Interaction Between Ionizing Radiation And Matter, Part 1 Photons, continued

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Attenuation coefficient

- σ: Cross section target area; surface proportional with the probability of interaction
- μ/ρ: Mass attenuation coefficient; the number of photons with a single energy E and direction which interacts per length unit, ρ: mass density
- $\mu/\rho=(N_A/A)_a\sigma$, $\mu/\rho=(N_AZ/A)_e\sigma$, where

  ${}_a\sigma$: atomic cross section, ${}_e\sigma$: electronic cross section

  (N_A/A): is the number of atoms per mass unit

  (N_AZ/A): is the number of electrons per mass unit

  $\approx$ constant for Z>1 (Hydrogen)

Attenuation coefficient (2)

- Total mass attenuation coefficient:

$$\frac{\mu}{\rho} = \frac{\tau}{\rho} + \frac{\sigma}{\rho} + \frac{\kappa}{\rho} + \frac{\sigma_R}{\rho}$$

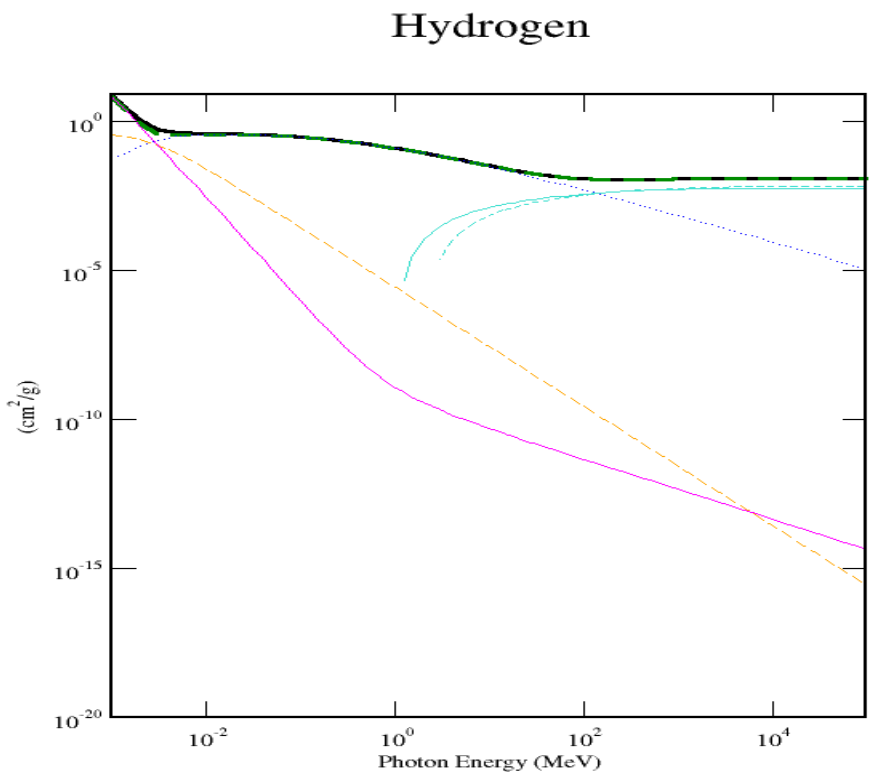
- Mass energy-transfer coefficient:

