Attenuation of Gamma Rays

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Abstract

The properties of radiation are difficult to observe, but one important observable is the affect of different materials in the propagation of radiation. In this experiment, we test the attenuation properties of gamma rays by running counting experiments on gamma rays passing through different materials.

1 Introduction

Radiation and radioactive materials have very pronounced interactions on the quantum scale, and therefore are very interesting to observe. The gamma rays emitted from Cobalt and Cesium isotopes are high energy and can pass through almost any material. The idea is that high energy gamma rays need to interact with an electron inside the material, and combine, exciting the electron. The chance of this happening lowers based on the energy of the photon, and based on the **attenuation coefficient** μ.

This coefficient is largely independent of the material, and more dependent on the photon energy, which is calculable. We can relate it to absorption laws by the following relation:

$$\mu = \frac{\alpha}{\rho} \tag{1}$$

Where α is the **absorption coefficient**. The absorption coefficient describes how photons are absorbed by a material, and is dependent on the type of material. It is used in Beer's Law, the idea that absorption is exponential (in terms of intensity).

$$I(x) = I_0 e^{-\alpha x} \tag{2}$$

This is the relation between intensity and thickness that will allow us to find α and therefore μ.

The radioactive isotopes in this experiment are Co-90 and Cs-137. They have the following spectra:

