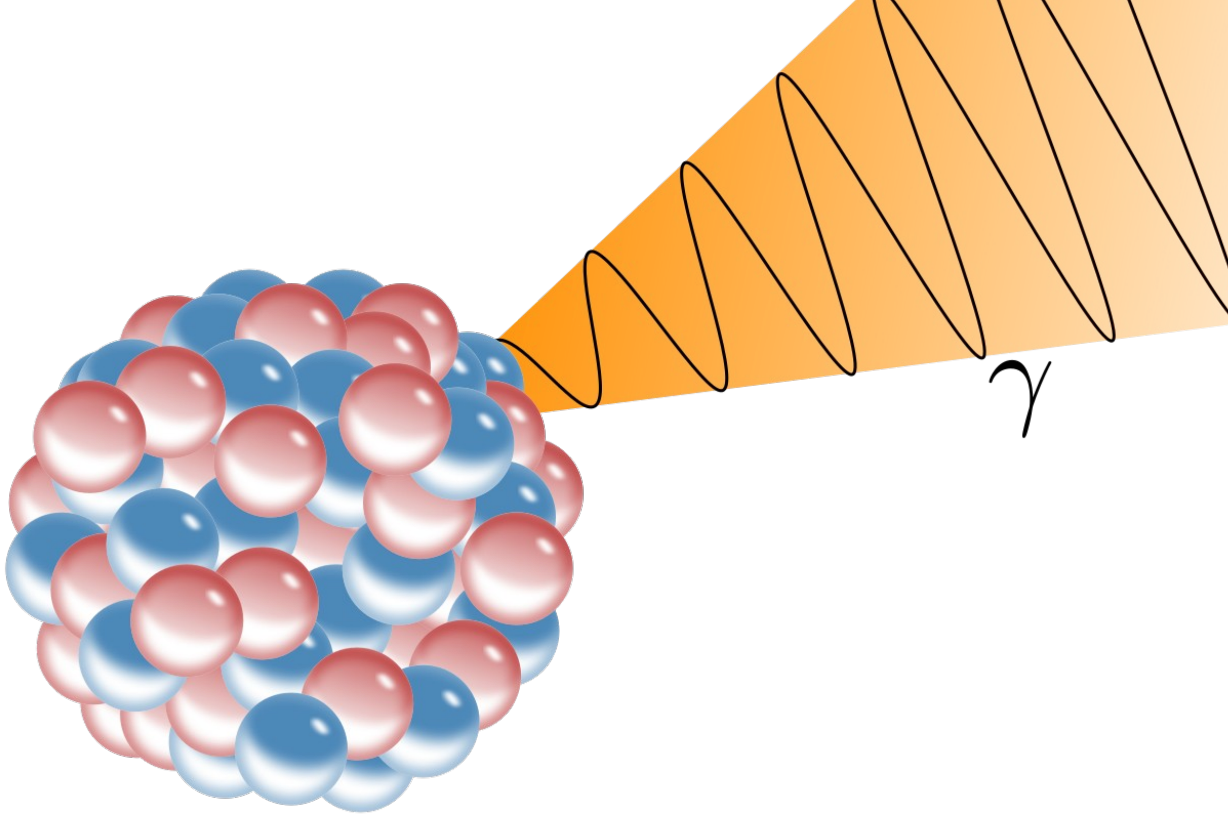
Radiation Lab

Attenuation of Radiation through the absorption of Gamma Rays



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Summary of topics:

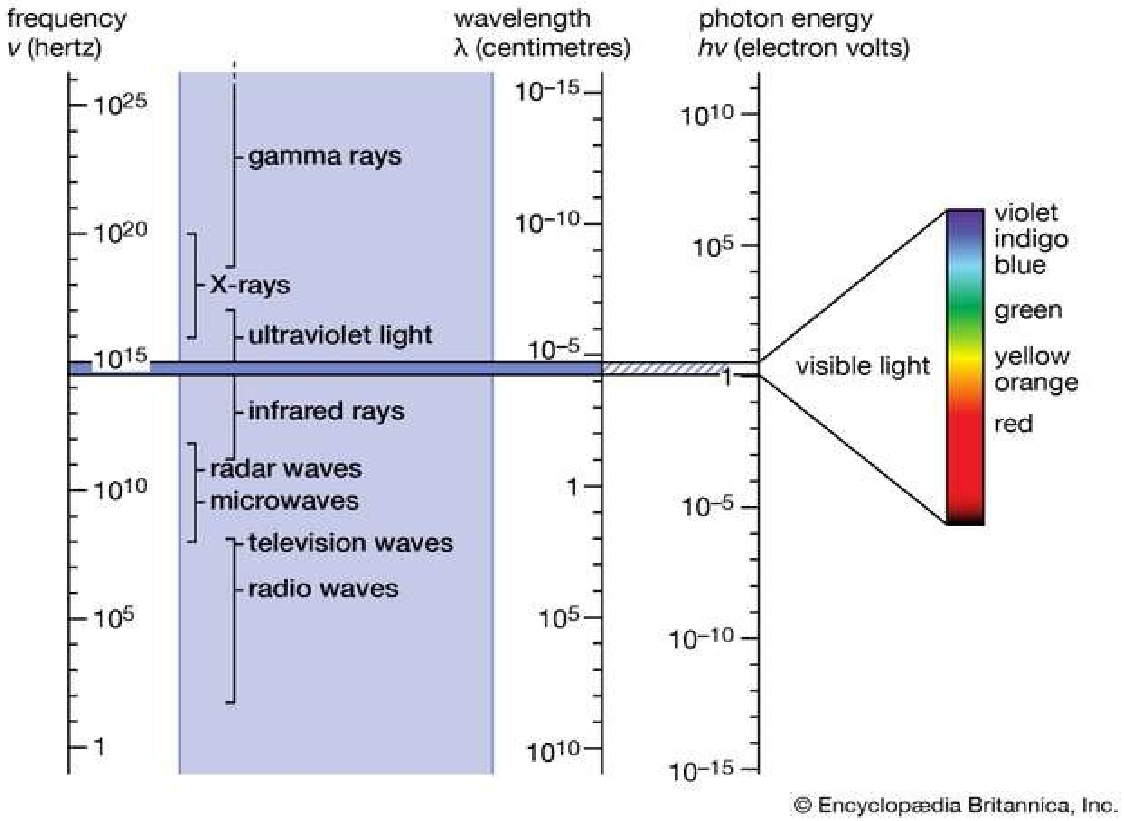
- Introduction
  - Radiation
  - Gamma Rays
  - History
- Theory
  - Gamma Rays interaction with matter
  - Linear and Mass Attenuation Coefficients
- Experiment
  - Lead
  - Cs-137
  - Geiger–Müller counter
  - Equipment summary
  - Procedure
- Results
- Error and Uncertainty
- Conclusions
- Questions.