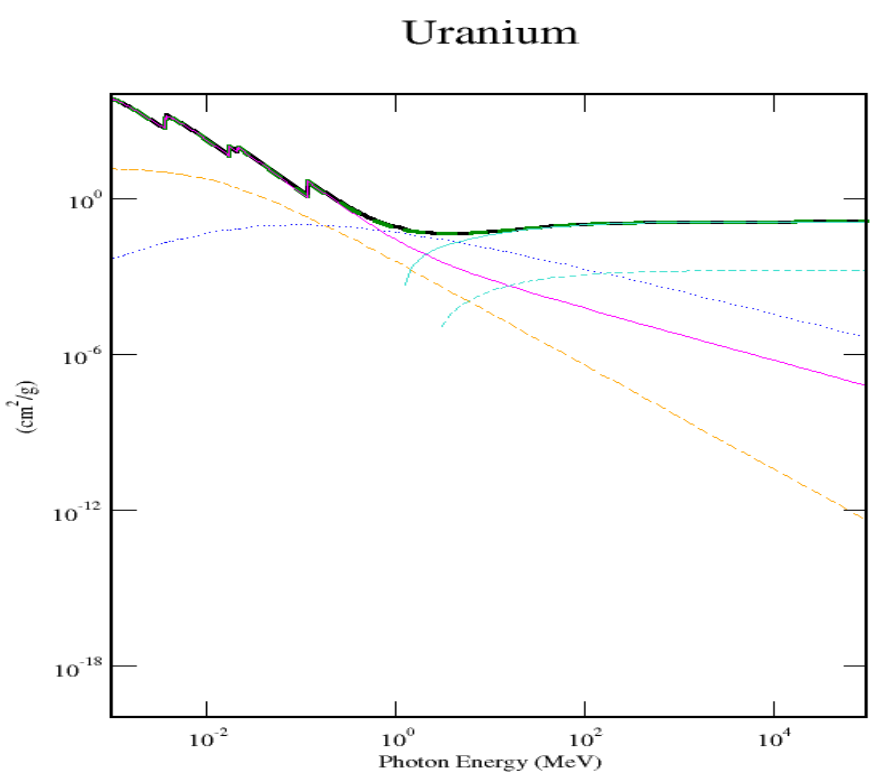
$$\frac{\mu_{tr}}{\rho} = \frac{\mu}{\rho}\frac{\bar{T}}{h\nu}$$

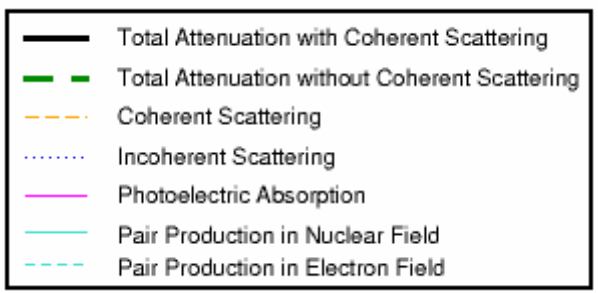
- Total mass energy-transfer coefficient:

$$\frac{\mu_{tr}}{\rho} = \frac{\tau_{tr}}{\rho} + \frac{\sigma_{tr}}{\rho} + \frac{\kappa_{tr}}{\rho}$$

Attenuation coefficients (3)







http://physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html

Braggs rule

- Braggs rule for mixtures of n-atoms/elements:

$$\left(\frac{\mu}{\rho}\right)_{mix} = \sum_{i=1}^{n} f_i \left(\frac{\mu}{\rho}\right)_i, \qquad \left(\frac{\mu_{tr}}{\rho}\right)_{mix} = \sum_{i=1}^{n} f_i \left(\frac{\mu_{tr}}{\rho}\right)_i, \qquad f_i = \frac{m_i}{\sum_{i=1}^{n} m_i}$$

- Mass energy-absorption coefficient: g represent the average fraction of secondary electron energy lost to photons

$$\left(\frac{\mu_{en}}{\rho}\right) = \left(\frac{\mu_{tr}}{\rho}\right)(1-g)$$

- Braggs rule:

$$\left(\frac{\mu_{en}}{\rho}\right)_{mix} \cong \sum_{i=1}^{n} f_i \left(\frac{\mu_{en}}{\rho}\right)_i$$

