Attenuation of γ Radiation by Matter

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November 3, 2014

1 Introduction

In order to understand the nature of absorption of gamma radiation by matter, we perform the following experiment to calculate the linear and mass attenuation coefficient.

2 Theory

When gamma radiation passes through matter, it undergoes absorption primarily by compton scattering, photoelectric effect and air production interactions. It is well known that intensity of radiation transmitted decreases exponentially with material thickness.

So we consider an exponential function defined as

$$i = i_0 \exp(-\mu d)$$

where$i_o$is the incident intensity of the beam,

$i(x)$ is the intensity received after being transmitted through thickness of x.

μ is the linear attenuation constant

if we take log on both sides, the equation becomes

$$\log i = -\mu d + \log i_0$$

$$\log r = -\mu d + c$$

The values of μ and c are calculated by fitting the graph of log r versus d.

The mass attenuation coefficient $\mu_m = \mu\rho$, where ρ is the density of material.

The experiment uses three different absorbers, aluminium lead and copper, each of whose attenuation coefficients can be determined by fitting the graph.

3 Procedure

Set the voltage at the previously determined operating voltage of 485V, and the preset time of counting to 60 seconds.

Placed the gamma source in the detector stand, to a appropriately near position and took background counts. Then, for each of the absorber set, took three sets of counts at each available thickness and tabulated the value.

4 Observations and Calculations

The graphs plot log r versus d for each of the absorbers.

Listing 1: Aluminium

Thickness, d [in mm]	Count	Count	Count [in 60 sec]
0.0	563	622	584
0.05	459	462	488
0.1	381	409	429
0.15	324	328	343
0.2	286	290	270
0.25	273	290	251
0.3	252	277	262
0.35	274	246	259
0.4	228	237	246
0.45	261	238	225

aluminium

$\log r = md + c$

$m = -1.91441 \pm 0.2667mm^{-1}$

$c = 6.19839 \pm 0.07119mm^{-1}$

$\mu = -m \approx 1.92mm^{-1}$

$\mu_m \approx (19.2cm^{-1})/(2.7g/cm^3) = 7.1cm^2/g$

The quoted values are $\mu = 115.5cm^{-1}$ and $\mu_m = 42.7cm^2/g$

Listing 2: Copper

Thickness, d [in mm]	Count	Count	Count [in 60 sec]
0.0	563	622	584
0.07	271	282	295
0.14	226	231	207

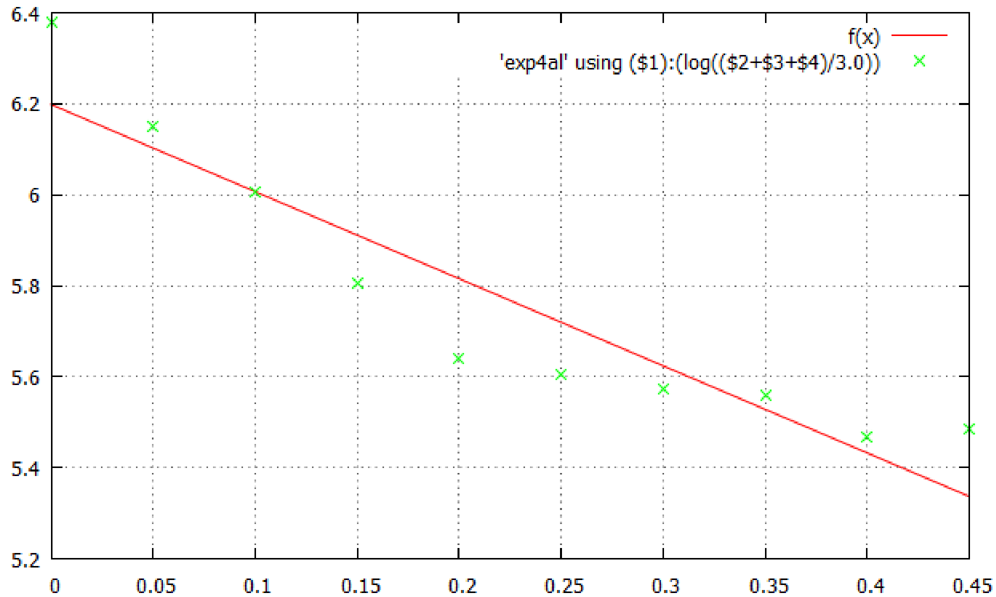


Figure 1: log r vs d where d is average count rate (sec^{-1}) and r has been defined earlier for Aluminium

