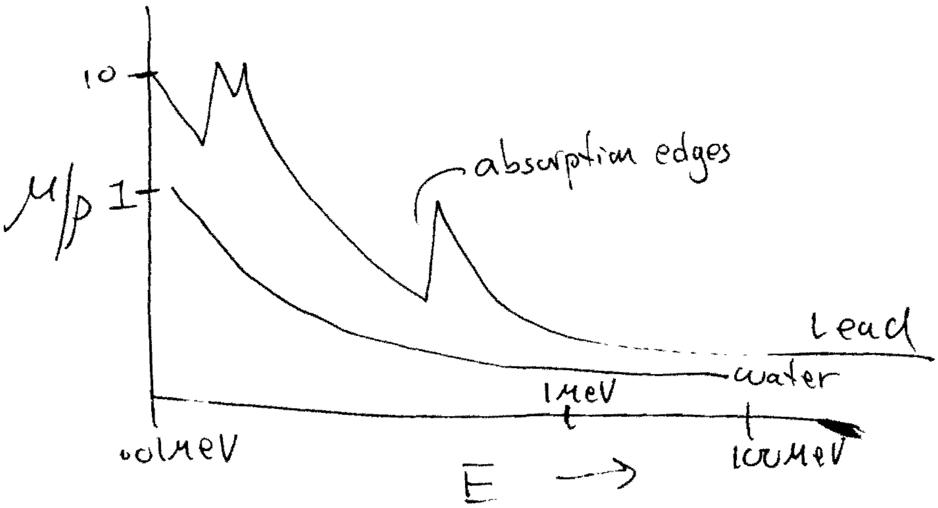
Chapter 5 X ray + γ-ray interactions with matter

Absorption Coefficients

If we plot μ vs energy, we are looking at the probability of a photon being absorbed at a particular energy (see pg 46)



1. Coherent Scatter
2. Photoelectric Effect
3. Compton Scatter
4. Pair production

1. Coherent Scatter (Rayleigh scatter)

- occurs only at low energies.
- a photon is absorbed by an electron in an atom.
- the electron starts to vibrate, <u>but it is not ejected or raised to a higher energy level.</u>
- the electron then emits the excess energy as a photon of the same energy, but in a different direction (scatter)

(2) Photoelectric Effect:

- As the photon energy increases, the photoelectric effect becomes important. (energies up to ~0.1MeV)

- The photoeletric effect:

  - a photon interacts with an inner shell electron
  - the photon is absorbed
  - the electron is ejected ($E = E_{ph} - E_B$)
  - Vacancies are filled from outer orbits giving rise to <u>Characteristic Radiation.</u>

- Photoelectric Effect depends on the Atomic Number of the material <u>and</u> on the photon energy.

$$\text{probability} \sim \frac{Z^3}{E^3}$$

- For the same energy, higher atomic number materials will interact via photoelectric effect more than lower Z-materials

e.g. - Diagnostic X-rays.

eff Atomic Number Tissue ~ 7.6
eff Atomic Number Bone ~ 12.5

∴ Bone absorbs more photons by p.e. than tissue, So bone appeare white on x-ray film and tissue more gray since the photons are going through.

(3) Compton ~~Scatter~~ Effect

- at yet higher energies (0.1 MeV ~ 10 MeV)

- a photon interacts with an Outer Shell electron
- Some energy is transferred to the electron, ejecting it.
- the remaining energy is re-emitted as a new photon with a lower energy.

- the energy of the new photon depends upon the angle of scatter.

- the energy depends upon the wavelength ($E = \frac{hc}{\lambda}$)

$$\Delta\lambda = 2.4 \times 10^{-12} (1 - \cos\theta) \text{ (meters)}$$

e.g.: a 210 keV photon is scattered at 80°. What are the energies of the ~~compton~~ scattered photon?

initial photon: 210 keV = 0.210 MeV

(2)

$$E = \frac{hc}{\lambda} = \frac{1.24 \times 10^{-12} \text{ (MeV-m)}}{\lambda}$$

$$\lambda = \frac{1.24 \times 10^{-12} \text{ (MeV-m)}}{0.210 \text{ MeV}} = 5.9 \times 10^{-12} \text{ m}$$

(1)

$$\Delta\lambda = 2.4 \times 10^{-12} (1 - \cos(80°))$$
$$= 2.4 \times 10^{-12} (1 - 0.174)$$
$$= 2.4 \times 10^{-12} (0.8264)$$
$$= 1.98 \times 10^{-12} \text{ m}$$

(4) Pair Production:

- ~~only occurs~~ Importent at energies above 10 MV.

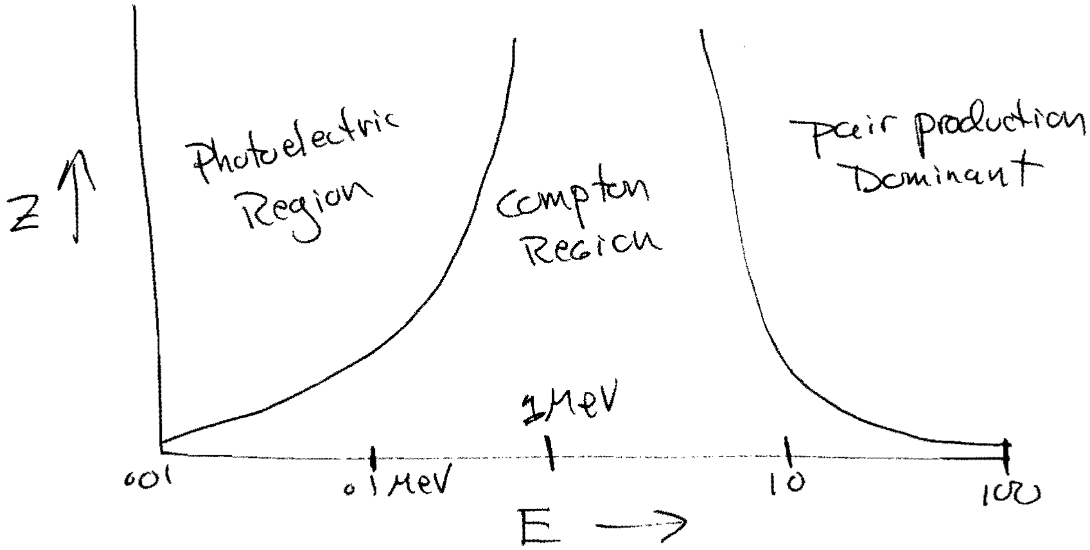
- a high energy photon ($E > 1.02$ MeV) interacts with the electric field of the atomic nucleus.
- the photon energy is converted to mass in the form of an electron and a positron.

- Since the mass of an electron and a positron are both 0.511 MeV, the minimum energy is: 0.511 MeV + 0.511 MeV = 1.022 MeV
pair production cannot occur below this energy.

- the electron & positron go off and interact with the surrounding tissue.

- the positron interacts with an electron and they annihilate each other (matter-antimatter) converting their mass into 2 - 0.511 MeV photons.
These photons are emitted in opposite directions.

Relative Importance



also, see graph on p. 54 and 56.