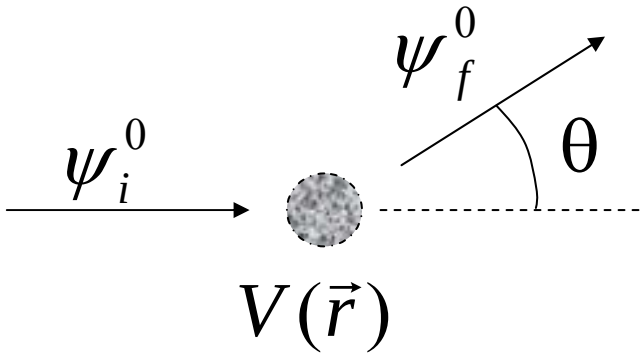
$$\left(\frac{\mu_{en}}{\rho}\right)_{mix} \equiv \left(\frac{\mu_{tr}}{\rho}\right)_{mix} (1-g_{mix}), \quad g_{mix} = \sum_{i=1}^{n} f_i g_i$$

Photon Interaction

- Five interaction processes between photons and matter:
  - Rayleigh scattering
  - Compton scattering
  - Photoelectric effect
  - Pair- and triplet -production
  - Photon-nuclear reactions

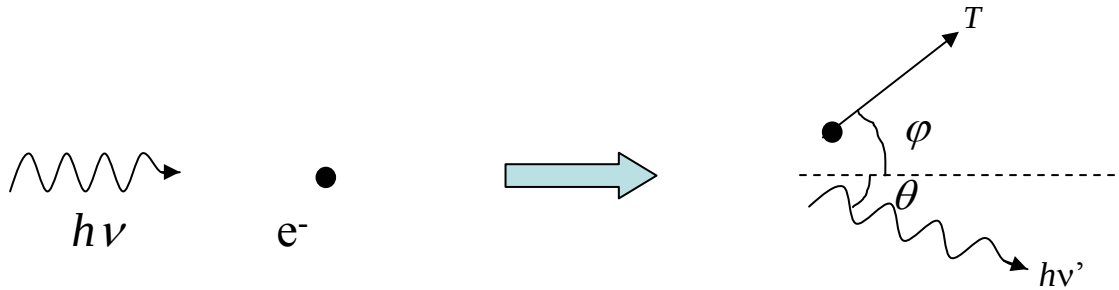
Rayleigh scattering

- Kinematics: $h\nu_i = h\nu_f$
  $T = 0$



- Atomic cross section: $${}_a\sigma_R \propto \left(\frac{Z}{h\nu}\right)^2 \quad \left(\mathrm{cm}^2/\mathrm{atom}\right)$$
- Mass Attenuation Coefficients: $$\frac{{}_a\sigma_R}{\rho} \propto \frac{Z}{(h\nu)^2} \quad \left(\mathrm{cm}^2/\mathrm{g}\right)$$
- Mass Energy-Transfer Coefficients: $$\frac{{}_a\sigma_{R\,tr}}{\rho} = 0 \quad \left(\mathrm{cm}^2/\mathrm{g}\right)$$

Compton scattering

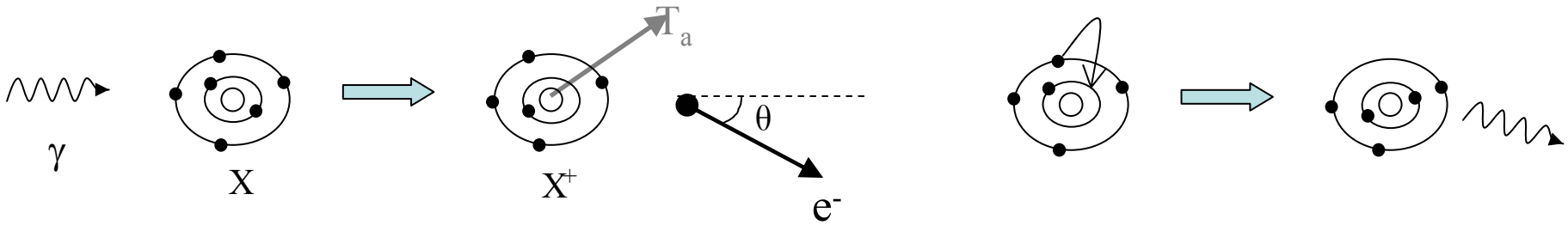


- Kinematics:

$$h\nu' = \frac{h\nu}{1+\left(h\nu/m_e c^2\right)\left(1-\cos\theta\right)}, \quad T = h\nu - h\nu', \quad \cot\varphi = \left(1+\frac{h\nu}{m_e c^2}\right)\tan\left(\frac{\theta}{2}\right)$$