Introduction : Radiation

- Emission of energy in the form of EM radiation or particles.
- Occurs naturally in unstable atoms, which radiate characteristic energies to form new stable atoms.

  - Electromagnetic Radiation (microwave, x-rays, gamma rays (γ).
  - Particle Radiation (alpha (α), beta (β), neutrons)

- Ionizing (< 10 electron volts) and non-ionizing.

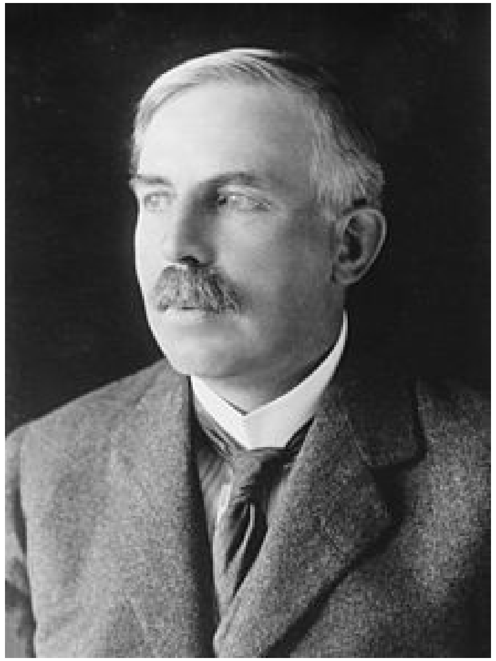


[1]

Introduction : History

Wilhelm Röntgen

Henri Becquerel



Ernest Rutherford

Perrie & Marie Curie

First discovery: William Herschel around 1800 (infrared radiation). [2]

Becquerel discovered radioactivity. Marie Curie coined the word, discovered it is specific to given elements of isotopes.

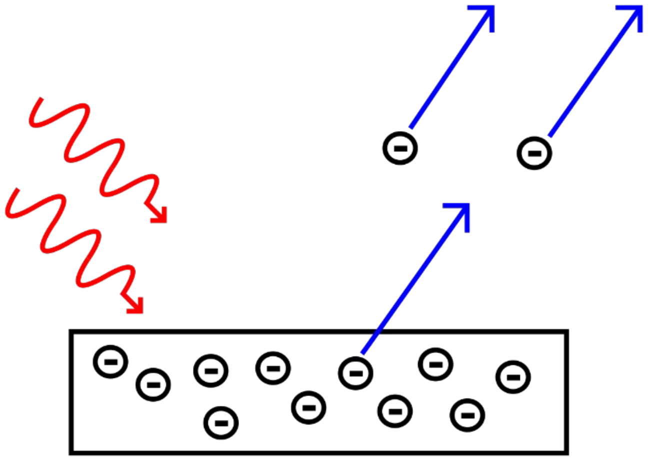
Introduction : Gamma Rays

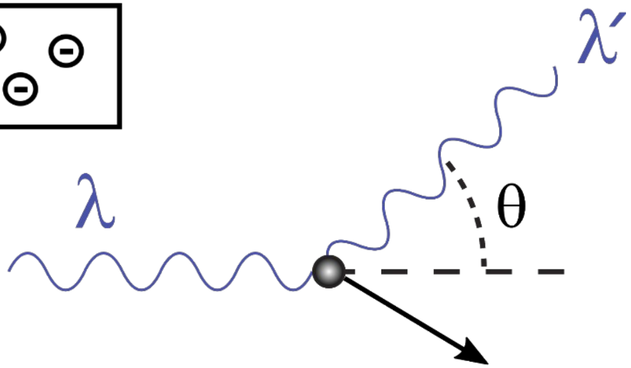
- Gamma rays are photons of a very high-frequency electromagnetic wave.
- Generated through unstable atoms radiating energy, or after particle emission
- Nuclear isomer undergoing isomeric transition and releasing photons.
- Discovered by French chemist/physicist Paul Villard.
  - In the early 20th century, detected powerful radiation from radium, distinct from α radiation (Becquerel) and β radiation (Rutherford)

