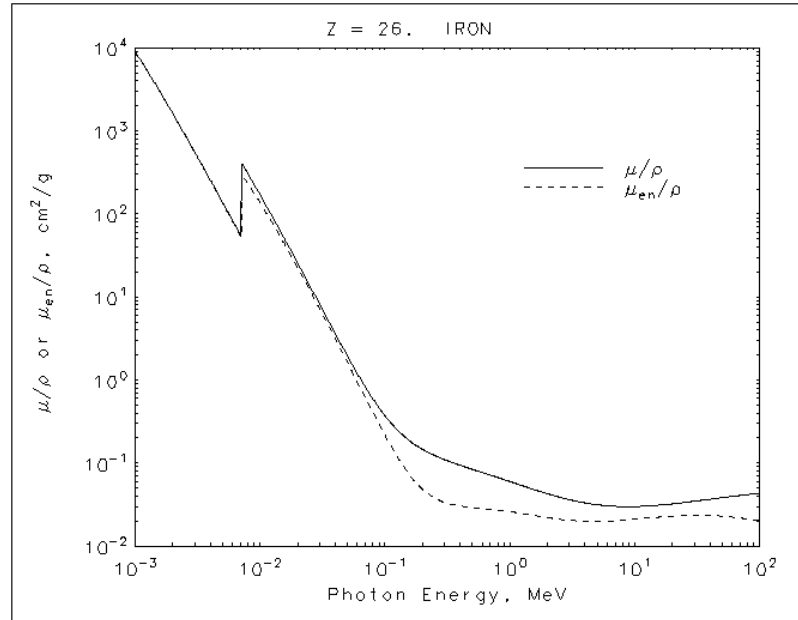


3RD SERIES OF EXERCISES – INTERACTION OF RADIATION WITH MATTER

1 – a) A beam of γ radiation with energy equal to 0.2 MeV passes through an iron sheet with thickness 2 mm . Given that the initial intensity of the beam is 10^6 photons per cm^2 per second, what is the intensity after the beam has passed through the plate (see tables)?

b) And if the beam has an energy of 1 MeV ?

($\rho_{\text{Fe}} = 7.86 \text{ g/cm}^3$)



2 – Consider a beam of γ rays with energy 100 keV and intensity of 5×10^6 photons per cm^2 per second. What is the intensity of the beam after passing through (see tables):

a) 1 mm of aluminium;

b) 1 mm of lead;
($\rho_{\text{Pb}} = 11.34 \text{ g/cm}^3$);

c) 0.5 cm of aluminium.

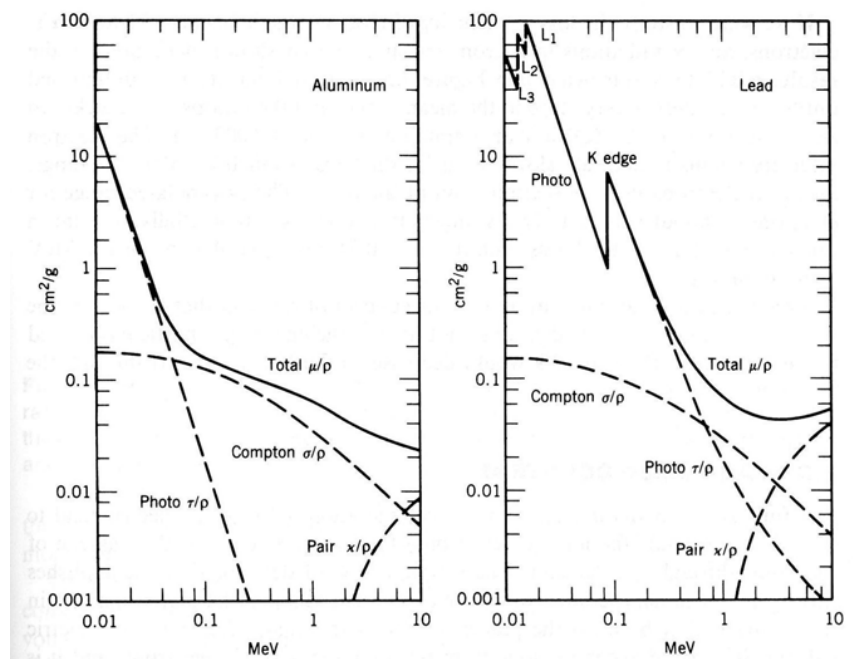


Figure 1 – Attenuation coefficient, divided by the density (μ/ρ) for gamma radiation of various energies, for aluminium and lead (Krane, pag. 203).