- Electronic cross section: ${}_e\sigma \propto Z^0 \quad \left(\mathrm{cm}^2/\mathrm{electron}\right)$
- Atomic cross section: ${}_a\sigma = Z \cdot {}_e\sigma \quad \left(\mathrm{cm}^2/\mathrm{atom}\right)$
- Mass Attenuation Coefficients: $\frac{{}_a\sigma}{\rho} = \frac{N_A Z}{A} \cdot {}_e\sigma \quad \left(\mathrm{cm}^2/\mathrm{g}\right)$
- Mass Energy-Transfer Coefficients: $\frac{{}_a\sigma_{tr}}{\rho} = \frac{{}_a\sigma}{\rho}\frac{\bar{T}}{h\nu} \quad \left(\mathrm{cm}^2/\mathrm{g}\right)$

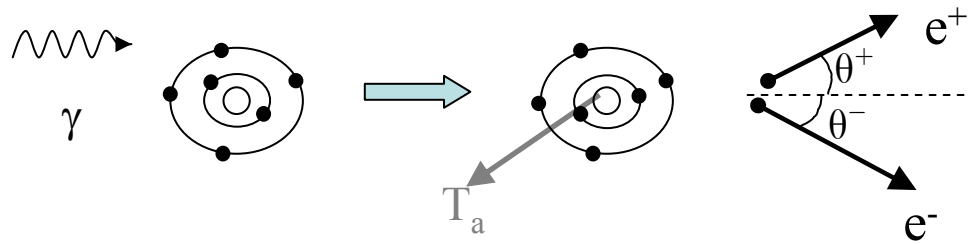
Photoelectric effect



- Kinematics: $T = h\nu - E_b - T_a \simeq h\nu - E_b$
- Atomic cross section: ${}_a\tau \propto \frac{Z^4}{(h\nu)^3} \quad \left(\mathrm{cm}^2/\mathrm{atom}\right)$
- Mass Attenuation Coefficients: $\frac{{}_a\tau}{\rho} \propto \left(\frac{Z}{h\nu}\right)^3 \quad \left(\mathrm{cm}^2/\mathrm{g}\right)$
- Mass Energy-Transfer Coefficients:

$$\frac{{}_a\tau_{tr}}{\rho} \propto \frac{{}_a\tau}{\rho}\left(\frac{h\nu - P_K Y_K h\bar{\nu}_K - (1-P_K)P_L Y_L h\bar{\nu}_L}{h\nu}\right) \quad \left(\mathrm{cm}^2/\mathrm{g}\right)$$

Pair- and triplet -production



- Kinematics: $h\nu = 2m_e c^2 + T^+ + T^-, \quad pair: \; h\nu_{\min} = 2m_e c^2$

  $trip: \quad h\nu_{\min} = 4m_e c^2$

- Atomic cross section: ${}_a\kappa_{par} \propto Z^2, \; {}_a\kappa_{tri} \propto Z \; \left(\mathrm{cm}^2/\mathrm{atom}\right)$

