

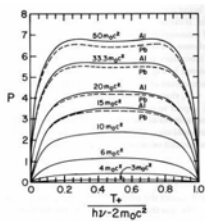
Interaction of Gamma- and X-ray in Matter

Five Interactions

- Compton effect
- Photoelectric effect
- Pair production
- Rayleigh (coherent) scattering
- Photonuclear interactions

$$d(\kappa) = \frac{\sigma_0 Z^2 P}{h\nu - 2m_0c^2} dT^+ \quad (\text{cm}^2/\text{atom})$$

$$\sigma_0 = \frac{r_0^2}{137} = \frac{1}{137} \left(\frac{e^2}{m_0c^2} \right)^2 = 5.80 \times 10^{-28} \text{ cm}^2/\text{electron},$$



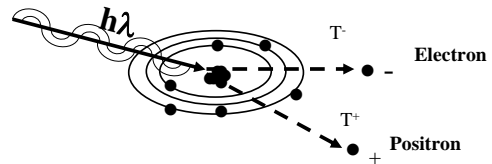
$$\kappa = \int_{T^+} d(\kappa) = \sigma_0 Z^2 \int_0^{(h\nu - 2m_0c^2)} \frac{P dT^+}{h\nu - 2m_0c^2}$$

$$= \sigma_0 Z^2 \int_0^1 P d\left(\frac{T^+}{h\nu - 2m_0c^2}\right) = \sigma_0 Z^2 \bar{P}$$

$$\frac{\kappa}{\rho} = \frac{N_A}{A} \sigma_0 Z^2 \bar{P} \quad (\text{cm}^2/\text{g})$$

FIGURE 7.18. The quantity P in Eq. (7.41), plotted as a function of the kinetic-energy fraction given in the position. The small difference between lead and aluminum shows the small amount of Z -dependence. (After Davison and Exans (1952). Reproduced with permission of R. D. Exans and the American Physical Society.)

Pair Production in the nuclear field

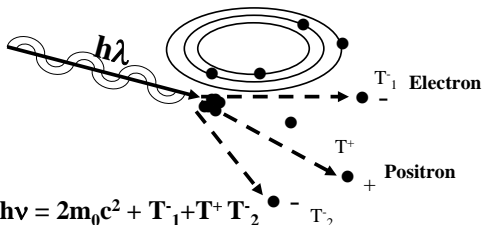


$$h\nu = 2m_0c^2 + T^- + T^+$$

$$\bar{T} = (h\nu - 2m_0c^2)/2$$

Effect occurs in a Coulomb force field.

Pair Production in the electron field



$$h\nu = 2m_0c^2 + T_1 + T^+ + T_2$$

$$\bar{T} = (h\nu - 2m_0c^2)/3$$

The threshold energy is $4m_0c^2$

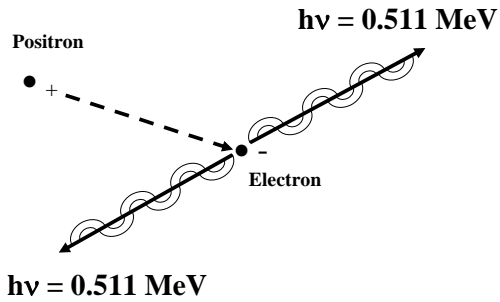
$$\frac{\kappa(\text{electrons})}{\kappa(\text{nucleus})} \cong \frac{1}{CZ}$$

1 for $h\nu = 2$
2 for $h\nu = 5$

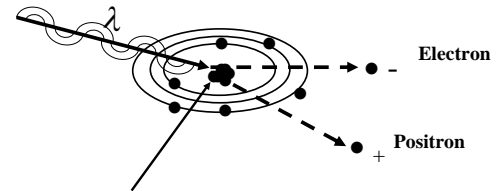
$$\left(\frac{\kappa}{\rho}\right)_{\text{pair}} = \left(\frac{\kappa}{\rho}\right)_{\text{nuclear}} + \left(\frac{\kappa}{\rho}\right)_{\text{electron}}$$

$$\frac{\kappa_{\text{tr}}}{\rho} = \frac{\kappa}{\rho} \left(\frac{h\nu - 2m_0c^2}{h\nu} \right)$$

Annihilation Radiation



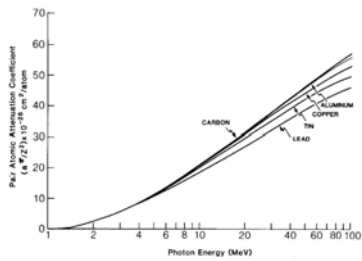
Pair Production Effect



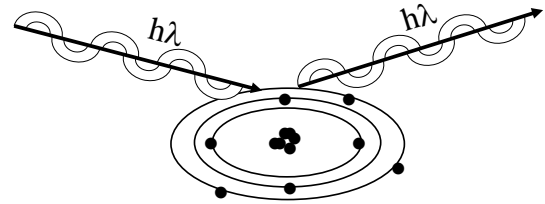
Strength of nuclear field depends on Z .

