Photoelectric absorption

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A bound electron can absorb completely the energy of a photon :

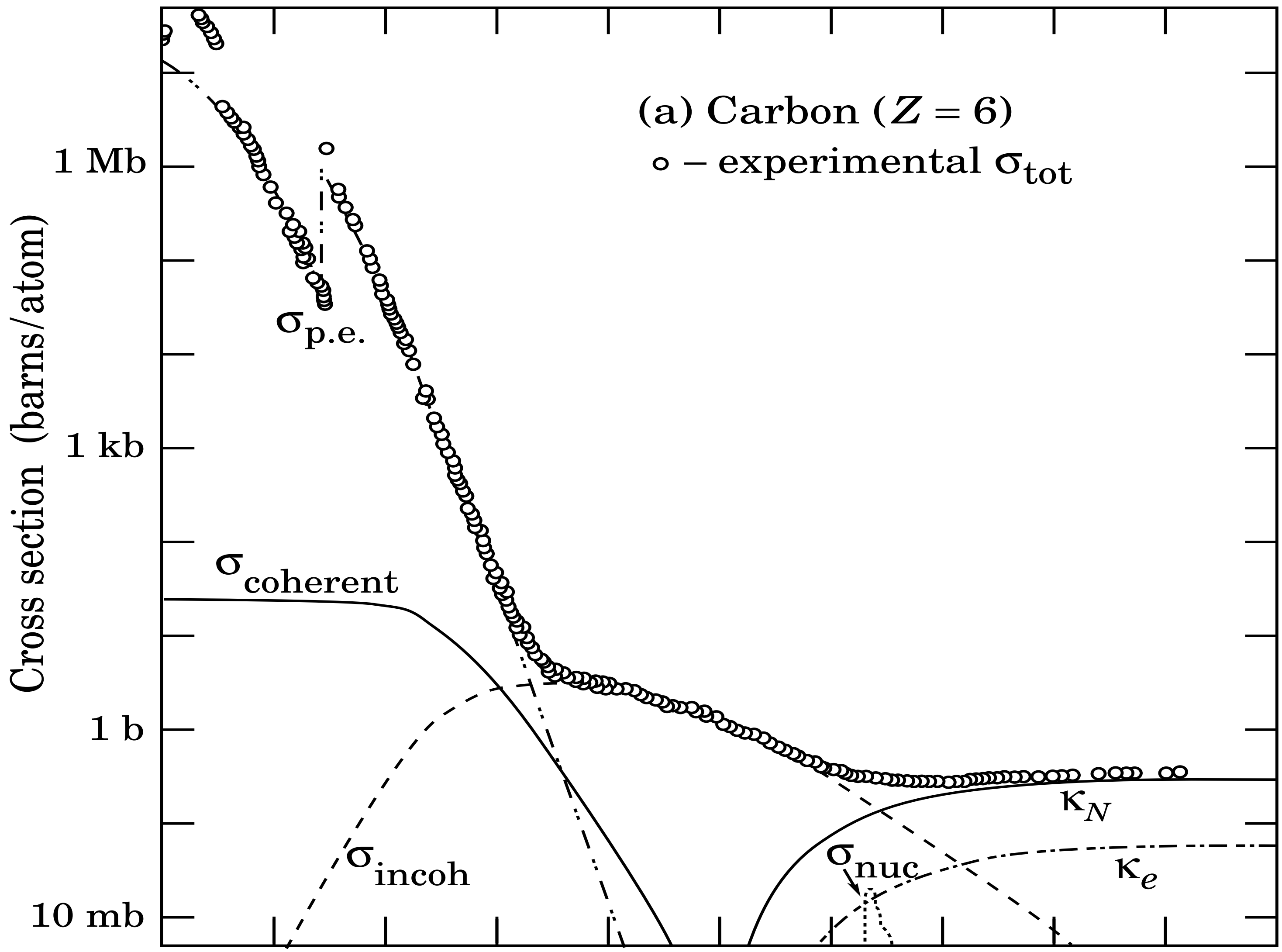
$$\gamma + atom \rightarrow atom^{+} + e^{-}$$

