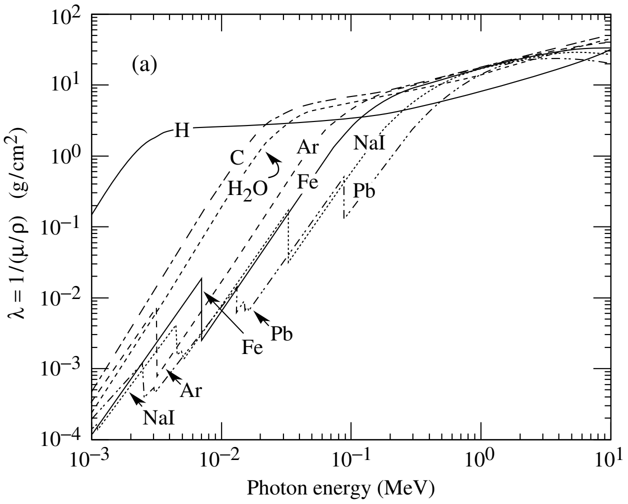
15. PHOTON AND ELECTRON ATTENUATION

Photon Attenuation Length



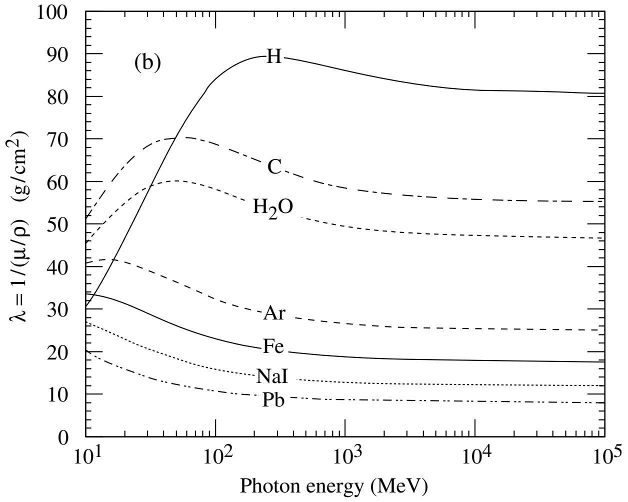


Figure 15.1: The photon mass attenuation length $\lambda = 1/(\mu/\rho)$ (also known as mfp, mean free path) for various absorbers as a function of photon energy, where μ is the mass attenuation coefficient. For a homogeneous medium of density ρ, the intensity I remaining after traversal of thickness t is given by the expression $I = I_0 \exp(-t\rho/\lambda)$. The accuracy is a few percent. Interpolation to other Z should be done in the cross section $\sigma = A/\lambda N_A$ cm^2/atom, where A is the atomic weight of the absorber material in grams and N_A is the Avogadro number. For a chemical compound or mixture, use $(1/\lambda)_{\rm eff} \approx \sum w_i(1/\lambda)_i$, accurate to a few percent, where w_i is the proportion by weight of the i^{th} constituent. The processes responsible for attenuation are given in Fig. 15.4. Not all of these processes necessarily result in detectable attenuation. For example, coherent Rayleigh scattering off an atom may occur at such low momentum transfer that the change in energy and momentum of the photon may not be significant.

(a) Low-energy region.

(b) The photon mass attenuation length, high-energy range (note that ordinate is linear scale). The attenuation length is constant beyond the range shown for at least two decades in energy.

From Hubbell, Gimm, and Øverbø, J. Phys. Chem. Ref. Data **9**, 1023 (80). See also J.H. Hubbell, Int. J. of Applied Rad. and Isotopes **33**, 1269 (82). Data courtesy J.H. Hubbell.

Photon Pair Conversion Probability

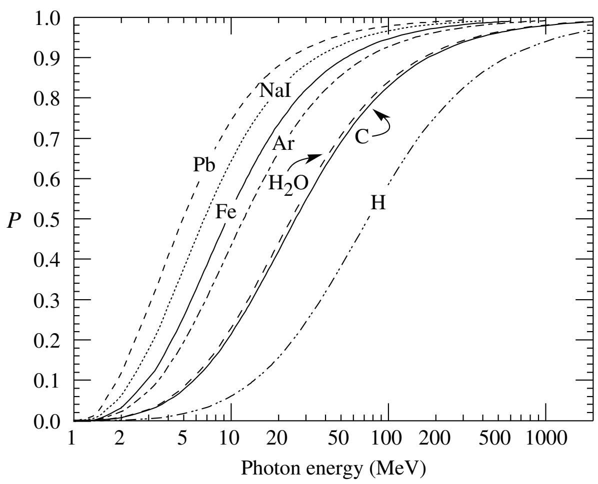


Figure 15.2: Probability P that a photon interaction will result in conversion to an e^+e^- pair. Except for a few-percent contribution from photonuclear absorption around 10 or 20 MeV, essentially all other interactions result in Compton scattering off an atomic electron. For a photon attenuation length λ (g/cm^2) (Fig. 15.1), the probability that a given photon will produce an electron pair (without first Compton scattering) in thickness t (cm) of absorber of density ρ (g/cm^3) is $P[1 - \exp(-t\rho/\lambda)]$.