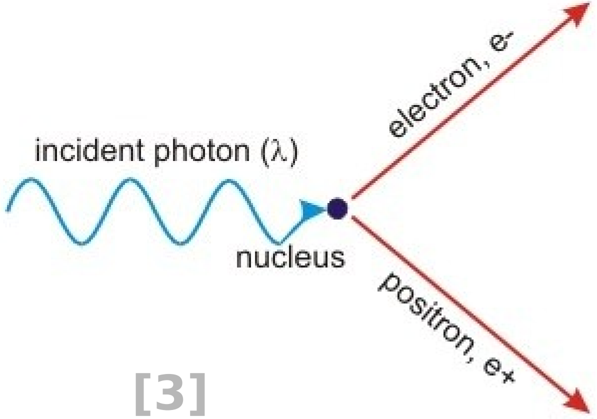
[2]

Theory: Gamma Rays and interaction with matter

- Photoelectric effect: Absorbed upon contact, electron ejected.
- Compton Effect : For 100 keV – 10 MeV gamma rays, imparts partial energy.
- Pair production : For energies >1.02 MeV, gamma ray photons can spontaneously transform into electrons & positrons.



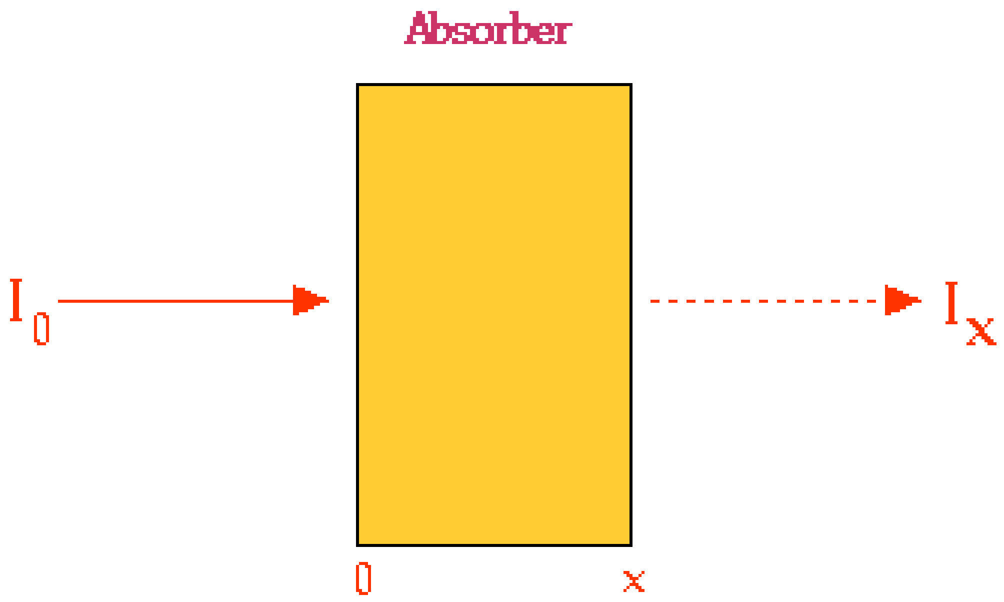




[3]

Theory: Linear and Mass Attenuation Coefficients

- Given their high energy, gamma rays are quite penetrative. A lot higher than other radiations. Some interact as previously mentioned, some pass through.
- Attenuation of gamma rays is simply the reduction of their intensities.
- Linear attenuation coefficient is a characterization of how easily a material can be penetrated by particles or energy.