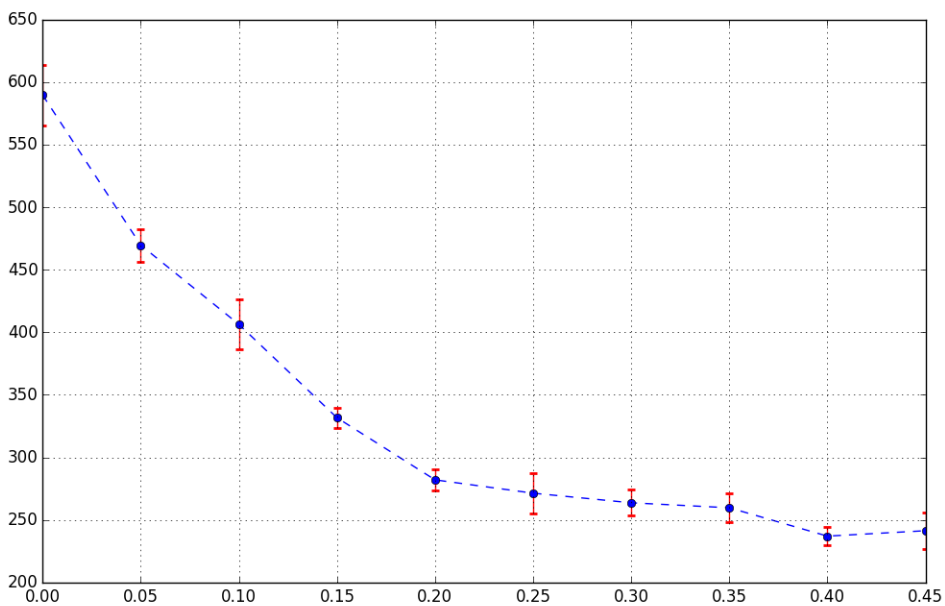


Figure 2: r vs d for Aluminium

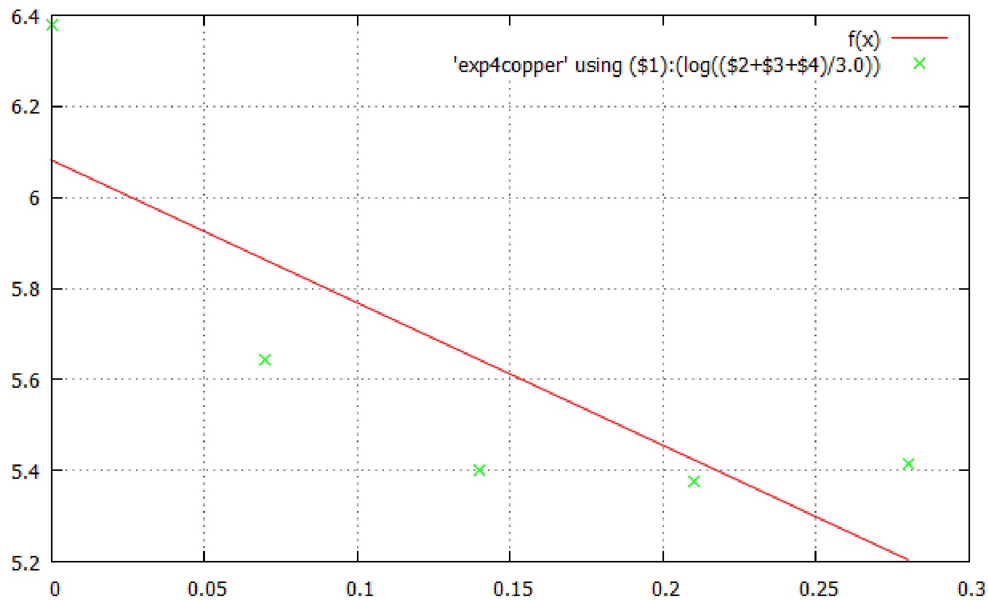


Figure 3: log r vs d for Copper

0.21	212	217	220
0.28	213	204	258

copper

$\log r = md + c$

$m = -3.1348 \pm 1.284 mm^{-1}$

$c = 6.08216 \pm 0.2202 mm^{-1}$

$\mu = -m \approx 3.14 mm^{-1}$

$\mu_m \approx (31.4 cm^{-1})/(8.93 g/cm^3) = 3.5 cm^2/g$

The quoted values are $\mu = 161.16 cm^{-1}$ and $\mu_m = 18.04 cm^2/g$

Listing 3: Lead

Thickness, d [in mm]	Count	Count	Count [in 60 sec]
0	563	622	584
0.3	276	260	269
0.6	258	283	274
0.9	266	264	266
1.2	257	261	218