3 – a) Repeat the previous exercise, for photons with energy equal to 1 MeV .

b) Regarding the huge differences in intensity observed for the lead sheet, from 2) to 3), what is this difference due to? What type of interaction do the photons undergo, at the energy of 2)?

4 – A monoenergetic gamma-ray beam, with an intensity of 3×10^6 photons per cm^2 per second, hits an aluminium sheet with thickness equal to 5 cm . After passing through the sheet, the beam intensity becomes 2×10^6 photons per cm^2 per second. What is the energy of the photons?

5 – a) A beam of γ radiation with energy equal to 0.5 MeV passes through an aluminium sheet with thickness 5 mm . What is the attenuation percentage of the beam?

b) What thickness of iron would be needed to reduce the intensity of the same beam to a thousandth of its initial value?

c) A second beam is composed, in equal proportions, of γ particles with energies 0.4 MeV and 1.0 MeV . The beam is incident on an iron sheet 2 mm thick. What are the relative percentages of particles of both energies after passing through the sheet? ($\rho_{\text{Al}} = 2.70\text{ g/cm}^3$; $\rho_{\text{Fe}} = 7.86\text{ g/cm}^3$; see the tables on the last pages)

6 – a) A beam of γ radiation with energy equal to 0.4 MeV passes through an aluminium sheet with thickness 5 mm . What is the attenuation percentage of the beam?

b) What thickness of copper would be needed to make the beam intensity reduced to a thousandth of its initial value?

c) A second beam, of unknown energy, passes through the same aluminium sheet from part a). It is observed that, after passing through the sheet, the beam intensity is reduced to about 60.8393% of its initial value. Calculate the attenuation that this same beam would undergo in a sheet of copper with the same thickness, 5 mm ($\rho_{\text{Cu}} = 8.94\text{ g/cm}^3$).

7 – a) A beam of γ radiation with energy equal to 0.3 MeV passes through a silver sheet with thickness 2 mm . What is the attenuation percentage of the beam?

b) What thickness of silver would be needed to make the beam intensity reduced to a tenth of its initial value?

c) A second beam, of unknown energy, passes through the same silver sheet from part a). It is observed that, after passing through the sheet, the beam intensity is reduced to about 92.7% of its initial value. What is the approximate energy of the photons?

($\rho_{\text{Ag}} = 10.49 \text{ g/cm}^3$; see the tables in the last pages)

8 – a) A beam of γ radiation with energy equal to 0.15 MeV passes through a silver sheet with thickness 3 mm, followed by an aluminium sheet of 1 mm. What is the total attenuation percentage of the beam?

b) Repeat the previous part for an energy of 0.5 MeV.

c) A second beam, of unknown energy, passes through the silver sheet from part a). It is observed that, after passing through the sheet, the beam intensity is reduced to about 84.86% of its initial value. Calculate the attenuation that this same beam would undergo in an aluminium sheet with a thickness of 5 mm.

($\rho_{\text{Al}} = 2.70 \text{ g/cm}^3$; $\rho_{\text{Ag}} = 10.49 \text{ g/cm}^3$; see the tables on the last page)

9 – Consult the NIST tables and determine the mass attenuation coefficient (μ/ρ) for a 0.4 MeV gamma-ray beam for the following compound substances:

a) Water (H_2O)

b) Sodium Iodide (NaI , $\rho = 3.67 \text{ g/cm}^3$)

c) Urea ($(\text{NH}_2)_2\text{CO}$, $\rho = 1.32 \text{ g/cm}^3$)

NIST data: <http://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html>

10 – A given metal alloy is composed of 30% Iron, 20% Copper and 50% Aluminium, with a density $\rho = 4.82 \text{ g/cm}^3$. Determine the attenuation percentage of a gamma-ray beam of 700 keV incident on a 1 mm sheet of this metal alloy.

