24. PHOTON AND ELECTRON INTERACTIONS WITH MATTER

Revised April 1998 by D.E. Groom (LBNL).

Photon Attenuation Length

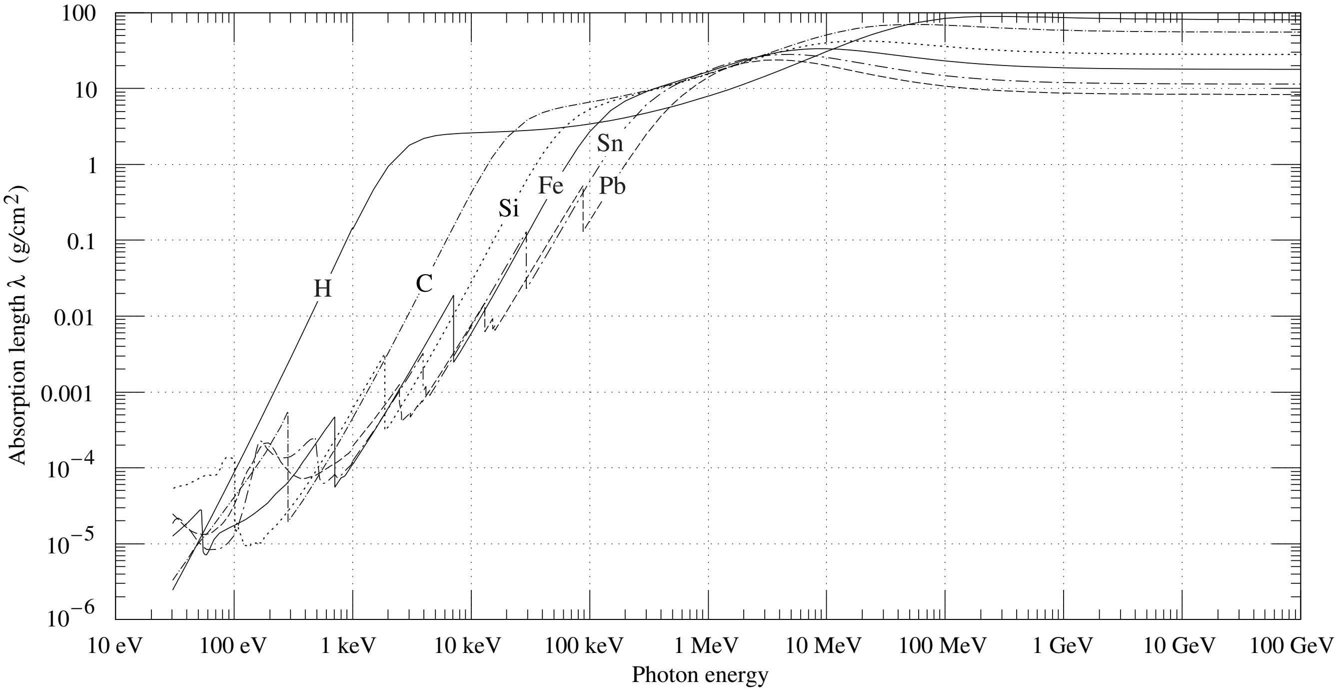

Figure 24.1: The photon mass attenuation length (or mean free path) $\lambda = 1/(\mu/\rho)$ for various elemental absorbers as a function of photon energy. The mass attenuation coefficient is μ/ρ, where ρ is the density. The intensity I remaining after traversal of thickness t (in mass/unit area) is given by $I = I_0 \exp(-t/\lambda)$. The accuracy is a few percent. For a chemical compound or mixture, $1/\lambda_{\rm eff} \approx \sum_{\rm elements} w_Z/\lambda_Z$, where w_Z is the proportion by weight of the element with atomic number Z. The processes responsible for attenuation are given in Fig. 24.4. Since coherent processes are included, not all these processes result in energy deposition.

The data for 30 eV $< E <$ 1 keV are obtained from `http://www-cxro.lbl.gov/optical_constants` (courtesy of Eric M. Gullikson, LBNL). The data for 1 keV $< E <$ 100 GeV are from `http://physics.nist.gov/PhysRefData`, through the courtesy of John H. Hubbell (NIST).

Photon Pair Conversion Probability

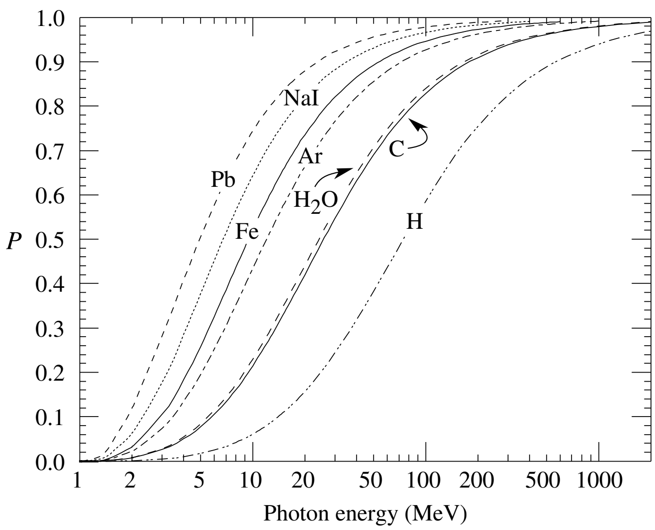

Figure 24.2: Probability P that a photon interaction will result in conversion to an e^+e^- pair. Except for a few-percent contribution from photonuclear absorption around 10 or 20 MeV, essentially all other interactions in this energy range result in Compton scattering off an atomic electron. For a photon attenuation length λ (Fig. 24.1), the probability that a given photon will produce an electron pair (without first Compton scattering) in thickness t of absorber is $P[1 - \exp(-t/\lambda)]$.