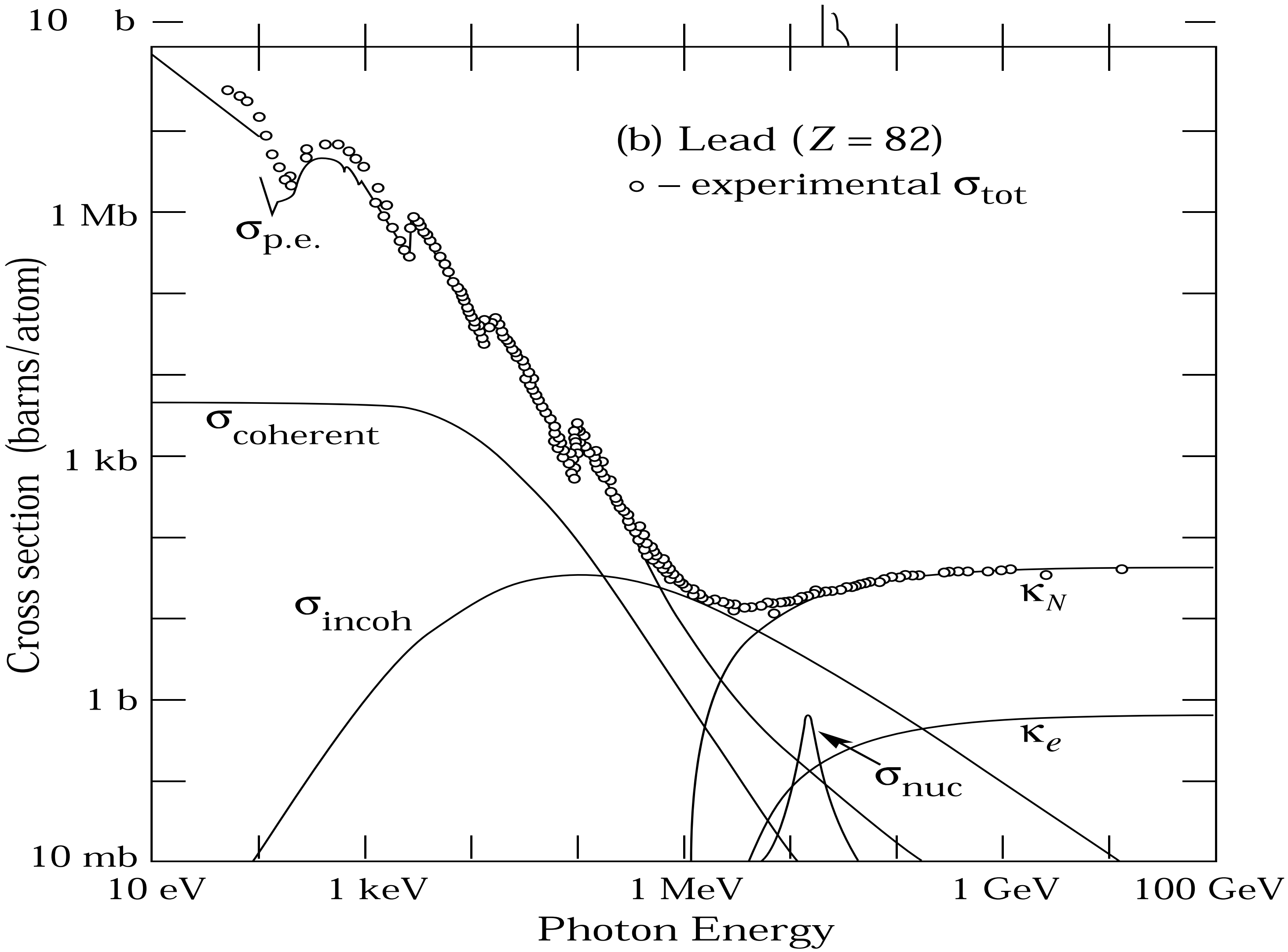
The electron is ejected with kinetic energy $T = E_\gamma - B_s$.
(E_γ: energy of the incident photon, B_s: binding energy of the corresponding subshell). The nucleus absorbs the recoil momentum.

The cross section per shell can be parametrized [Biggs87] :

$$\sigma_s = r_e^2 \; \alpha^4 \; Z^5 \; f\left(\frac{1}{E_\gamma^{a(E_\gamma)}}\right)$$

with f : nonsimple function of $1/E_\gamma$, and $1 \leq a(E_\gamma) \leq 4$.