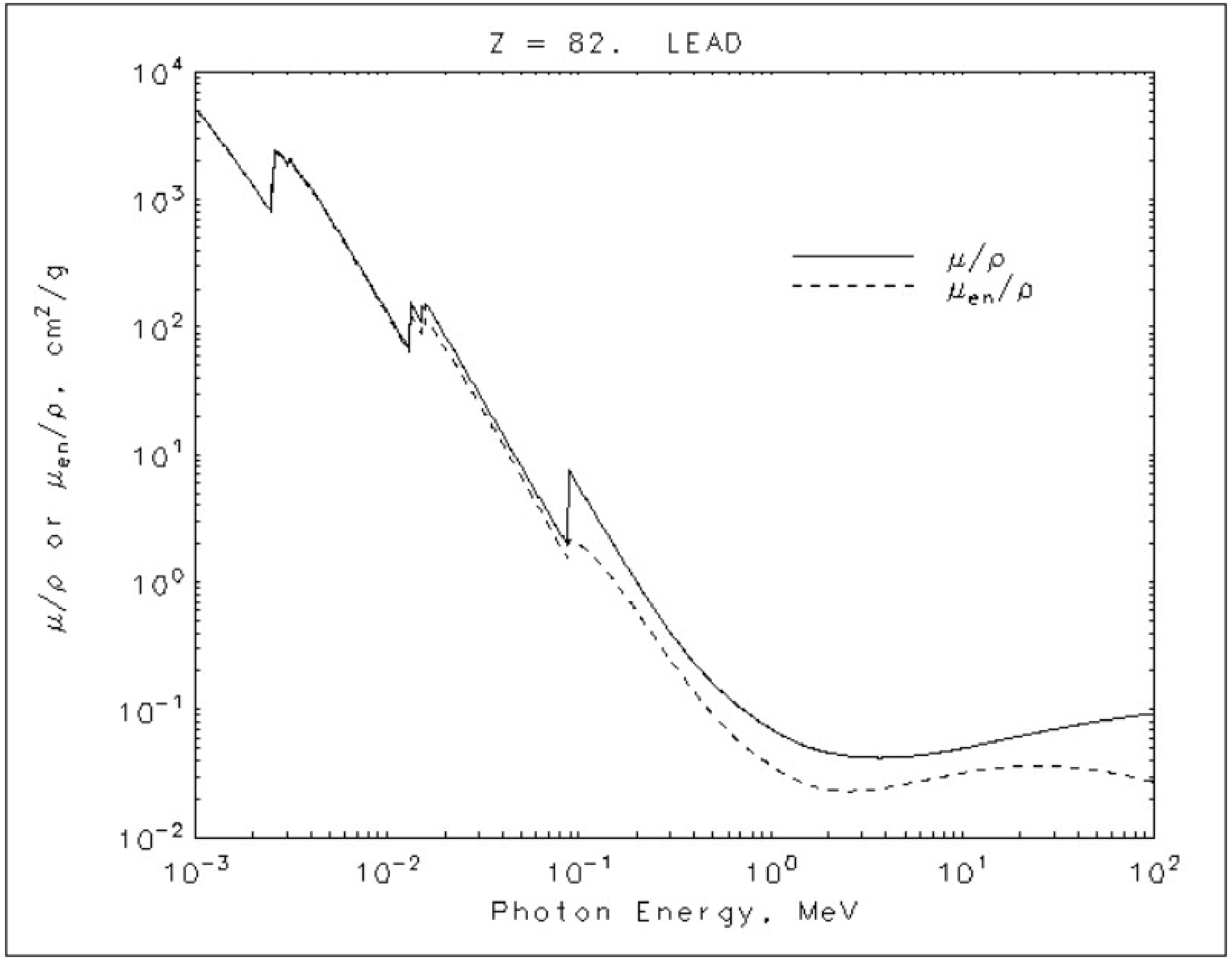
[5]

Theory: Linear and Mass Attenuation Coefficients

The attenuation of gamma rays itself is exponential in nature and follows the equation;

$$I = I_o e^{-\mu X}$$

Where I_o is the original intensity of the incoming beam or particles or photons, X is the thickness, and μ is the linear attenuation coefficient.



[6]

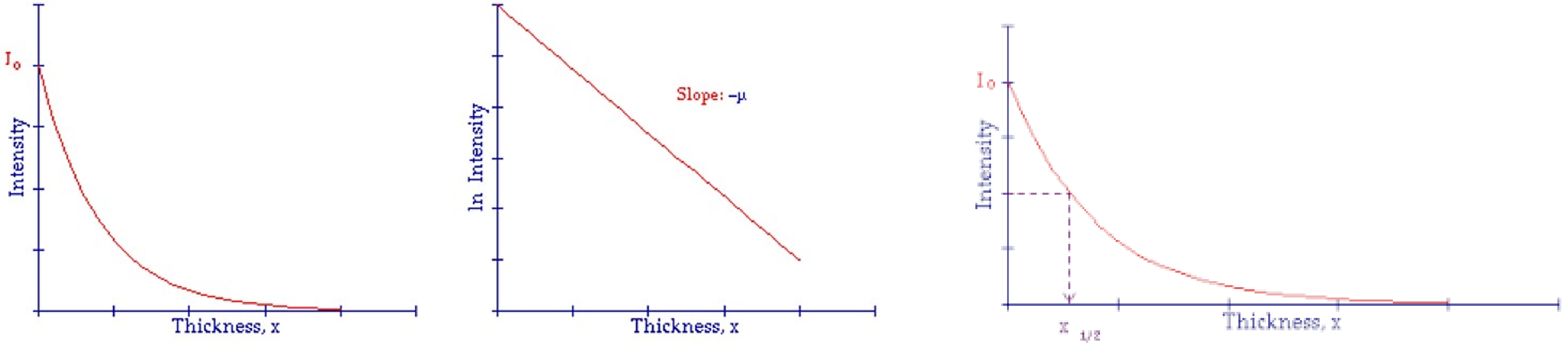
Theory: Linear and Mass Attenuation Coefficients

If half of the incoming intensity is attenuated;

$\frac{1}{2} I = I_o e^{-\mu X_{1/2}}$

or' $\mu = \ln(2)/X_{1/2}$

This gives us two ways to determine the linear attenuation coefficient.



[5]

Intensity (I_0 and *ln*(I_0)) vs Thickness (X) plots.