CITATION: L. Montanet *et al.*, Physical Review **D50**, 1173 (1994) and 1995 off-year partial update for the 1996 edition available on the PDG WWW pages (URL: `http://pdg.lbl.gov/`)

Contributions to Photon Cross Section in Carbon and Lead

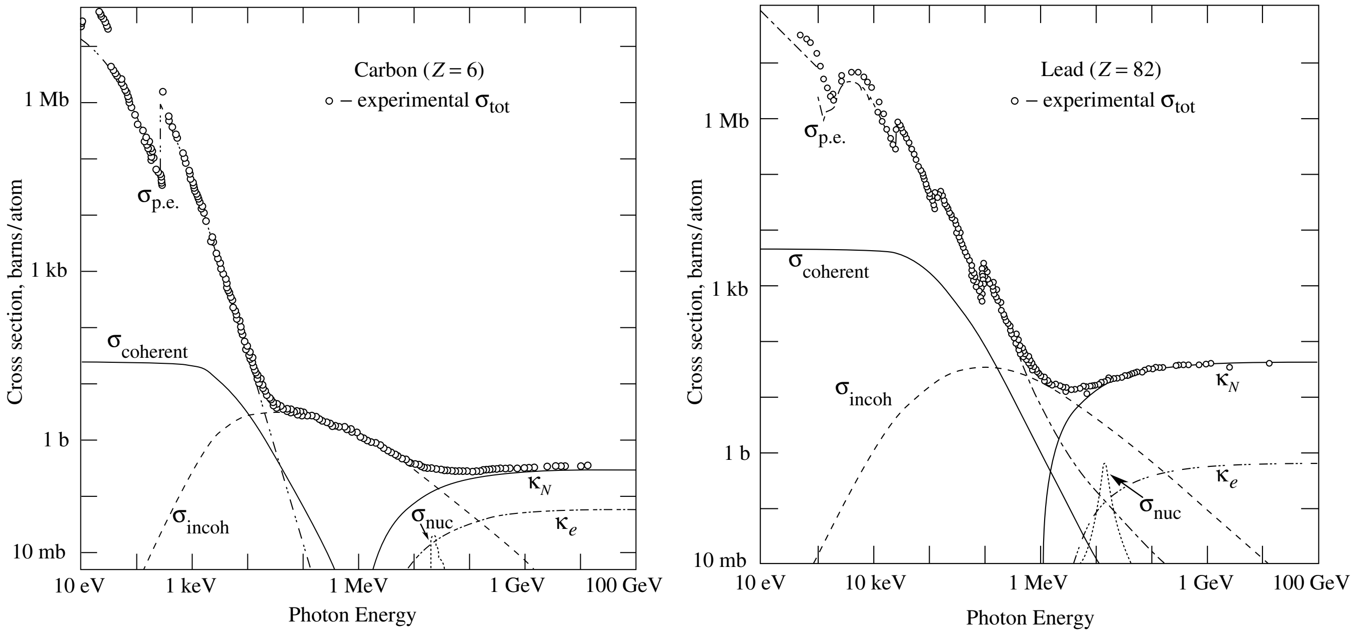


Figure 15.3: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes.

$\sigma_{\rm p.e.}$ = Atomic photo-effect (electron ejection, photon absorption)
$\sigma_{\rm coherent}$ = Coherent scattering (Rayleigh scattering—atom neither ionized nor excited)
$\sigma_{\rm incoherent}$ = Incoherent scattering (Compton scattering off an electron)
κ_n = Pair production, nuclear field
κ_e = Pair production, electron field
$\sigma_{\rm nuc}$ = Photonuclear absorption (nuclear absorption, usually followed by emission of a neutron or other particle)

From Hubbell, Gimm, and Øverbø, J. Phys. Chem. Ref. Data **9**, 1023 (80). The photon total cross section is assumed approximately flat for at least two decades beyond the energy range shown. Figures courtesy J.H. Hubbell.

Fractional Energy Loss for Electrons and Positrons in Lead

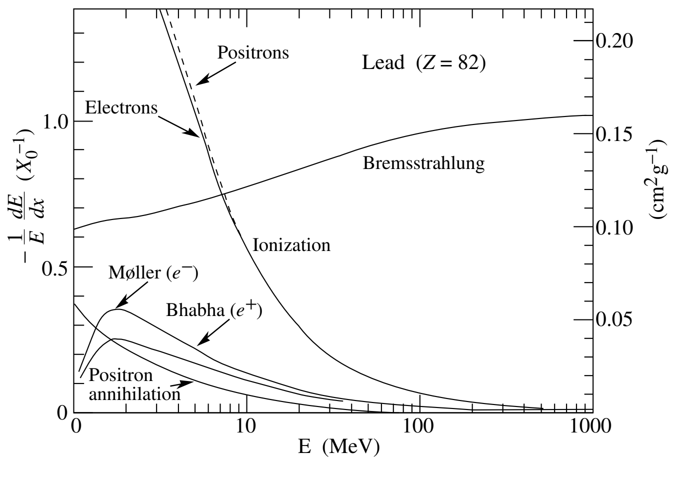


Figure 15.4: Fractional energy loss per radiation length in lead as a function of electron or positron energy. Electron (positron) scattering is considered as ionization when the energy loss per collision is below 0.255 MeV, and as Moller (Bhabha) scattering when it is above. Adapted from Fig. 3.2 from Messel and Crawford, *Electron-Photon Shower Distribution Function Tables for Lead, Copper, and Air Absorbers*, Pergamon Press, 1970. Messel and Crawford use $X_0(\mathrm{Pb}) = 5.82\ \mathrm{g/cm^2}$, but we have modified the figures to reflect the value given in the Table of Atomic and Nuclear Properties of Materials, namely $X_0(\mathrm{Pb}) = 6.4\ \mathrm{g/cm^2}$. The development of electron-photon cascades is approximately independent of absorber when the results are expressed in terms of inverse radiation lengths (*i.e.*, scale on left of plot).