lead

$\log r = md + c$

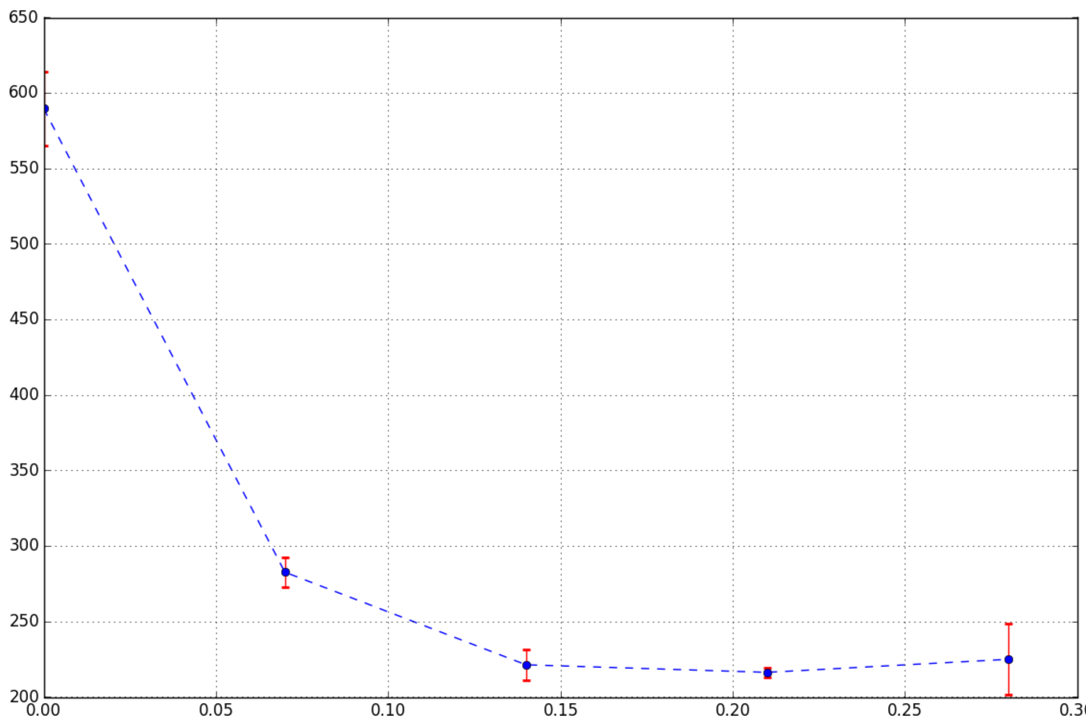


Figure 4: r vs d for Copper

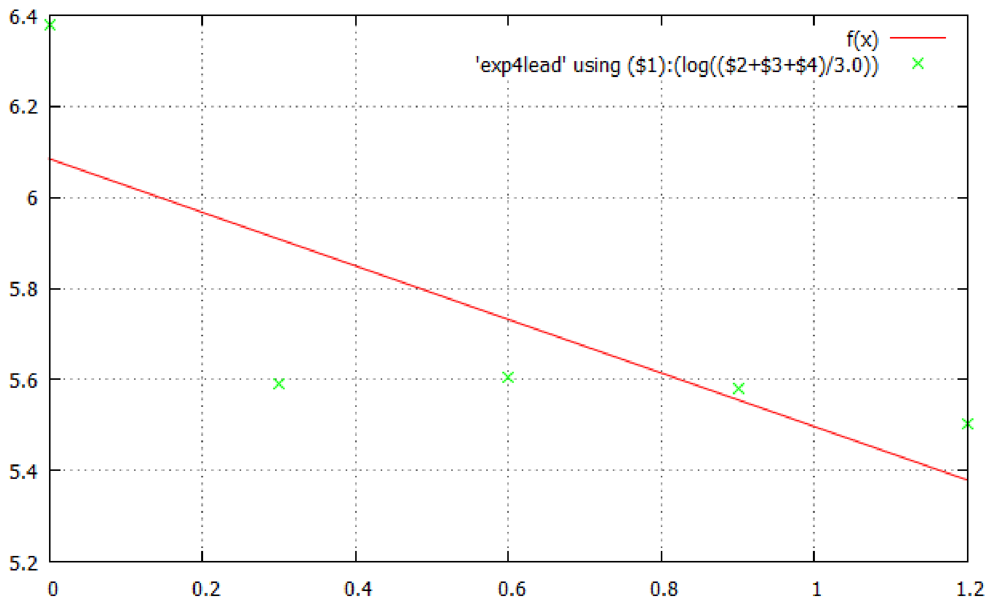


Figure 5: log r vs d for Lead

$m = -0.588374 \pm 0.2848 mm^{-1}$

$c = 6.08502 \pm 0.2093 mm^{-1}$

$\mu = -m \approx 0.59 mm^{-1}$

$\mu_m \approx (5.9 cm^{-1})/(11.34 g/cm^3) = 0.52 cm^2/g$

The quoted values are $\mu = 11.55 cm^{-1}$ and $\mu_m = 5.55 cm^2/g$

Listing 4: Fit Result

```
After 5 iterations the fit converged.
final sum of squares of residuals : 0.117364
rel. change during last iteration : -2.12843e-015

degrees of freedom     (FIT_NDF)                        : 8
rms of residuals       (FIT_STDFIT) = sqrt(WSSR/ndf)    : 0.121122
variance of residuals  (reduced chisquare) = WSSR/ndf   : 0.0146705

Final set of parameters            Asymptotic Standard Error
=======================            ==========================

m               = -1.91441         +/- 0.2667       (13.93%)
```