Theory: Linear and Mass Attenuation Coefficients

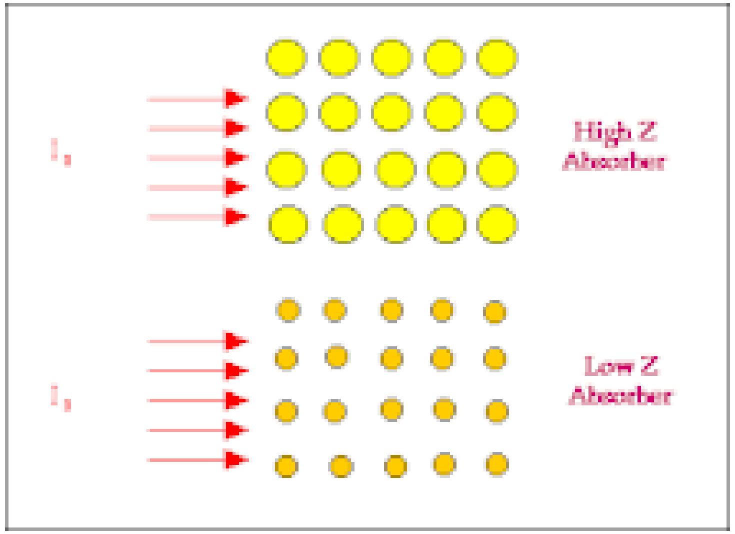
Relationship to various parameters of the absorbing material:

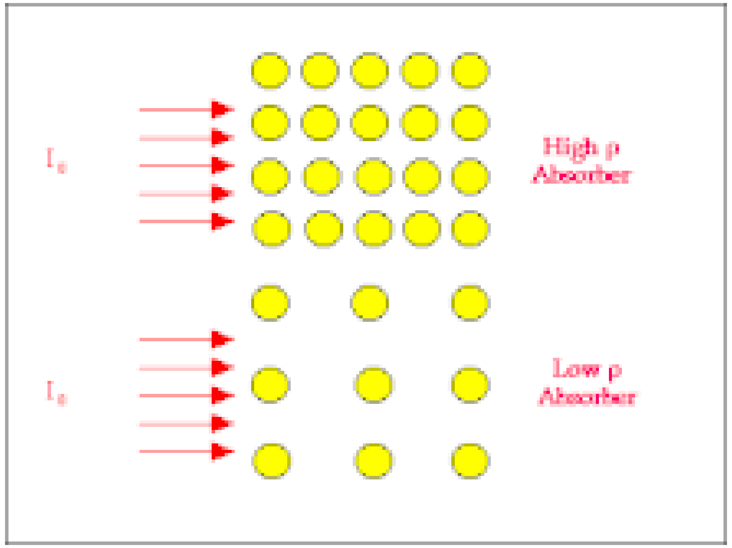
a) Atomic Number

b) Density

c) Thickness

d) Gamma-Ray energy





[5]

Experiment: Lead

Lead is a chemical element with Z=82 denoted as Pb.

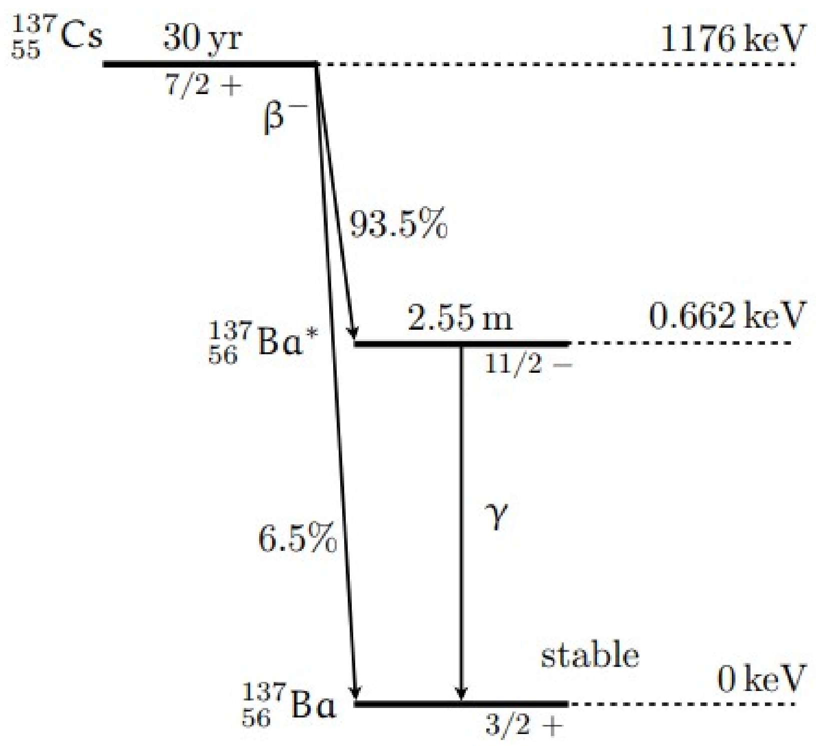
- Interesting as it's a cheap and malleable metal.
- Density of high density of 11.34g/cm3.
- Mass attenuation coefficient of lead is expected to be 0.1136 g/cm2 for a 662keV source. [6]

[7]

