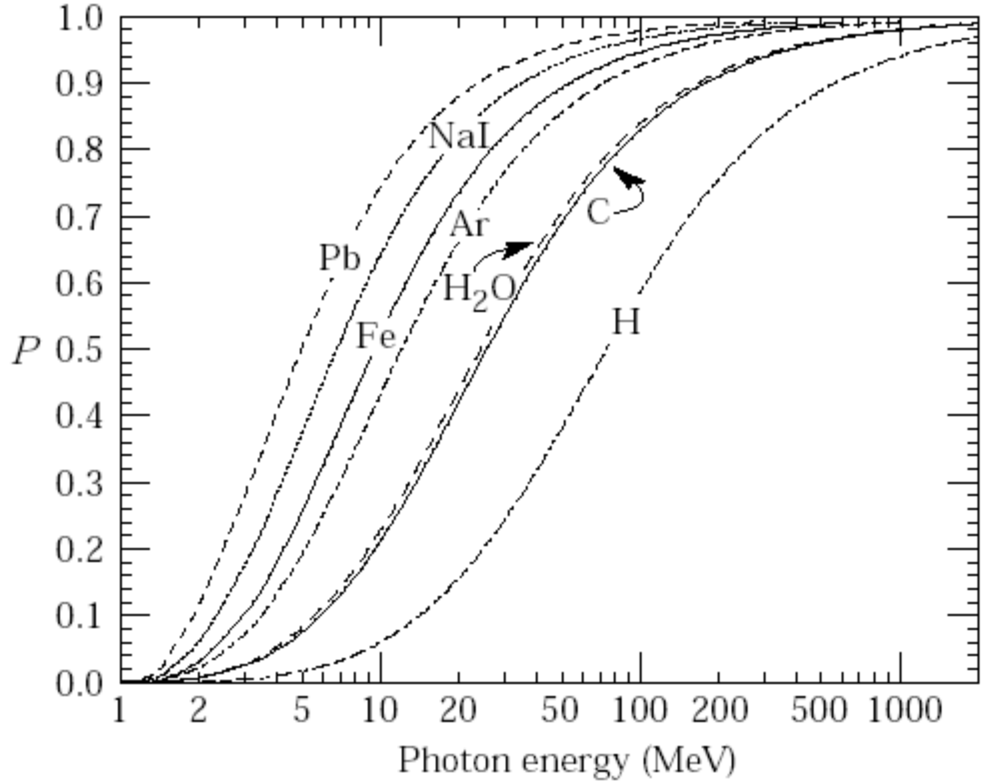




Interaction of Photons with Matter –4–

Pair production: E_γ > 1.022 MeV, the conversion of a photon into a matter/antimatter pair of electrons in the presence of a nucleus (or an electron). The process generally depends on the Z^2 of the medium and grows with photon energy. The two moving electrons share the remainder of the initial photon energy. Eventually the positron annihilates at the end of its range giving two 511 keV photons.

Probability of conversion, to be multiplied by a geometric cross section.