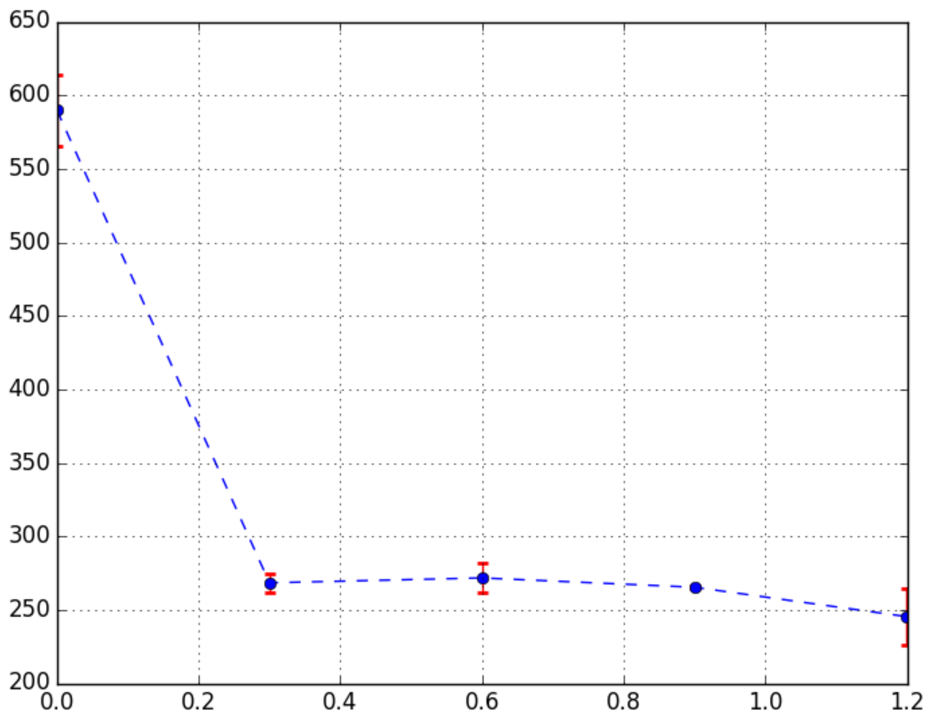


Figure 6: r vs d for lead

```
c               = 6.19839          +/- 0.07119      (1.149%)


correlation matrix of the fit parameters:

                m      c
m               1.000
c              -0.843  1.000

gnuplot> plot f(x), 'exp4al' using ($1):(log(($2+$3+$4)/3.0))












After 4 iterations the fit converged.
final sum of squares of residuals : 0.24254
rel. change during last iteration : -2.52445e-009

degrees of freedom    (FIT_NDF)                        : 3
rms of residuals      (FIT_STDFIT) = sqrt(WSSR/ndf)    : 0.284336
variance of residuals (reduced chisquare) = WSSR/ndf   : 0.0808467

Final set of parameters            Asymptotic Standard Error
=======================            ==========================

m               = -3.1348          +/- 1.284        (40.98%)
c               = 6.08216          +/- 0.2202       (3.621%)