Experiment: Caesium

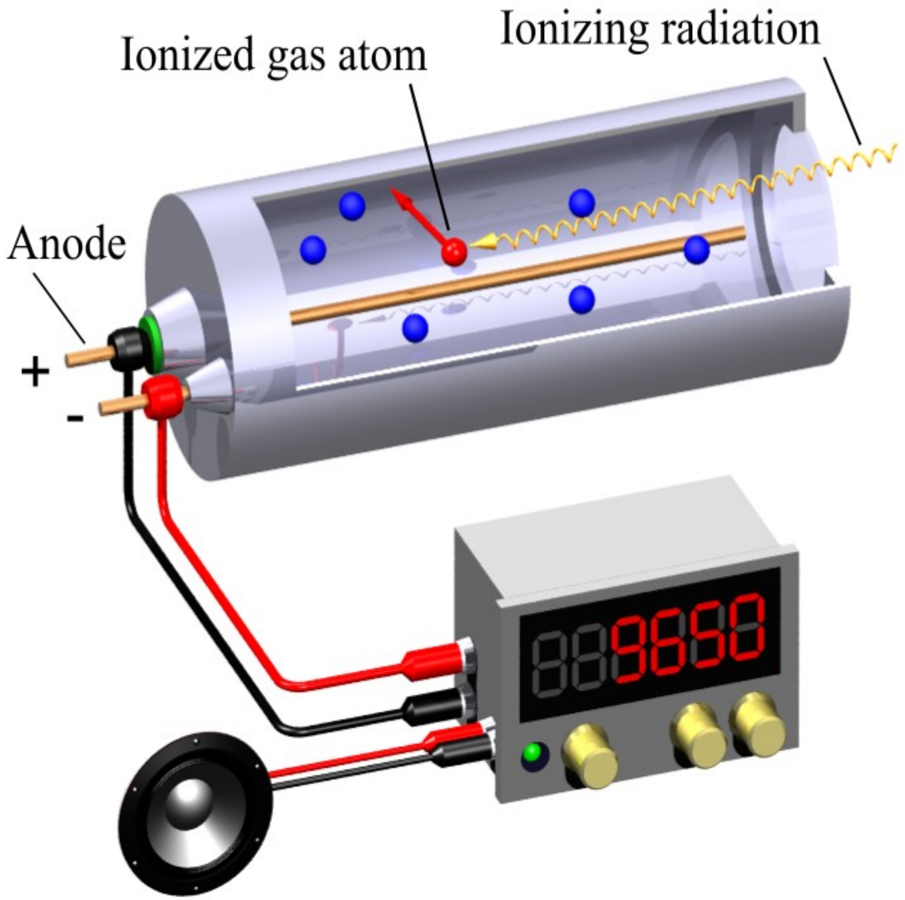
The gamma ray source: Caesium-137 (Z=55)

- The Caesium nucleus can decay into a more stable nucleus through two different means as shown in the energy level diagram.
- Isomeric transition to a stable Ba-137, by emitting 662 keV of energy.



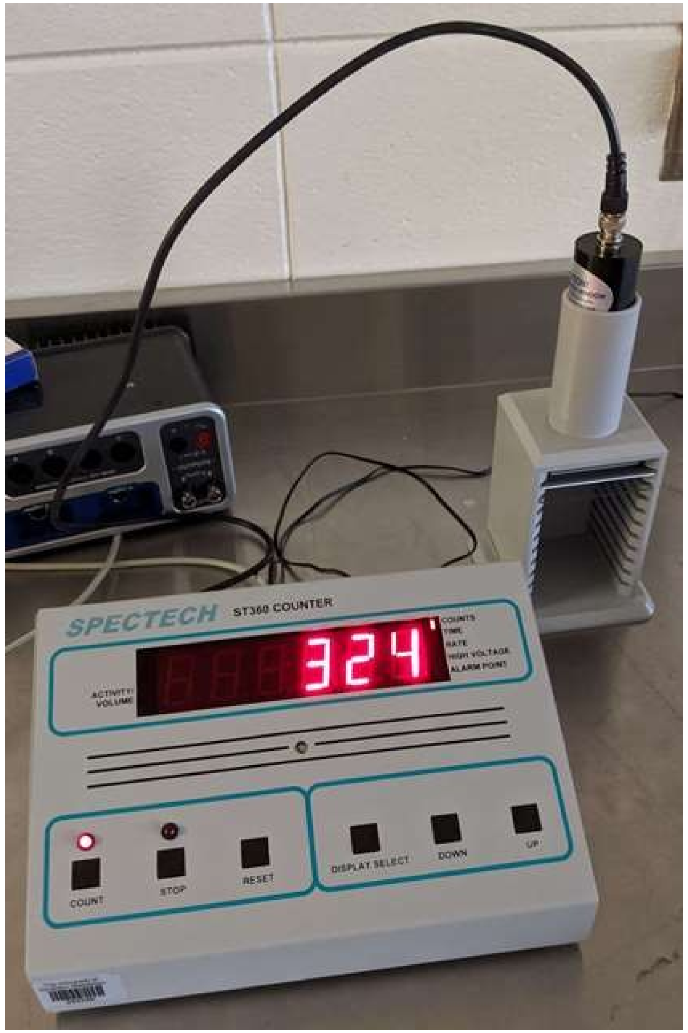
Experiment: Geiger–Müller counter

- A Geiger–Müller counter is an instrument that detects ionizing radiation.
  - Airtight compartment.
  - Thin conducting wire.
  - High potential difference
  - “avalanche” detection.
- Needs to be calibrated.
  - Optimal operating voltage.
  - Resolving time.
  - Efficiency.