(a) Carbon (Z = 6)
o – experimental σtot
1 Mb
1 kb
1 b
10 mb
Cross section (barns/atom)
σp.e.
σcoherent
σincoh
σnuc
κN
κe


(b) Lead (Z = 82)
○ – experimental σtot
σp.e.
σcoherent
σincoh
σnuc
κN
κe
10 b
1 Mb
1 kb
1 b
10 mb
Cross section (barns/atom)
10 eV
1 keV
1 MeV
1 GeV
100 GeV
Photon Energy

The total cross section has discontinuities at $E_\gamma = B_s$ (absorption edge).

There are several parametrizations and tables of the cross sections. See [Cullen97, Biggs87].

If $E_\gamma > B_K$ the absorption occurs mainly on the K-shell (80% of the cases).

The electron is emitted forward in the direction of the incident photon at high E_γ, and perpendicular to the photon at low E_γ [Sauter31, Gavri61].

Following the photoabsorption in the K-shell, characteristic X-rays or Auger electrons are emitted [Perkin91].

Cross section per atom

We use a parametrisation of the photoabsorption cross section proposed by Biggs and al. [Biggs87] :

$$\sigma(Z, E_\gamma) = \frac{a(Z, E_\gamma)}{E_\gamma} + \frac{b(Z, E_\gamma)}{E_\gamma^2} + \frac{c(Z, E_\gamma)}{E_\gamma^3} + \frac{d(Z, E_\gamma)}{E_\gamma^4} \quad (1)$$

The coefficients a, b, c, d are fitted with experimental data by the least square method separately in each energy interval [Grichi94].

As a rule, the interval borders are equal to the corresponding photoabsorption edges.

Mean free path

$$\lambda(E_\gamma) = \left(\sum_i n_{ati} \cdot \sigma(Z_i, E_\gamma) \right)^{-1}$$

n_{ati} : nb of atoms per volume of the i^{th} element in the material.

At initialization stage, the function `BuildPhysicsTables()` computes and tabulates :

- crossSectionPerAtom for all elements
- meanFreePath for all materials

The cross section and mean free path can be tabulated only above 50 keV. Below this, they are too discontinue: they are recomputed 'on fly' from formula 1.

final state

choose an Element : the binding energy of the shells depend of Z_i. In a compound material one choose randomly an Element according :

$$Prob(Z_i, E_\gamma) = \frac{n_{ati}\sigma(Z_i, E_\gamma)}{\sum_i [n_{ati} \cdot \sigma_i(E_\gamma)]}$$

final state : the simulation is presently rather crude.
A quanta can be absorbed if $E_\gamma > B_{shell}$. The shell energies are taken from `G4AtomicShells` data. One choose the closest atomic shell available.

The photoelectron is emitted with kinetic energy:

$$T_{photoelectron} = E_\gamma - B_{shell}(Z_i)$$

Theta distribution of the photoelectron

The polar angle of the photoelectron is sampled from the Sauter-Gavrila distribution (for K-shell) [Gavri59], which is correct only to zero order in αZ :

$$\frac{d\sigma}{d(\cos\theta)} \sim \frac{\sin^2\theta}{(1-\beta\cos\theta)^4}\left\{1+\frac{1}{2}\gamma(\gamma-1)(\gamma-2)(1-\beta\cos\theta)\right\} \quad (2)$$

where β and γ are the Lorentz factors of the photoelectron.

Relaxation

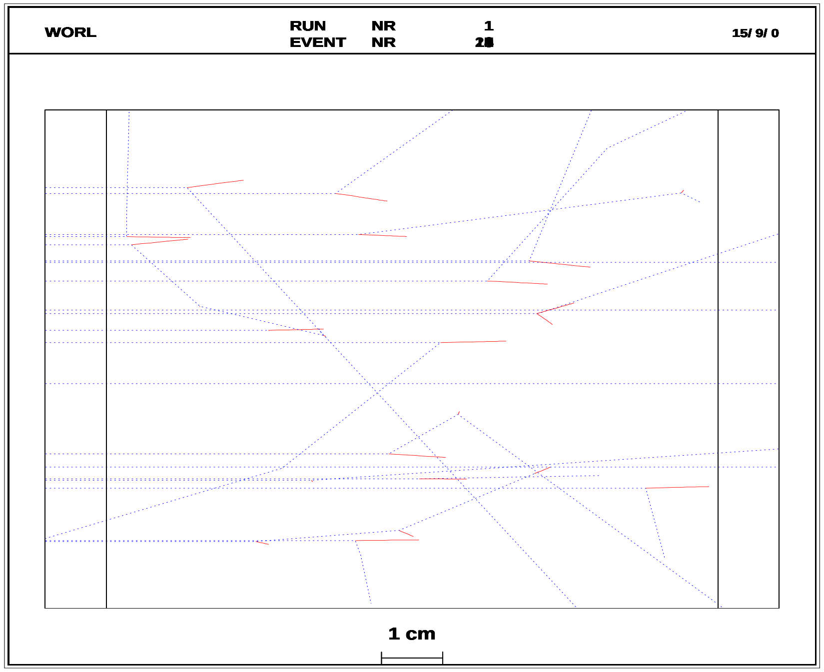
In the current implementation the relaxation of the atom is not simulated, but instead is counted as a local energy deposit.