11 – A radiation source emits γ rays isotropically. A Geiger detector, with a window of area 4 cm^2 , registers, at 10 cm from the source, about 9500 counts per second. Assume that the detector is perfectly aligned with the source.

a) Neglecting the attenuation of the air, what would the count rate be at 20 cm from the source? And at 30 ?

b) Neglecting the attenuation of the air, determine the activity of the source, in Curie.

12 – a) Describe how a Geiger counter works.

b) A Geiger counter is hit by a beam of electrons with energy equal to 2 MeV and intensity $10^6/\text{second}$. An identical counter is hit by a beam of γ photons with energy equal to 2 MeV and intensity $10^6/\text{second}$. What is the number of counts in the detector in each case (assuming perfect efficiencies)? Why?

13 – A given radiation contains α particles of 4 MeV, β particles of 0.1 MeV and γ particles with energy 0.01 MeV. What must the minimum thickness of aluminium shielding be to ensure that no more than 10% of the radiation intensity gets through?

(NOTE: recall the different notions of “range” for the three types of radiation)

14 – a) A beam of γ radiation with energy equal to 2.0 MeV passes through a lead sheet with thickness 1 mm, followed by an aluminium sheet of 7 mm. What is the attenuation percentage of the beam?

b) The HVL (Half-Value Length) of a material is defined as the thickness of that material needed to reduce the intensity of a given radiation by half. The TVL (Tenth-Value Length) is the thickness needed to reduce the intensity to a tenth. Calculate, for the radiation in part a), the HVL and TVL of lead and aluminium.

c) A second beam, of unknown energy, passes through the same lead sheet from part a). It is observed that, after passing through the sheet, the beam intensity is reduced to about 63.31% of its initial value. What is the energy of this second beam?

15 – Consider the interaction of protons with matter.

a) Explain what the *Bragg peak* is and its importance for proton therapy.

b) For a beam of protons of a given energy interacting with two materials of mass numbers A_1 and A_2 and densities ρ_1 and ρ_2 , the ranges R_1 and R_2 of the beam in each material satisfy the Bragg-Kleeman rule,

$$\frac{R_2}{R_1} = \frac{\rho_1}{\rho_2} \sqrt{\frac{A_2}{A_1}}$$

Compare the range of a proton beam in liquid water ($\rho = 1.0 \text{ g/cm}^3$) and water vapour ($\rho = 0.76 \text{ mg/cm}^3$)

c) Compare the range of protons in liquid water ($A_{\text{average}} = 6.0$) and air ($A_{\text{average}} = 14.3$, $\rho = 1.2 \text{ mg/cm}^3$).

**Attenuation coefficients of
Copper**

Energy (MeV)	μ/ρ (cm ² /g)
1.00000E-03	1.057E+04
1.04695E-03	9.307E+03
1.09610E-03	8.242E+03
1.09610E-03	9.347E+03
1.50000E-03	4.418E+03
2.00000E-03	2.154E+03
3.00000E-03	7.488E+02
4.00000E-03	3.473E+02
5.00000E-03	1.899E+02
6.00000E-03	1.156E+02
8.00000E-03	5.255E+01
8.97890E-03	3.829E+01
8.97890E-03	2.784E+02
1.00000E-02	2.159E+02
1.50000E-02	7.405E+01
2.00000E-02	3.379E+01
3.00000E-02	1.092E+01
4.00000E-02	4.862E+00
5.00000E-02	2.613E+00
6.00000E-02	1.593E+00
8.00000E-02	7.630E-01
1.00000E-01	4.584E-01
1.50000E-01	2.217E-01
2.00000E-01	1.559E-01
3.00000E-01	1.119E-01
4.00000E-01	9.413E-02
5.00000E-01	8.362E-02
6.00000E-01	7.625E-02
8.00000E-01	6.605E-02
1.00000E+00	5.901E-02
1.25000E+00	5.261E-02
1.50000E+00	4.803E-02
2.00000E+00	4.205E-02
3.00000E+00	3.599E-02
4.00000E+00	3.318E-02
5.00000E+00	3.177E-02
6.00000E+00	3.108E-02
8.00000E+00	3.074E-02
1.00000E+01	3.103E-02
1.50000E+01	3.247E-02
2.00000E+01	3.408E-02