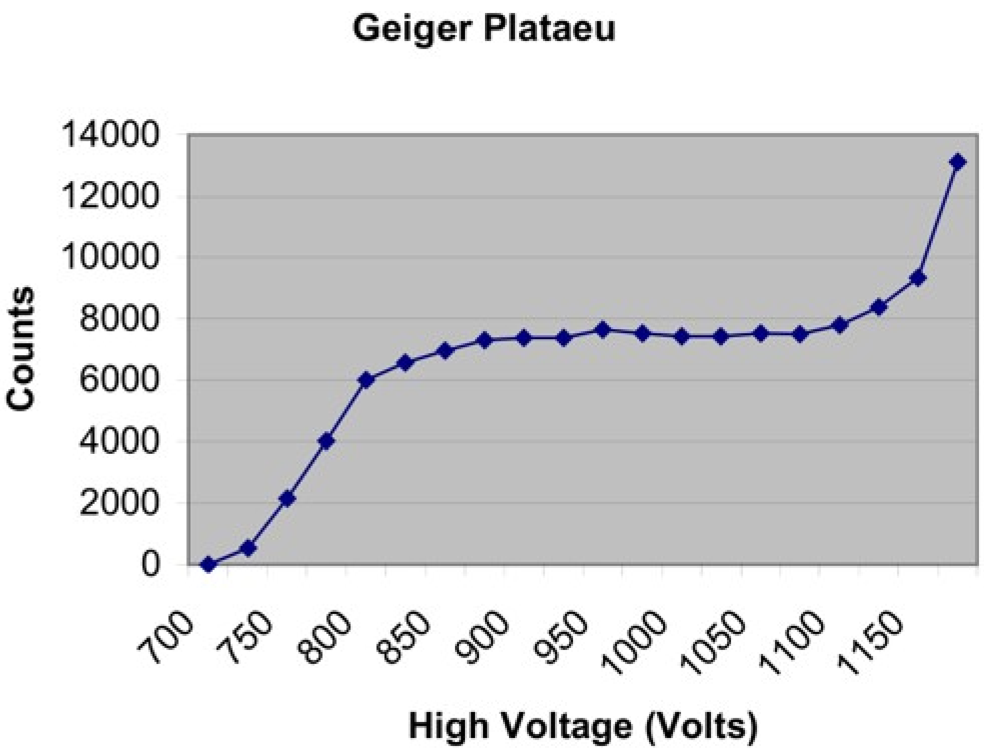
Experiment: Equipment

- SPECTECH radiation counter
  - High voltage
  - Preset times
  - Preset step-voltages
- Geiger –Mueller Counter
- Various radiation sources.
- Lead Absorber Set
  - Lead (0.038-0.25 inches)