attenuation

$$\sigma_{tot} = \sigma_{pair} + \sigma_{comp} + \sigma_{phot} + \sigma_{rayl} \quad \longrightarrow \mu = n_{at}\, \sigma_{tot}$$

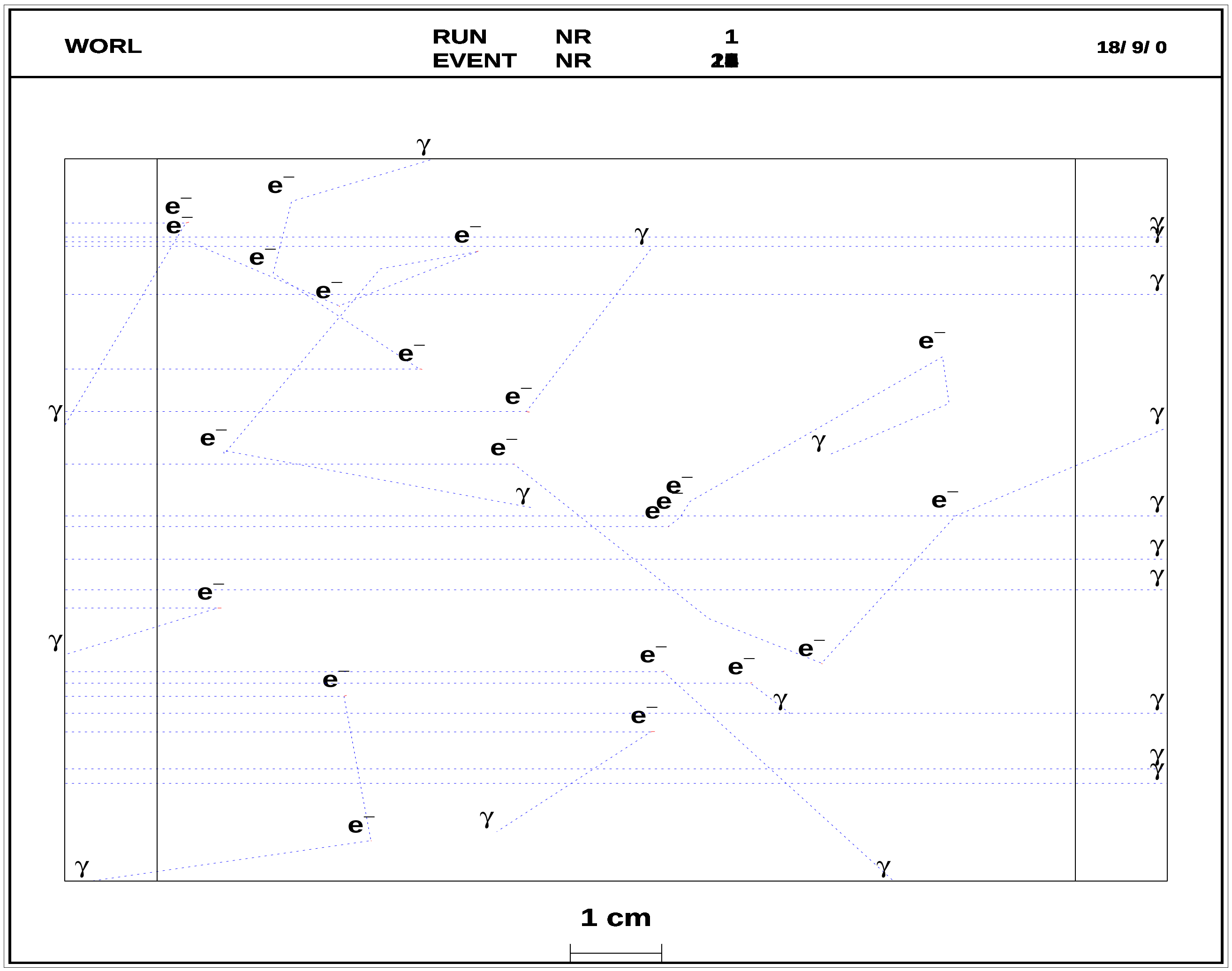
A beam of monoenergetic photons is attenuated in intensity (not in energy) according : $I(x) = I(0)\exp(-\mu\, x) = I(0)\exp(-x/\lambda)$

Below : 20 photons, 5 MeV, entering 10 cm of Al. 4 exit unaltered.