Interaction of Photons with Matter –5–

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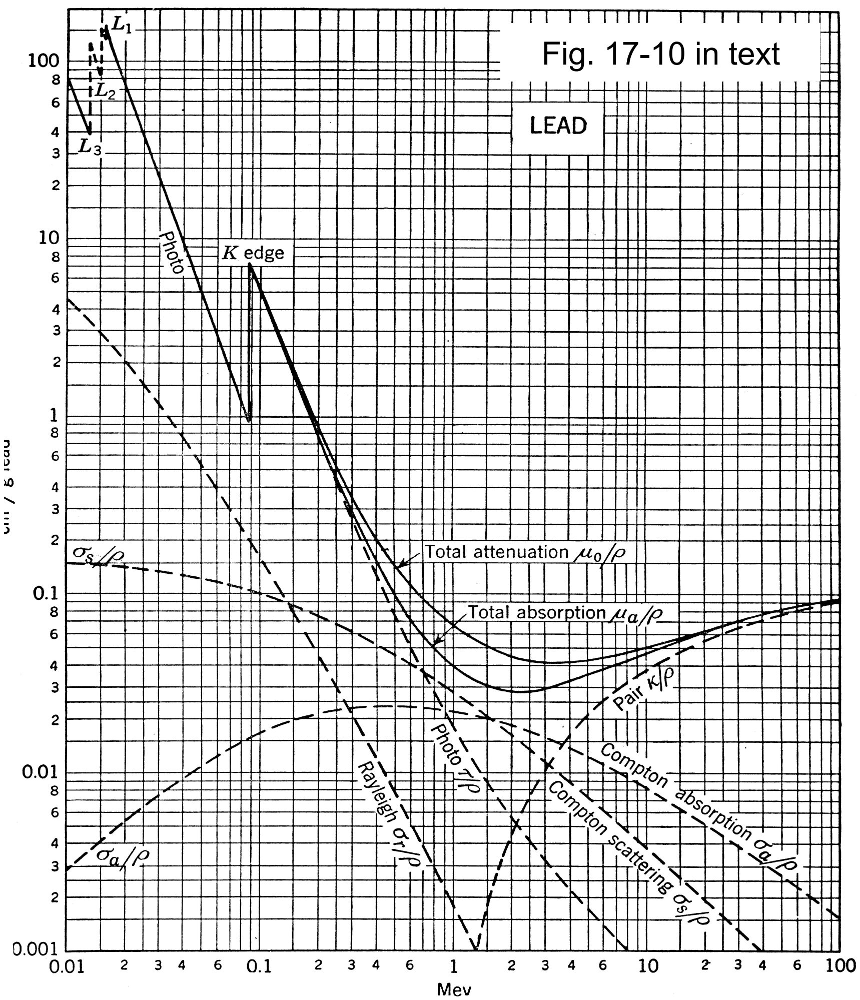
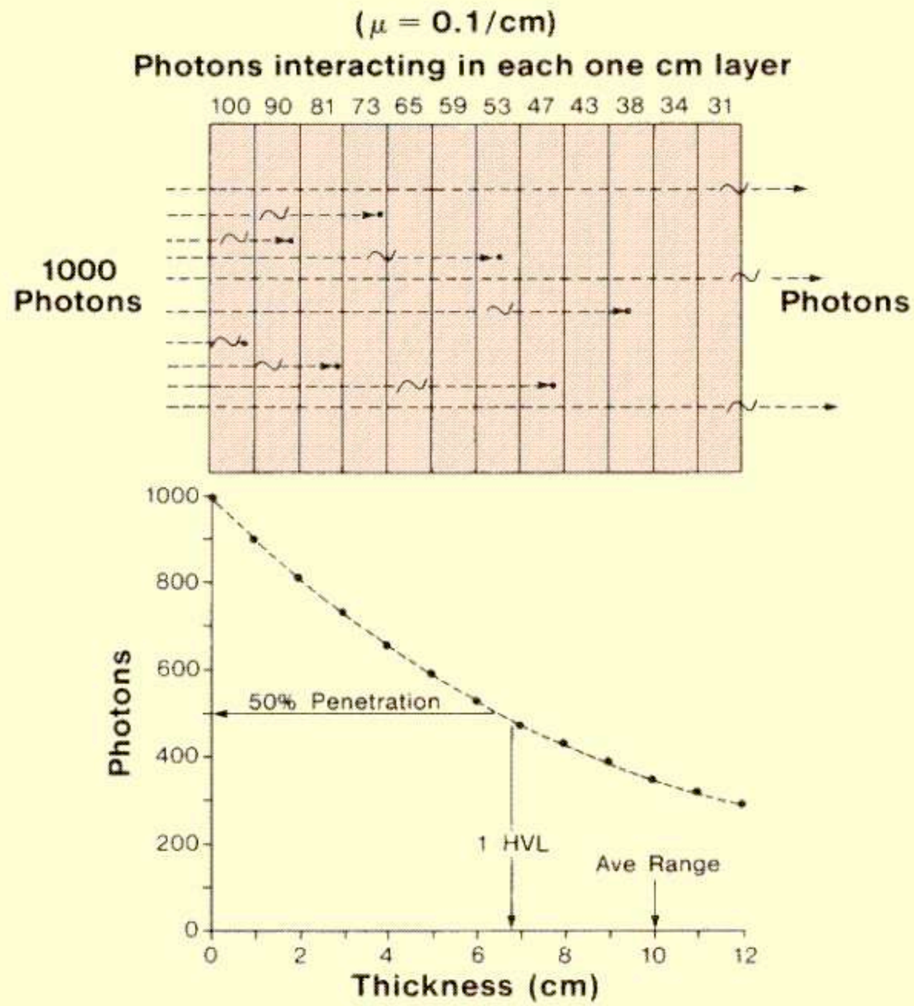
mass-attenuation coefficient from
The Atomic Nucleus by R.Evans





http://www.sprawls.org/ppmi2/RADPEN/

N.B. Exponential attenuation means the beam cannot be completely absorbed.

Interaction of Neutrons with Matter –1–

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A beam of neutrons passes through material until each undergoes a collision at random and is removed from the beam. In contrast to photons, the neutrons are 'scattered' by nuclei and usually only leave a portion of their energy in the medium until they are very slow and are absorbed. Thus, the intensity of the beam will continuously drop as the beam propagates through the medium and the mean kinetic energy of the neutrons will also generally decrease. The degradation of the beam intensity follows the Beer-Lambert exponential attenuation law and will be characterized by an attenuation coefficient.