Contributions to Photon Cross Section in Carbon and Lead

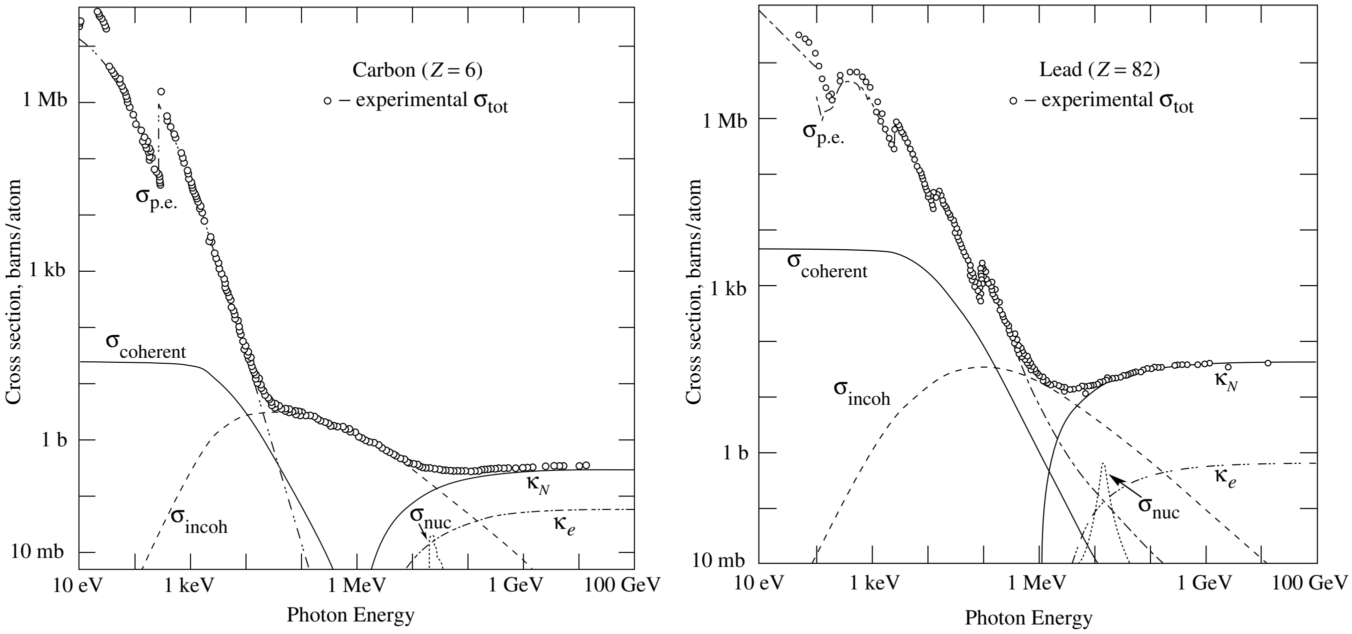

Figure 24.3: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes:

$\sigma_{\rm p.e.}$ = 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). Data for these and other elements, compounds, and mixtures may be obtained from `http://physics.nist.gov/PhysRefData`. The photon total cross section is assumed approximately flat for at least two decades beyond the energy range shown. Figures courtesy J.H. Hubbell (NIST).

Fractional Energy Loss for Electrons and Positrons in Lead

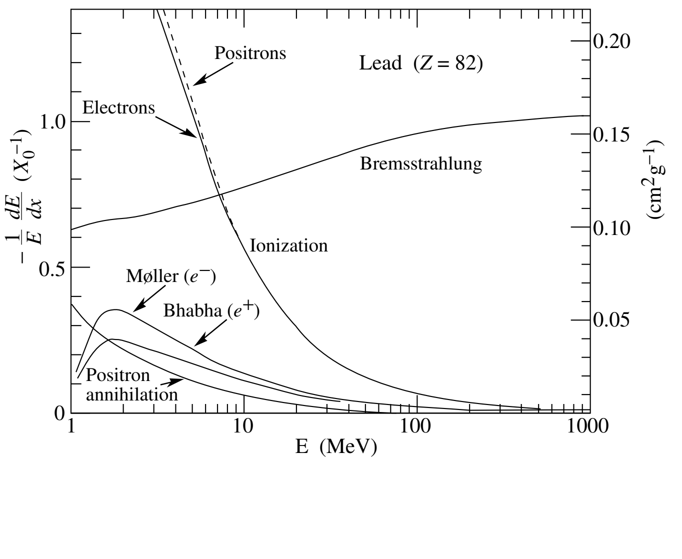

Figure 24.4: Fractional energy loss per radiation length in lead as a function of electron or positron energy. Electron (positron) scattering is considered as ionization when the energy loss per collision is below 0.255 MeV, and as Moller (Bhabha) scattering when it is above. Adapted from Fig. 3.2 from Messel and Crawford, *Electron-Photon Shower Distribution Function Tables for Lead, Copper, and Air Absorbers*, Pergamon Press, 1970. Messel and Crawford use X_0(Pb) = 5.82 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(Pb) = 6.4 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).