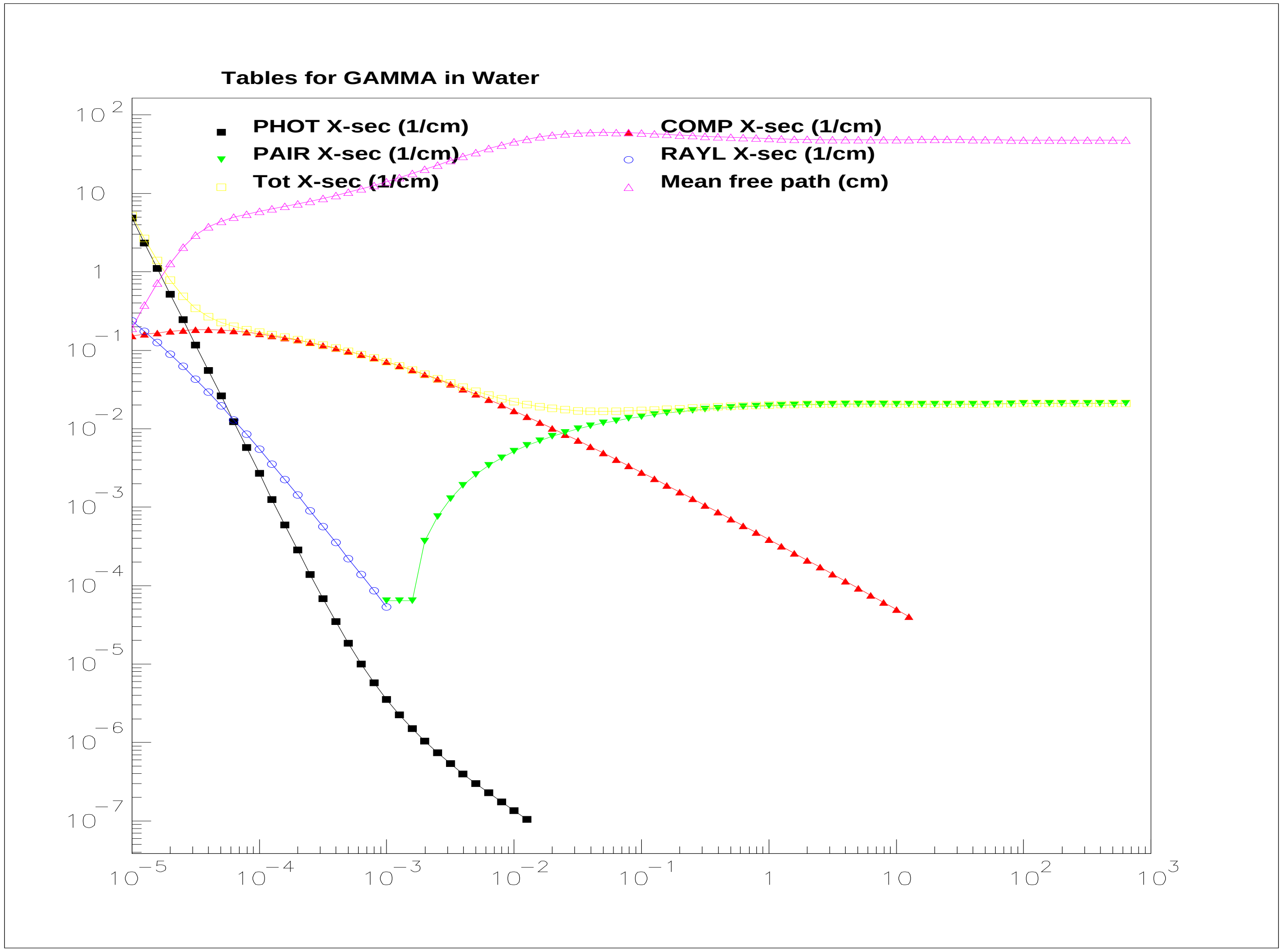


20 photons, 400 keV, entering 10 cm of water.