**Coefficientes de atenuação do
Ferro**

Energia (MeV)	μ/ρ (cm ² /g)
1.00000E-03	9.085E+03
1.50000E-03	3.399E+03
2.00000E-03	1.626E+03
3.00000E-03	5.576E+02
4.00000E-03	2.567E+02
5.00000E-03	1.398E+02
6.00000E-03	8.484E+01
7.11200E-03	5.319E+01
7.11200E-03	4.076E+02
8.00000E-03	3.056E+02
1.00000E-02	1.706E+02
1.50000E-02	5.708E+01
2.00000E-02	2.568E+01
3.00000E-02	8.176E+00
4.00000E-02	3.629E+00
5.00000E-02	1.958E+00
6.00000E-02	1.205E+00
8.00000E-02	5.952E-01
1.00000E-01	3.717E-01
1.50000E-01	1.964E-01
2.00000E-01	1.460E-01
3.00000E-01	1.099E-01
4.00000E-01	9.400E-02
5.00000E-01	8.414E-02
6.00000E-01	7.704E-02
8.00000E-01	6.699E-02
1.00000E+00	5.995E-02
1.25000E+00	5.350E-02
1.50000E+00	4.883E-02
2.00000E+00	4.265E-02
3.00000E+00	3.621E-02
4.00000E+00	3.312E-02
5.00000E+00	3.146E-02
6.00000E+00	3.057E-02
8.00000E+00	2.991E-02
1.00000E+01	2.994E-02
1.50000E+01	3.092E-02
2.00000E+01	3.224E-02

Attenuation coefficients of

Silver

Energy (MeV)	μ/ρ (cm ² /g)
1.00000E-03	7.039E+03
1.50000E-03	2.790E+03
2.00000E-03	1.401E+03
3.00000E-03	5.136E+02
3.35110E-03	3.887E+02
3.35110E-03	1.274E+03
3.43632E-03	1.200E+03
3.52370E-03	1.126E+03
3.52370E-03	1.547E+03
3.66203E-03	1.409E+03
3.80580E-03	1.282E+03
3.80580E-03	1.468E+03
4.00000E-03	1.305E+03
5.00000E-03	7.385E+02
6.00000E-03	4.610E+02
8.00000E-03	2.164E+02
1.00000E-02	1.193E+02
1.50000E-02	3.998E+01
2.00000E-02	1.836E+01
2.55140E-02	9.527E+00
2.55140E-02	5.539E+01
3.00000E-02	3.668E+01
4.00000E-02	1.720E+01
5.00000E-02	9.444E+00
6.00000E-02	5.766E+00
8.00000E-02	2.651E+00
1.00000E-01	1.470E+00
1.50000E-01	5.426E-01
2.00000E-01	2.972E-01
3.00000E-01	1.560E-01
4.00000E-01	1.131E-01
5.00000E-01	9.321E-02
6.00000E-01	8.153E-02
8.00000E-01	6.766E-02
1.00000E+00	5.921E-02
1.25000E+00	5.217E-02
1.50000E+00	4.754E-02
2.00000E+00	4.209E-02
3.00000E+00	3.754E-02
4.00000E+00	3.606E-02
5.00000E+00	3.577E-02
6.00000E+00	3.601E-02
8.00000E+00	3.723E-02
1.00000E+01	3.882E-02
1.50000E+01	4.276E-02
2.00000E+01	4.609E-02