$$I = I_0 \, e^{-\mu x} \qquad \mu = \rho_N \sigma_{Total}$$

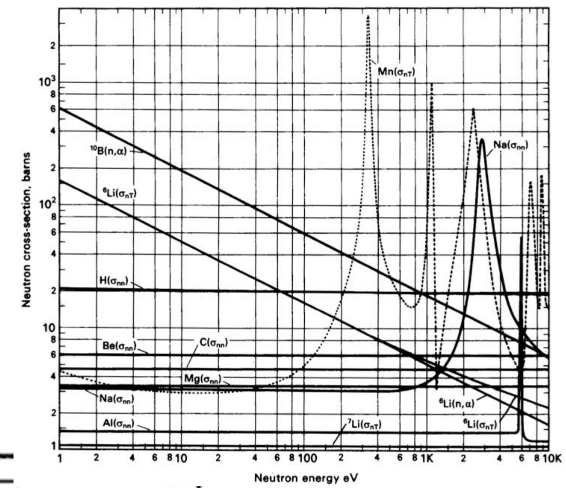
Hierarchical List of neutron reactions:

A(n,γ) A+1 -- radiative capture
A(n,n) A -- elastic scattering
A(n,n') A* -- inelastic scattering
A(n, 2n) A-1
A(n,p) A(Z-1) A(n,np)A-1(Z-1) etc.
A(n,α)
A(n,f)

Note that the H(n,n)H produces a recoil proton

Interaction of Neutrons with Matter –2–

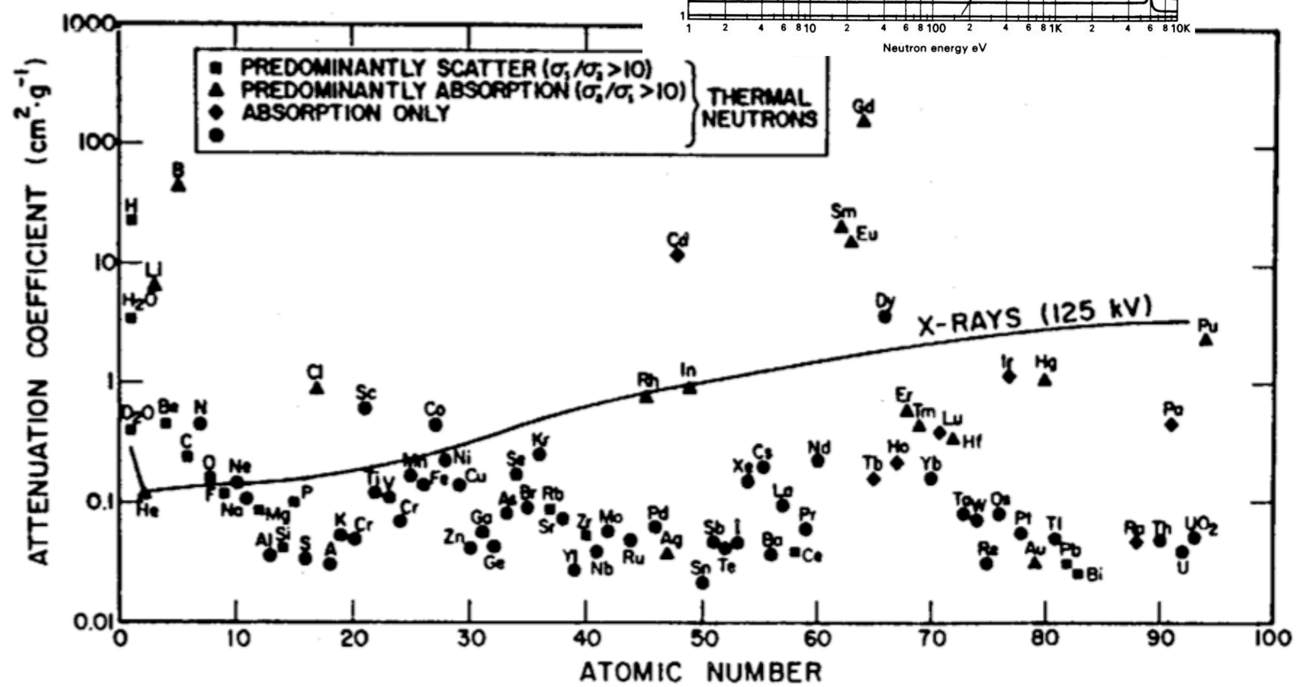
Neutron reaction cross sections have a characteristic shape, one or more Breit-Wigner resonances and then a 1/v dependence at the lowest energies. [We already know this!]



Total attenuation coefficients can be obtained by combination of the elemental cross sections.

e.g., $\mu \sim 150\ cm^2/g$ for rock * $3\ g/cm^3 = 450\ /cm$

$\mu \sim 5\ cm^2/g$ for water * $1\ g/cm^3 = 5\ /cm$



Summary of attenuation

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Radiation	Range	Intensity	Energy
Alpha	Fixed	Constant	Drops slowly
Beta	~ Fixed	Decreases	Drops rapidly
Neutron	Exponential	Exponential	Drops rapidly
Gamma	Exponential	Exponential	Constant