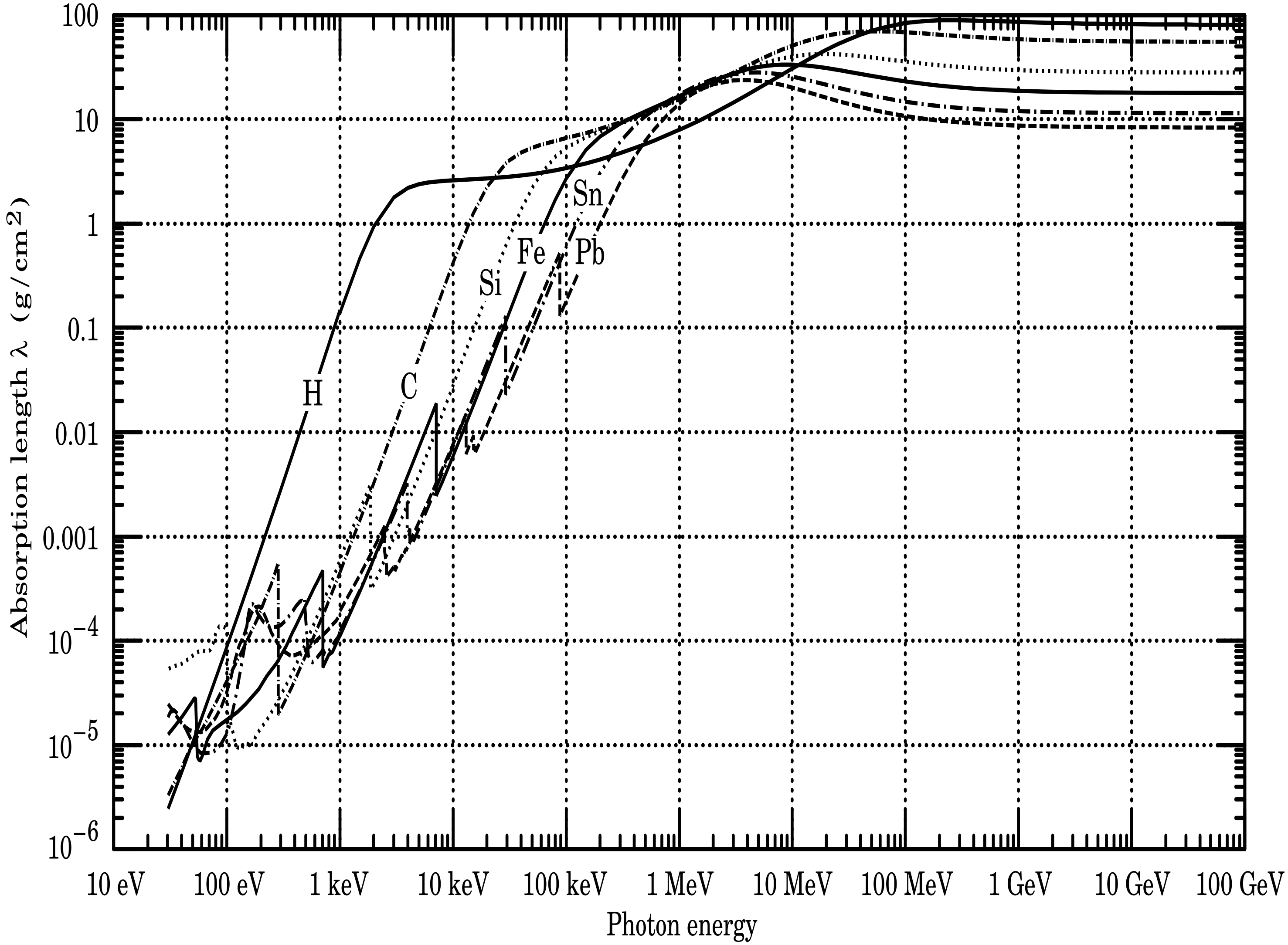
(compare with e^- and protons)



Macroscopic cross sections for photon in water. (⟶ mean free path)



photon energy (GeV)


100
10
1
0.1
0.01
0.001
10^{-4}
10^{-5}
10^{-6}
Absorption length λ (g/cm²)
10 eV
100 eV
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
Photon energy
H
C
Si
Fe
Sn
Pb

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