Pair Production

$$a\pi/\rho \text{ (per atom)} \propto Z^2$$



Coherent Scattering



Scattering of x-ray photon through small angle without change or loss of energy to medium.

$h\nu$	$h\nu = 0.1 \text{ MeV}$	1 MeV	10 MeV
Al	15°	2°	0.5°
Pb	30°	4°	1.0°

$$\sigma_R \propto \frac{Z^2}{(h\nu)^2} \quad (\text{cm}^2/\text{atom})$$

$$\frac{\sigma_R}{\rho} \propto \frac{Z}{(h\nu)^2} \quad (\text{cm}^2/\text{g or m}^2/\text{kg})$$

Element	$h\nu = 0.01 \text{ MeV}$	0.1 MeV	1.0 MeV
C	0.07	0.02	0
Cu	0.006	0.08	0.007
Pb	0.03	0.03	0.03

Photonuclear interactions

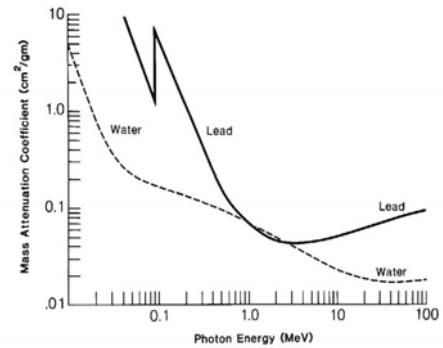
Less than 5% of the dose due to pair production

More of a problem for radiation shielding

Total Mass Attenuation Coefficient

$$\mu/\rho = \tau/\rho + \sigma_R/\rho + \sigma/\rho + \mathcal{E}/\rho$$

Total Attenuation Coefficient



Mass energy-transfer coefficient

$$\mu_{tr}/\rho = \tau_{tr}/\rho + \sigma_{tr}/\rho + \mathcal{E}_{tr}/\rho$$

$$= \frac{\tau}{\rho} \left[\frac{hv - p_e Y_e \overline{h\nu_e} - (1 - p_e) Y_e \overline{h\nu_e}}{hv} \right] + \frac{\sigma}{\rho} \left[\frac{T}{h\nu} \right] + \frac{\mathcal{E}}{\rho} \left[\frac{hv - 2m_0c^2}{hv} \right]$$

Mass energy-absorption coefficient

$$\mu_{en}/\rho = \mu_{tr}/\rho(1-g)$$

Coefficients for compounds and mixtures

$$\left(\frac{\mu}{\rho} \right)_{mix} = \left(\frac{\mu}{\rho} \right)_A f_A + \left(\frac{\mu}{\rho} \right)_B f_B + \dots$$

$$\left(\frac{\mu_{tr}}{\rho} \right)_{mix} = \left(\frac{\mu_{tr}}{\rho} \right)_A f_A + \left(\frac{\mu_{tr}}{\rho} \right)_B f_B + \dots$$

$$\left(\frac{\mu_{en}}{\rho} \right)_{mix} = \left(\frac{\mu_{en}}{\rho} \right)_A f_A + \left(\frac{\mu_{en}}{\rho} \right)_B f_B + \dots$$

$$= \left(\frac{\mu_{tr}}{\rho} \right)_A (1 - g_A) f_A + \left(\frac{\mu_{tr}}{\rho} \right)_B (1 - g_B) f_B + \dots$$

Coefficients for compounds and mixtures

$$\left(\frac{\mu_{tr}}{\rho} \right)_{mix} = \left(\frac{\mu_{tr}}{\rho} \right)_A f_A + \left(\frac{\mu_{tr}}{\rho} \right)_B f_B + \dots$$

$$\left(\frac{\mu_{en}}{\rho} \right)_{mix} = \left(\frac{\mu_{tr}}{\rho} \right)_A (1 - f_A g_A - f_B g_B - \dots) f_A + \left(\frac{\mu_{tr}}{\rho} \right)_B (1 - f_A g_A - f_B g_B - \dots) f_B + \dots$$

$$= \left(\frac{\mu_{tr}}{\rho} \right)_{mix} (1 - f_A g_A - f_B g_B - \dots)$$

$$= \left(\frac{\mu_{tr}}{\rho} \right)_{mix} (1 - g_{mix})$$

Tables of photon interaction coefficients

Appendix D.1 contains K-N interaction and energy transfer cross sections in units of cm^2/e , for the energy range 1 keV to 100 MeV.

Appendix D.2 provides photon interaction cross sections per atom for several representative elements, compounds, and mixtures over the same energy range.

Appendix D.3 tabulates mass attenuation coefficients, mass energy transfer coefficients and mass energy absorption coefficients.

Appendix D.4 is for mass energy absorption coefficients corrected for radiative losses due to positron in-flight annihilation as well as bremsstrahlung.

Higgins PD, Attix FH, Hubbel JH, Seltzer S, Berger MJ and Sibata C: Mass energy-transfer and mass energy-absorption coefficients, including in-flight positron annihilation for photon energies 1 keV to 100 MeV. NISTR 4680, US Department of Commerce, National Institute of Standards and Technology, Nov 1991.