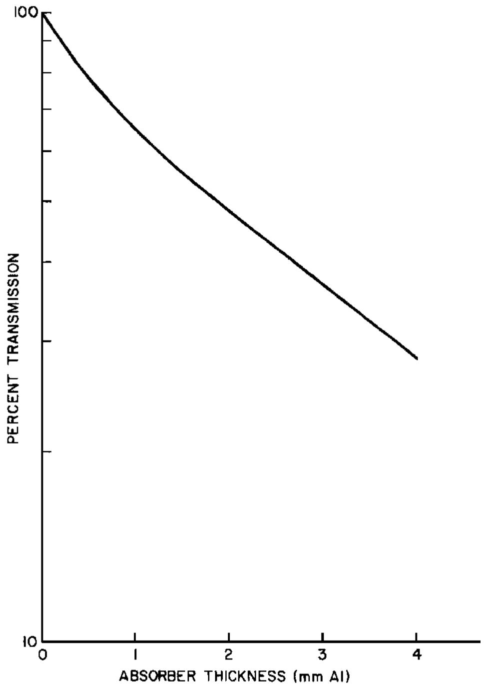


MARGIN FIGURE 4-11
Semilogarithmic plot of the number of x rays in a polyenergetic beam as a function of thickness of an attenuating medium. The penetrating ability (HVL) of the beam increases continuously with thickness because lower-energy photons are selectively removed from the beam. The straight-line relationship illustrated in Margin Figure 4-10 for a narrow beam of monoenergetic photons is not achieved for a polyenergetic x-ray beam.

Energy Absorption and Energy Transfer

The attenuation coefficient μ (or μ_a, μ_e, μ_m) refers to total attenuation (i.e., absorption plus scatter). Sometimes it is necessary to determine the energy truly absorbed in a material and not simply scattered from it. To express the energy absorbed, the energy absorption coefficient μ_{en} is used, where μ_{en} is given by the expression

$$\mu_{\text{en}} = \mu \frac{E_a}{h\nu} \tag{4-18}$$

In this expression, μ is the attenuation coefficient, E_a is the average energy absorbed in the material per photon interaction, and $h\nu$ is the photon energy. Thus, the energy absorption coefficient is equal to the attenuation coefficient times the fraction of energy truly absorbed. Energy absorption coefficients may also be expressed as mass energy absorption coefficients $(\mu_{\text{en}})_m$, atomic energy absorption coefficients $(\mu_{\text{en}})_a$, or electronic energy absorption coefficients $(\mu_{\text{en}})_e$ by dividing the energy absorption coefficient μ_{en} by the physical density, the number of atoms per cubic meter, or the number of electrons per cubic meter, respectively.

Example 4-7

The attenuation coefficient for 1-MeV photons in water is 7.1 m^{-1}. If the energy absorption coefficient for 1-MeV photons in water is 3.1 m^{-1}, find the average energy absorbed in water per photon interaction.

By rearranging Eq. (4-15), we obtain

$$\begin{aligned} E_a &= \frac{\mu_{\text{en}}}{\mu}(h\nu) \\ &= \frac{3.1\ \text{m}^{-1}}{7.1\ \text{m}^{-1}}(1\ \text{MeV}) \end{aligned}$$

$$= 0.44 \text{ MeV}$$
$$= 440 \text{ keV}$$

Example 4-8

An x-ray tube emits 10^{12} photons per second in a highly collimated beam that strikes a 0.1-mm-thick radiographic screen. For purposes of this example, the beam is assumed to consist entirely of 40-keV photons. The attenuation coefficient of the screen is 23 m^{-1}, and the mass energy absorption coefficient of the screen is 5 m^{-1} for 40-keV photons. Find the total energy in keV absorbed by the screen during a 0.5-sec exposure.

The number of photons incident upon the screen is

$$(10^{12} \text{ photons/sec})(0.5 \text{ sec}) = 5 \times 10^{11} \text{ photons}$$

The number of interactions that take place in the screen is [from Eq. (4-7)]

$$\begin{aligned} I_{\text{at}} &= I_0(1 - e^{-\mu x}) \\ &= 5 \times 10^{11}\left[1 - ^{-(23 \text{ m}^{-1})(10^{-3} \text{ m/mm})}\right] \\ &= 1.2 \times 10^9 \text{ interactions} \end{aligned}$$

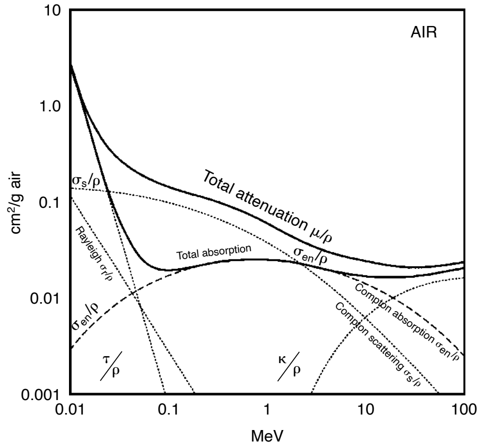
The average energy absorbed per interaction is [from Eq. (4-15)]

$$\begin{aligned} E_a &= \frac{\mu_{\text{en}}}{\mu}(h\nu) \\ &= \frac{5 \text{ m}^{-1}}{23 \text{ m}^{-1}}(40 \text{ keV}) \\ &= 8.7 \text{ keV} \end{aligned}$$

The total energy absorbed during the 0.5-sec exposure is then

$$(1.2 \times 10^9)(8.7 \text{ keV}) = 1.3 \times 10^{10} \text{ keV}$$

Energy absorption coefficients and attenuation coefficients for air are plotted in Margin Figure 4-12 as a function of photon energy.



MARGIN FIGURE 4-12
Mass attenuation coefficients for photons in air. The curve marked "total absorption" is $(\mu/\rho) = (\sigma/\rho) + (\tau/\rho) + (\kappa/\rho)$, where σ, τ, and κ are the corresponding linear coefficients for Compton absorption, photoelectric absorption, and pair production. When the Compton mass scattering coefficient σ_s and the Compton absorption coefficient τ_a/ρ are added, the total Compton mass attenuation coefficient σ/ρ is obtained.