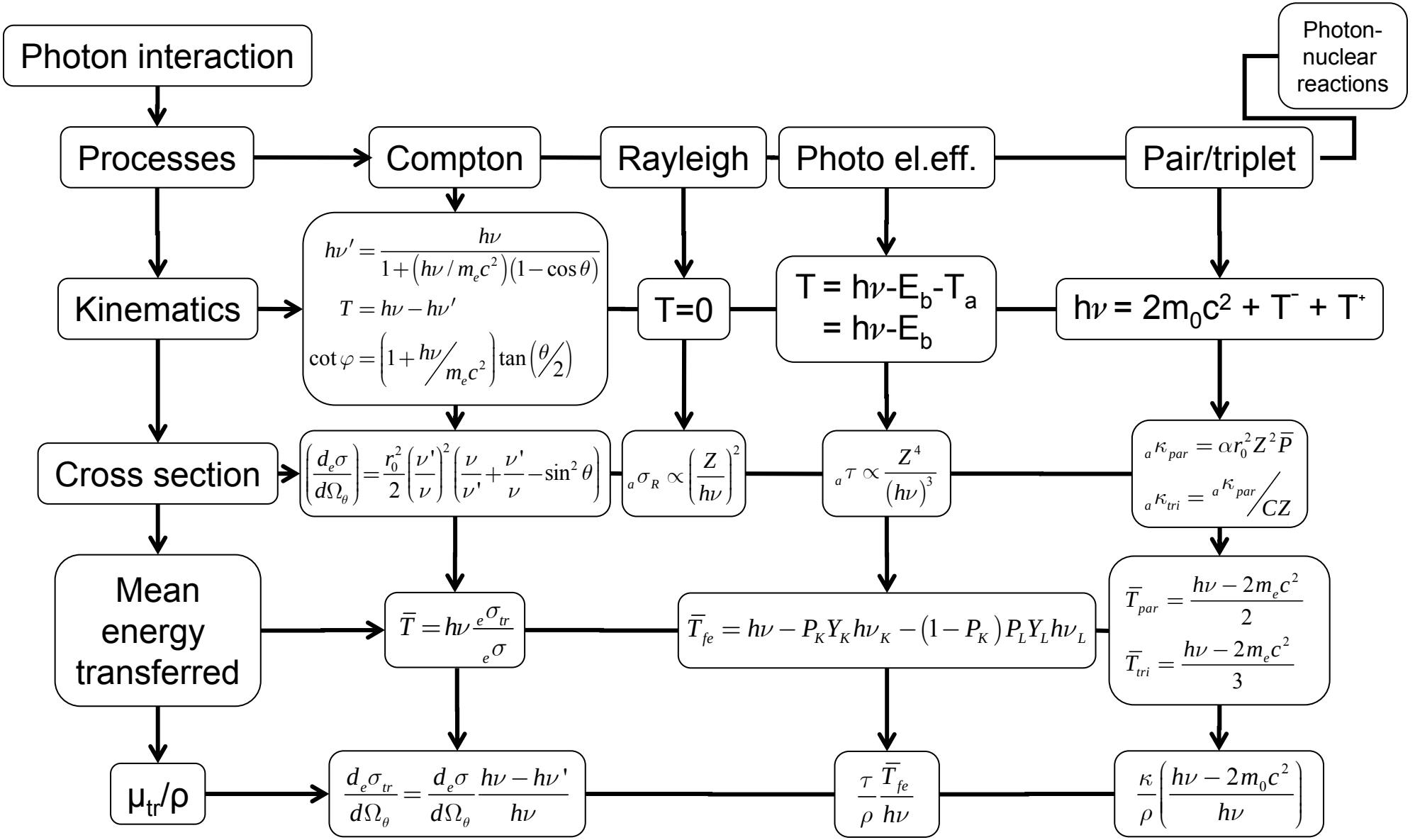
- Mass Attenuation Coef.: $\frac{{}_a\kappa_{par}}{\rho} \propto Z, \; \frac{{}_a\kappa_{tri}}{\rho} \propto Z^0 \; \left(\mathrm{cm}^2/\mathrm{g}\right)$

- Mass Energy-Transfer Coef.: $\frac{{}_a\kappa_{tr}}{\rho} = \frac{{}_a\kappa}{\rho}\left(1 - \frac{2m_0 c^2}{h\nu}\right) \; \left(\mathrm{cm}^2/\mathrm{g}\right)$