Coeficientes de atenuação do

Alumínio

Energia (MeV)	μ/ρ (cm ² /g)
1.00000E-03	1.185E+03
1.50000E-03	4.022E+02
1.55960E-03	3.621E+02
1.55960E-03	3.957E+03
2.00000E-03	2.263E+03
3.00000E-03	7.880E+02
4.00000E-03	3.605E+02
5.00000E-03	1.934E+02
6.00000E-03	1.153E+02
8.00000E-03	5.033E+01
1.00000E-02	2.623E+01
1.50000E-02	7.955E+00
2.00000E-02	3.441E+00
3.00000E-02	1.128E+00
4.00000E-02	5.685E-01
5.00000E-02	3.681E-01
6.00000E-02	2.778E-01
8.00000E-02	2.018E-01
1.00000E-01	1.704E-01
1.50000E-01	1.378E-01
2.00000E-01	1.223E-01
3.00000E-01	1.042E-01
4.00000E-01	9.276E-02
5.00000E-01	8.445E-02
6.00000E-01	7.802E-02
8.00000E-01	6.841E-02
1.00000E+00	6.146E-02
1.25000E+00	5.496E-02
1.50000E+00	5.006E-02
2.00000E+00	4.324E-02
3.00000E+00	3.541E-02
4.00000E+00	3.106E-02
5.00000E+00	2.836E-02
6.00000E+00	2.655E-02
8.00000E+00	2.437E-02
1.00000E+01	2.318E-02
1.50000E+01	2.195E-02
2.00000E+01	2.168E-02

Attenuation coefficients of

Lead

Energy (MeV)	μ/ρ (cm ² /g)
1.00000E-03	5.210E+03
1.50000E-03	2.356E+03
2.00000E-03	1.285E+03
2.48400E-03	8.006E+02
2.48400E-03	1.397E+03
2.53429E-03	1.726E+03
2.58560E-03	1.944E+03
2.58560E-03	2.458E+03
3.00000E-03	1.965E+03
3.06640E-03	1.857E+03
3.06640E-03	2.146E+03
3.30130E-03	1.796E+03
3.55420E-03	1.496E+03
3.55420E-03	1.585E+03
3.69948E-03	1.442E+03
3.85070E-03	1.311E+03
3.85070E-03	1.368E+03
4.00000E-03	1.251E+03
5.00000E-03	7.304E+02
6.00000E-03	4.672E+02
8.00000E-03	2.287E+02
1.00000E-02	1.306E+02
1.30352E-02	6.701E+01
1.30352E-02	1.621E+02
1.50000E-02	1.116E+02
1.52000E-02	1.078E+02
1.52000E-02	1.485E+02
1.55269E-02	1.416E+02
1.58608E-02	1.344E+02
1.58608E-02	1.548E+02
2.00000E-02	8.636E+01
3.00000E-02	3.032E+01
4.00000E-02	1.436E+01
5.00000E-02	8.041E+00
6.00000E-02	5.021E+00
8.00000E-02	2.419E+00
8.80045E-02	1.910E+00
8.80045E-02	7.683E+00
1.00000E-01	5.549E+00
1.50000E-01	2.014E+00
2.00000E-01	9.985E-01
3.00000E-01	4.031E-01
4.00000E-01	2.323E-01
5.00000E-01	1.614E-01
6.00000E-01	1.248E-01
8.00000E-01	8.870E-02
1.00000E+00	7.102E-02
1.25000E+00	5.876E-02
1.50000E+00	5.222E-02
2.00000E+00	4.606E-02
3.00000E+00	4.234E-02
4.00000E+00	4.197E-02
5.00000E+00	4.272E-02
6.00000E+00	4.391E-02
8.00000E+00	4.675E-02
1.00000E+01	4.972E-02
1.50000E+01	5.658E-02
2.00000E+01	6.206E-02