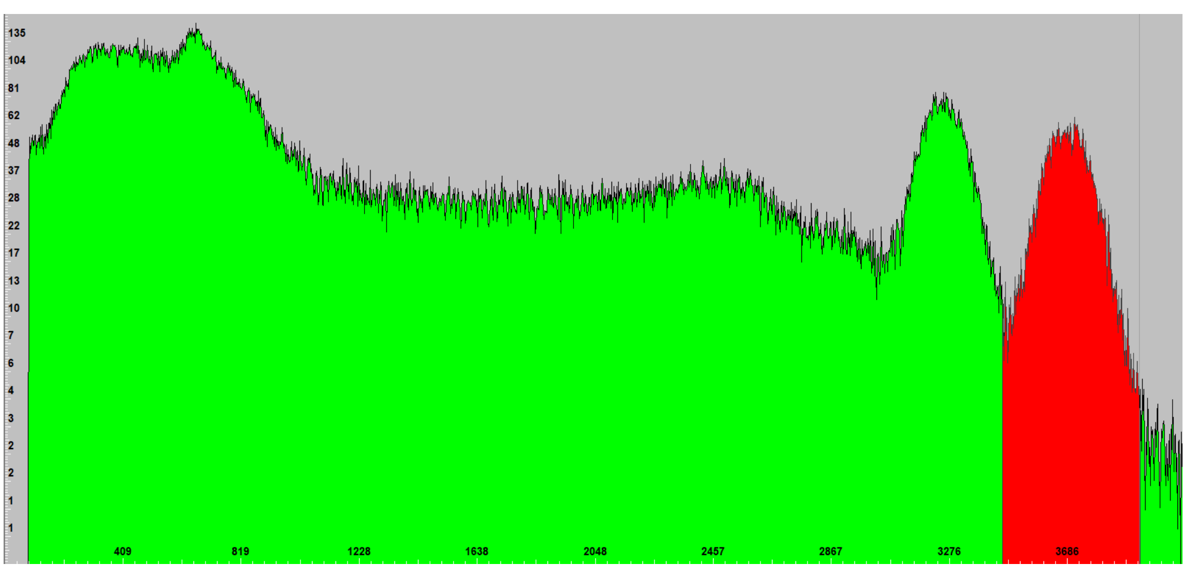

Figure 1: spectrum of cobalt-90 showing the two distinct photopeaks

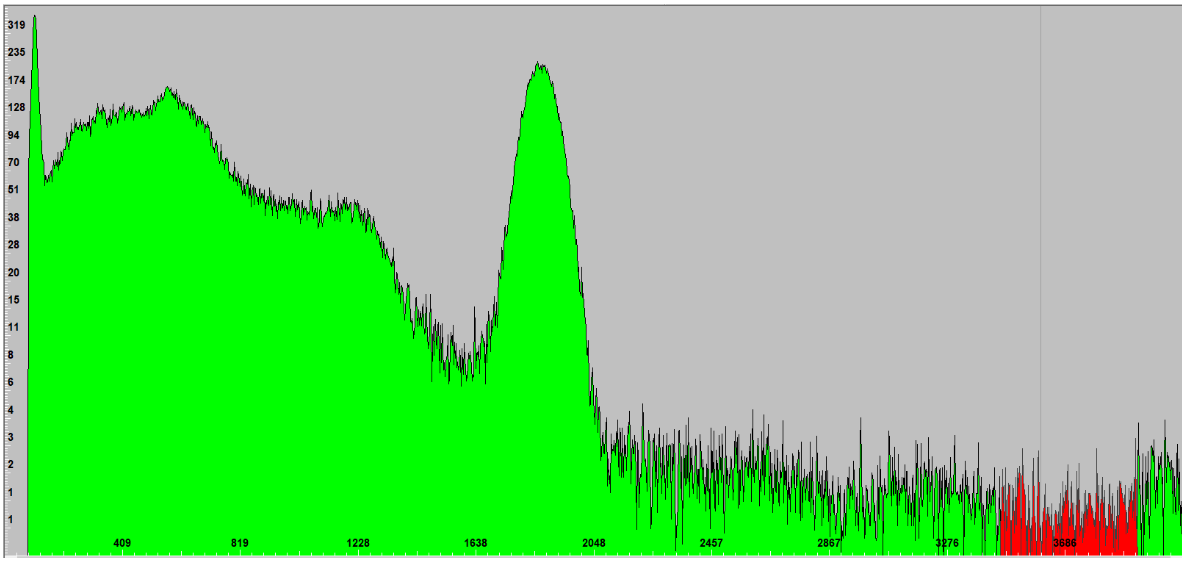

Figure 2: spectrum of Cesium-137 showing one distinct photopeak

The highlight on the cobalt spectrum shows the intensity measurements made during the experiment. The highest energy photopeak corresponds to the highest energy gamma rays, and therefore the most measurable gamma rays.

2 Experiment and Measurements

We measured the attenuation coefficient for cobalt-90 by determining intensity values for emitted gamma rays passing through aluminum and lead. The radioactive source was placed on a tray beneath a gamma ray detector, which would count the incoming rays. The detector fed into an MCA (multi-channel-analyzer) which would process thousands of incoming rays simultaneously, sorting them into a spectrum like the ones above. In order to obtain a smooth spectrum the channel count was set to 4096, and data was collected over a 300 second interval.

2.1 Aluminum

The aluminum plates had enough variation in thickness that we decided to measure each one individually before placing it on the stack on top of the radioactive source. Using the MCA and detector, we measured the net count for seven different thicknesses in order to find the absorption coefficient.

Number of Plates	Thickness of plate (mm)	Total Thickness (mm)	Net Area (W/m^2)
0	0	0	9400 ± 97
1	14.04 ± 0.01	14.04 ± 0.01	8430 ± 92
2	13.26 ± 0.01	27.3 ± 0.02	6820 ± 83
3	13.21 ± 0.01	40.5 ± 0.03	5510 ± 74
4	13.19 ± 0.01	53.7 ± 0.04	4210 ± 65
5	13.13 ± 0.01	66.8 ± 0.05	4100 ± 64
6	13.08 ± 0.01	79.9 ± 0.06	3270 ± 57

Table 1: absorption data for emitted gamma rays passing through varying thicknesses of aluminum. The uncertainty in the net area was determined using the square root law [1]

2.2 Lead

The lead plates, like the aluminum were varied in thickness, so we measured each one individually before we placed it on the stack. We had five plates, and therefore have six measurements of absorption.