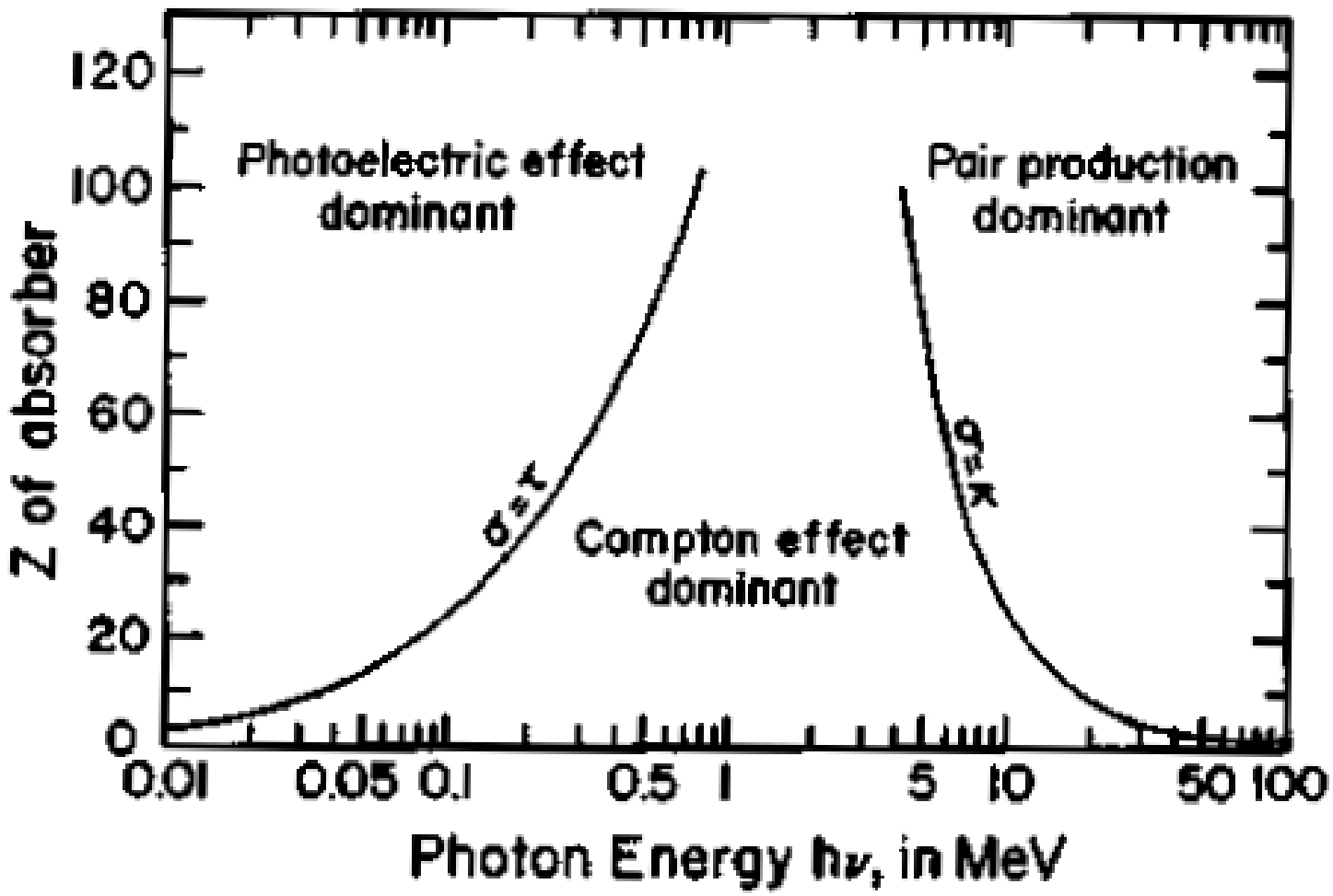
Photonuclear interactions

- Photon (energy above a few MeV) excites a nucleus
- Proton or neutron is emitted
- (γ, n) interactions may lead to radiation protection problems
- Example: Tungsten W (γ, n)
- Not important in dosimetry

Photon Interaction Summary



Summary


Photoelectric effect
dominant
Compton effect
dominant
Pair production
dominant
σ≈τ
σ≈κ
Z of absorber
120
100
80
60
40
20
0
0.01
0.05
0.1
0.5
1
5
10
50
100
Photon Energy hν, in MeV