```

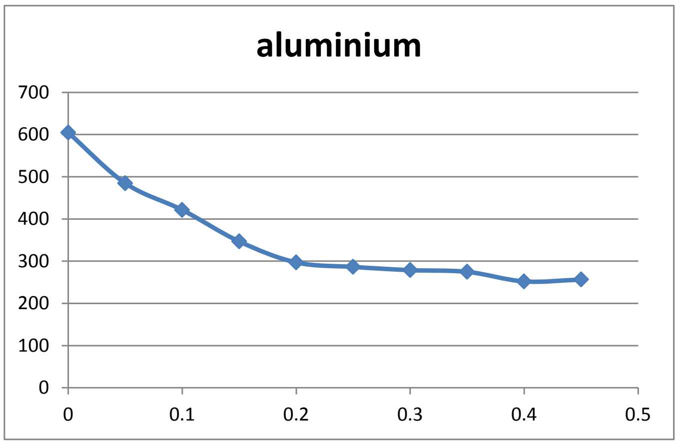
```
correlation matrix of the fit parameters:

               m      c
m              1.000
c             -0.816  1.000
gnuplot> plot f(x), 'exp4copper' using ($1):(log(($2+$3+$4)/3.0))
```

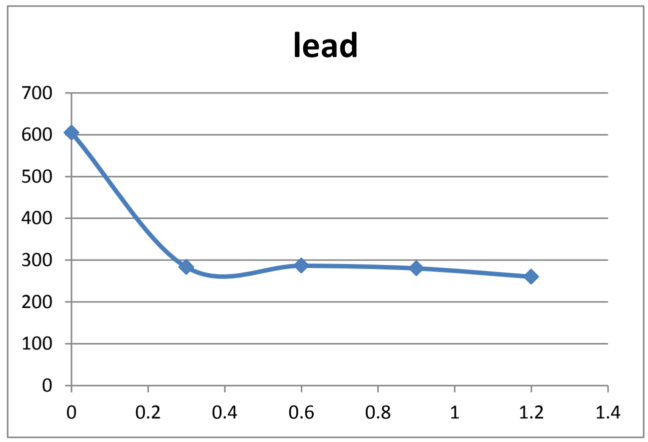
```
After 4 iterations the fit converged.
final sum of squares of residuals : 0.218959
rel. change during last iteration : -7.97395e-012

degrees of freedom    (FIT_NDF)                        : 3
rms of residuals      (FIT_STDFIT) = sqrt(WSSR/ndf)    : 0.27016
variance of residuals (reduced chisquare) = WSSR/ndf   : 0.0729862

Final set of parameters            Asymptotic Standard Error
=======================            ==========================

m               = -0.588374        +/- 0.2848       (48.4%)
c               = 6.08502          +/- 0.2093       (3.439%)
```