Number of Plates	Thickness of plate (mm)	Total Thickness (mm)	Net Area (W/m^2)
0	0	0	9400 ± 97
1	5.60 ± 0.01	5.60 ± 0.01	7030 ± 84
2	4.75 ± 0.01	10.35 ± 0.02	5800 ± 76
3	5.48 ± 0.01	15.83 ± 0.03	4230 ± 65
4	4.79 ± 0.01	20.62 ± 0.04	2910 ± 54
5	5.28 ± 0.01	25.9 ± 0.05	2460 ± 50

Table 2: absorption data for emitted gamma rays passing through varying thicknesses of lead. The uncertainty in the net area was determined using the square root law [1]

From this data it is clear that the net area decreases by much more when using lead, even though the thickness of the lead is smaller.

3 Analysis and Discussion

We expect the data to have a nonlinear relationship (as per equation 2), and we can deal with this by linearizing the data in the following way:

$$ln(I) = ln(I_0) - \alpha x \tag{3}$$

By taking the natural logarithm of the net area data, we create a linear function of x, with the slope being the absorption coefficient α. It is important to note that a background measurement of 358 net area in 300 seconds was subtracted off each net area. For the aluminum,

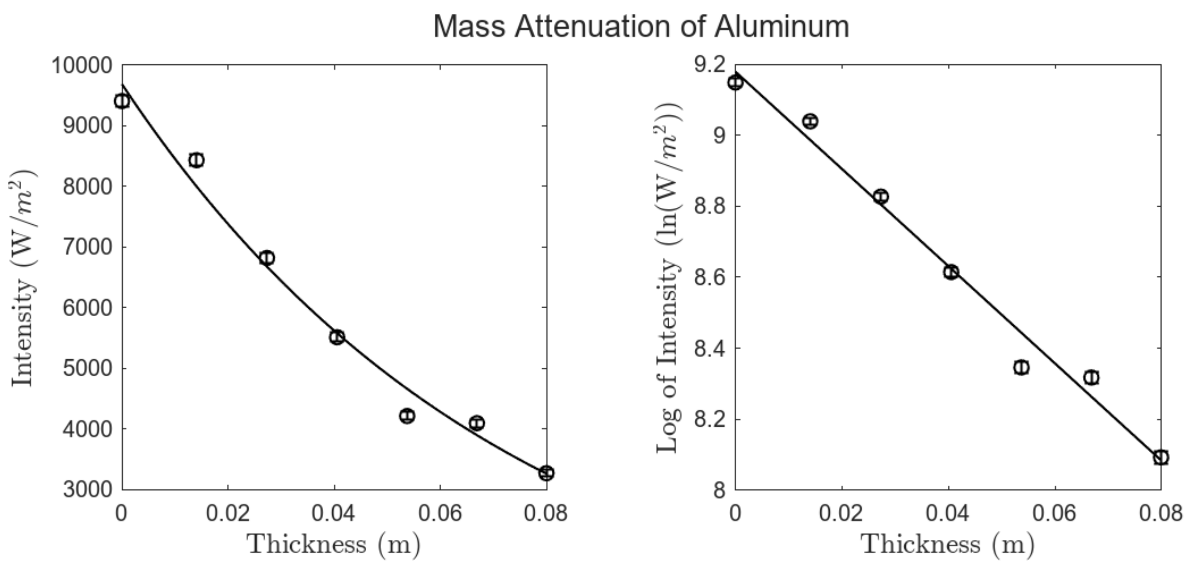

Figure 3: raw attenuation data (left) and linearized attenuation data (right) for gamma rays passing through aluminum. The slope of the graph on the right provides a method of determining the absorption coefficient

The fit for the plot on the left is exponential, and it shows the data does indeed follow an exponential trend. The graph on the right provides a slope of -14.7 ± 1, which corresponds to an absorption coefficient of $\alpha = 14.7 \pm 1\ m^{-1}$. To calculate the mass attenuation coefficient, we simply divide by the density $\rho_{Al} = 2.7\ g/cm^3$, and we get a value of

$$\mu = 0.054 \pm 0.004\ cm^2/g \tag{4}$$

The accepted value for the mass attenuation coefficient is around 0.0533 cm^2/g [2], meaning my experimental value had a percent difference of 2%. The accepted value was interpolated from the NIST data for Aluminum.

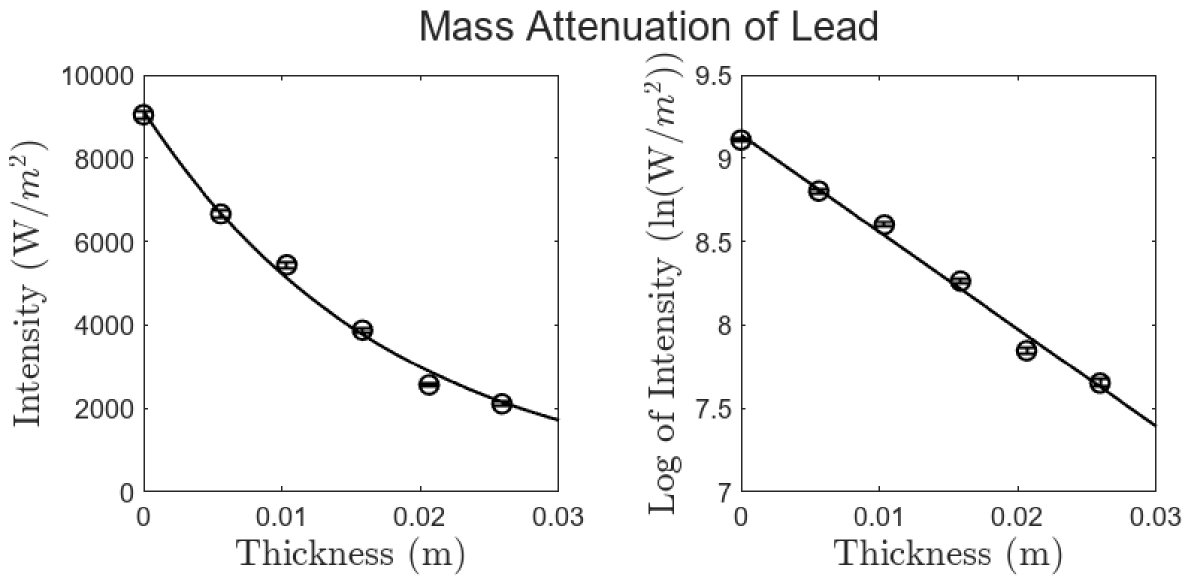

Figure 4: raw attenuation data (left) and linearized attenuation data (right) for gamma rays passing through lead. The data was linearized to find the mass attenuation coefficient

For lead, the plots were similar: The slope of the linearized plot was fitted to be -58.4 ± 3, meaning $\alpha = 58.4 \pm 3$. The density of lead is 11.3 g/cm^3, and using this we can find the mass attenuation coefficient.

$$\mu = 0.052 \pm 0.003 \ cm^2/g \tag{5}$$

The accepted value [2] is 0.0566, meaning my value has a percent difference of 9%.

4 Conclusion

The mass attenuation value depends on the energy of the gamma rays, not on the material itself. This is demonstrated by the values I calculated for the mass attenuation values of aluminum and lead, 0.054 ± 0.004 and 0.052 ± 0.003. Practically the same value for two different materials. These are the mass attenuation values of lead and aluminum **for Cobalt-90**. It is important to include the isotope in the definition, as it defines the energy of the photons.

Both linear and exponential fits were provided for the experimental data, but only the linear fit was used to determine the coefficient. Linearizing the data actually improves the accuracy of the coefficient, as techniques for fitting linear data are generally better than techniques for fitting nonlinear functions. If one was to use the exponential, one would get a value close to the linear one, but less accurate.

Gamma rays have much importance in the subjects of physics and astronomy. They make up much of the cosmological radiation, and can even be very dangerous. The attenuation of the rays through different materials has numerous applications in these fields, and can be used to understand both cosmological and quantum behavior.

References

[1] J. R. Taylor, *An introduction to error analysis :* 2nd ed. (University Science Books, Mill Valley, Calif : c1982.).

[2] J. Hubbel and S. Seltzer, *X-ray mass attenuation coefficients*, tech. rep. NIST Standard Reference Database 126 (National Institute of Standards and Technology, Gaithersburg, MD, 2004).