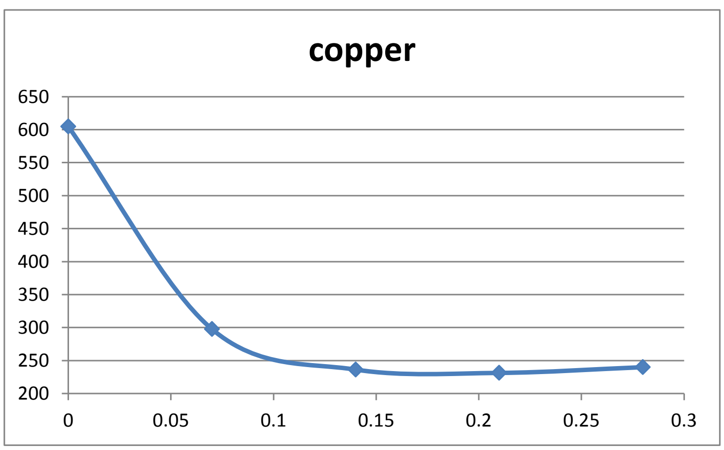
```
correlation matrix of the fit parameters:

               m      c
m              1.000
c             -0.816  1.000
gnuplot> plot f(x), 'exp4lead' using ($1):(log(($2+$3+$4)/3.0))
```

The detailed observations have been listed below:

Operating voltage	485		Source: Cesium			Distance of source: 4 slots			
		Al absorber							
Background	Cs only	thickness(mm)	counts	without back		without back		without back	
12	578	0	578	563	637	622	599	584	604.6667
15	637	0.05	474	459	477	462	503	488	484.6667
12	599	0.1	396	381	424	409	444	429	421.3333
21	604.6667	0.15	339	324	343	328	358	343	346.6667
15		0.2	301	286	305	290	285	270	297
15		0.25	288	273	305	290	266	251	286.3333
		0.3	267	252	292	277	277	262	278.6667
		0.35	289	274	261	246	274	259	274.6667
		0.4	243	228	252	237	261	246	252
		0.45	276	261	253	238	240	225	256.3333
		lead absorber							
		thickness(mm)	counts	without back		without back		without back	
		0	578	563	637	622	599	584	604.6667
		0.3	291	276	275	260	284	269	283.3333
		0.6	273	258	298	283	289	274	286.6667
		0.9	281	266	279	264	281	266	280.3333
		1.2	272	257	276	261	233	218	260.3333
		copper absorber							
		thickness(mm)	counts	without back		without back		without back	
		0	578	563	637	622	599	584	604.6667
		0.07	286	271	297	282	310	295	297.6667
		0.14	241	226	246	231	222	207	236.3333
		0.21	227	212	232	217	235	220	231.3333
		0.28	228	213	219	204	273	258	240


aluminium
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5


lead
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4


copper
650
600
550
500
450
400
350
300
250
200
0
0.05
0.1
0.15
0.2
0.25
0.3

5 Results and Conclusions

The graph of log r versus d was plotted, and values of linear and mass coefficient were calculated.

The linear fits in the log graph are not appropriate, which might contribute in highly erroneous results for attenuation coefficients obtained as:

aluminium - 14 % error in μ

copper - 41 % error in μ

lead - 48 % error in μ