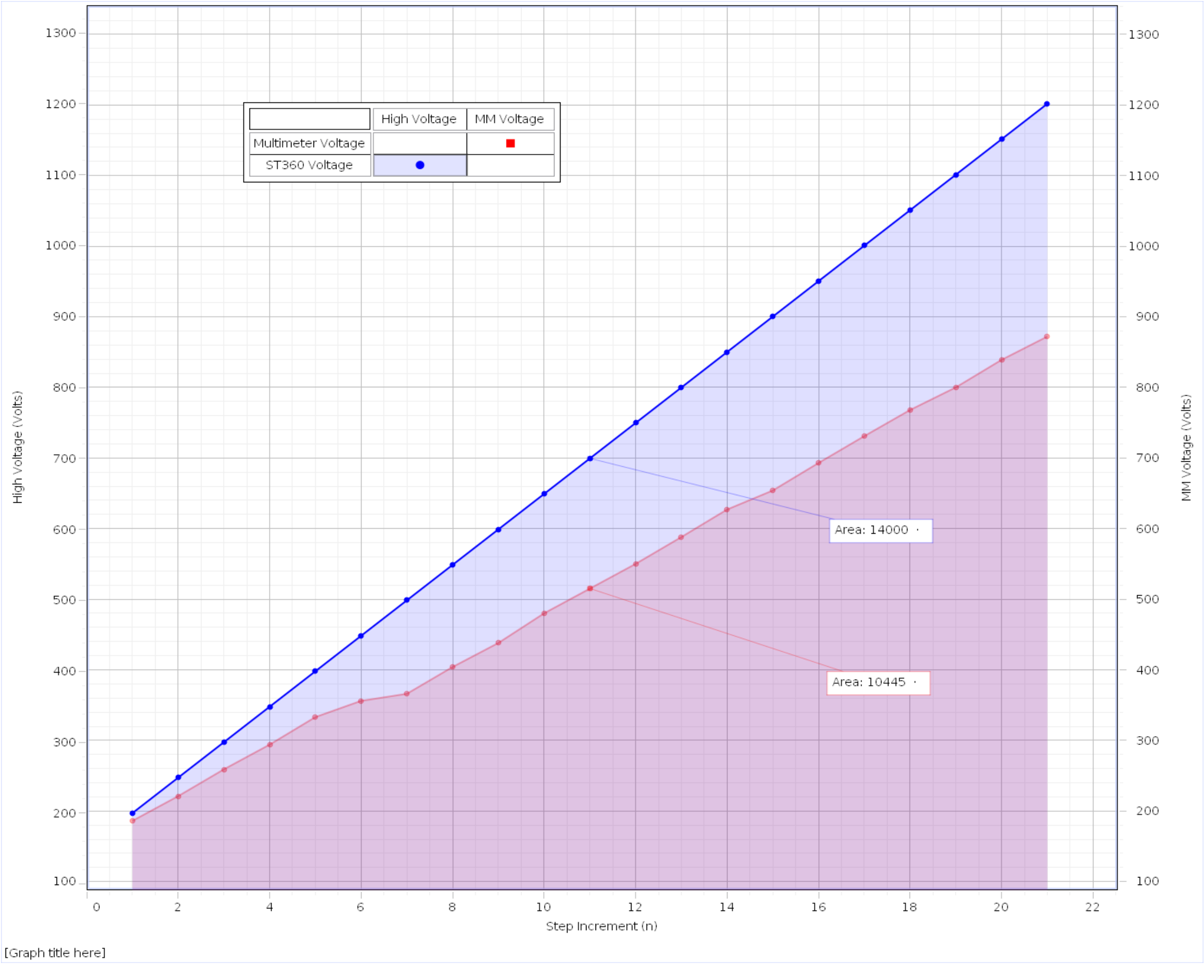
Experiment: Procedu

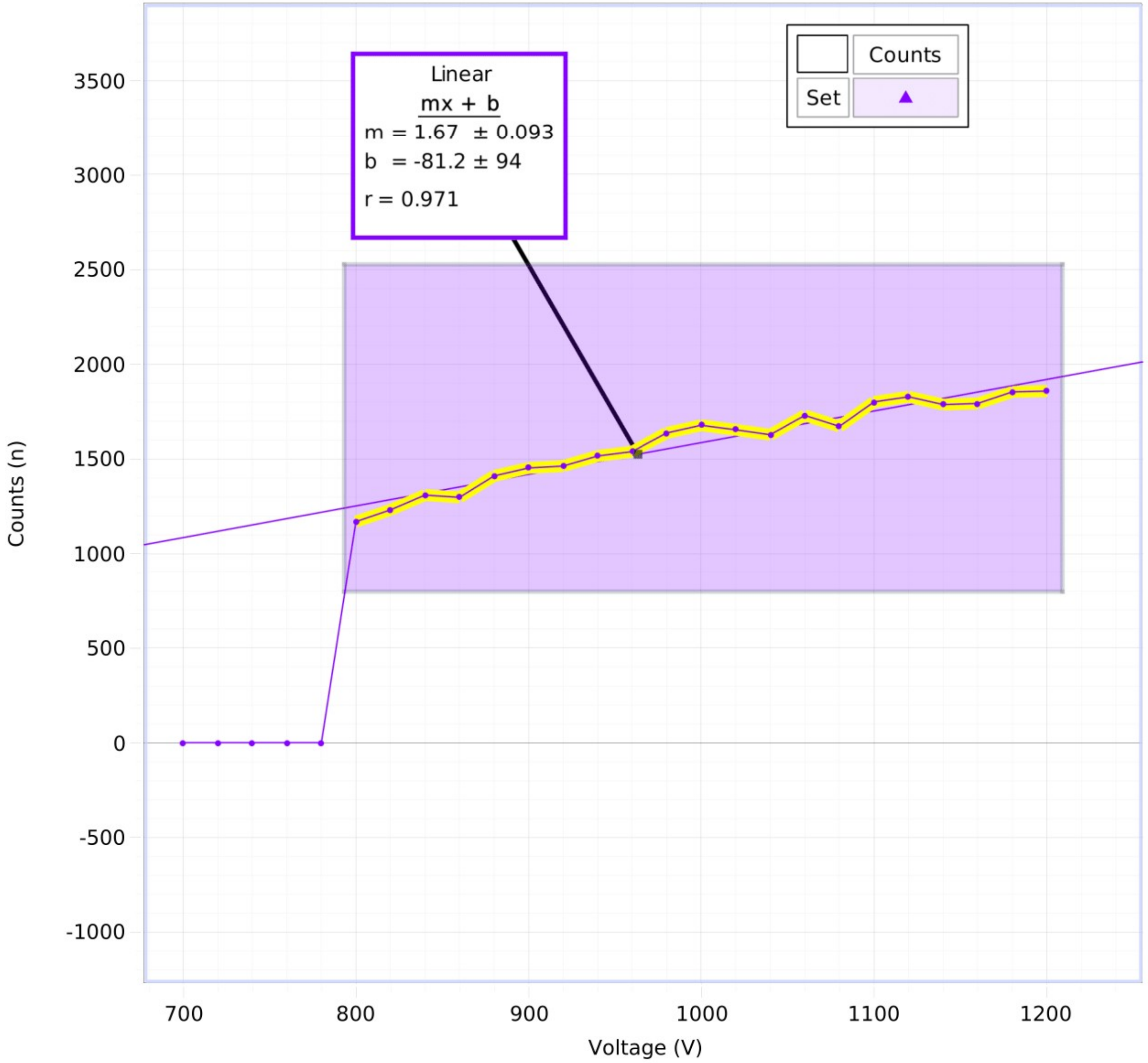
- GM Counter plateau
  - Knee-Voltage
- Background Radiation
- Resolving time
- Efficiency
- Procedures
  - First method
  - Second method
  - Third method
  - Shelfs of the well of the GM tube



A plateau graph for a Geiger–Müller counter.

Results: Optimal Voltage Issue

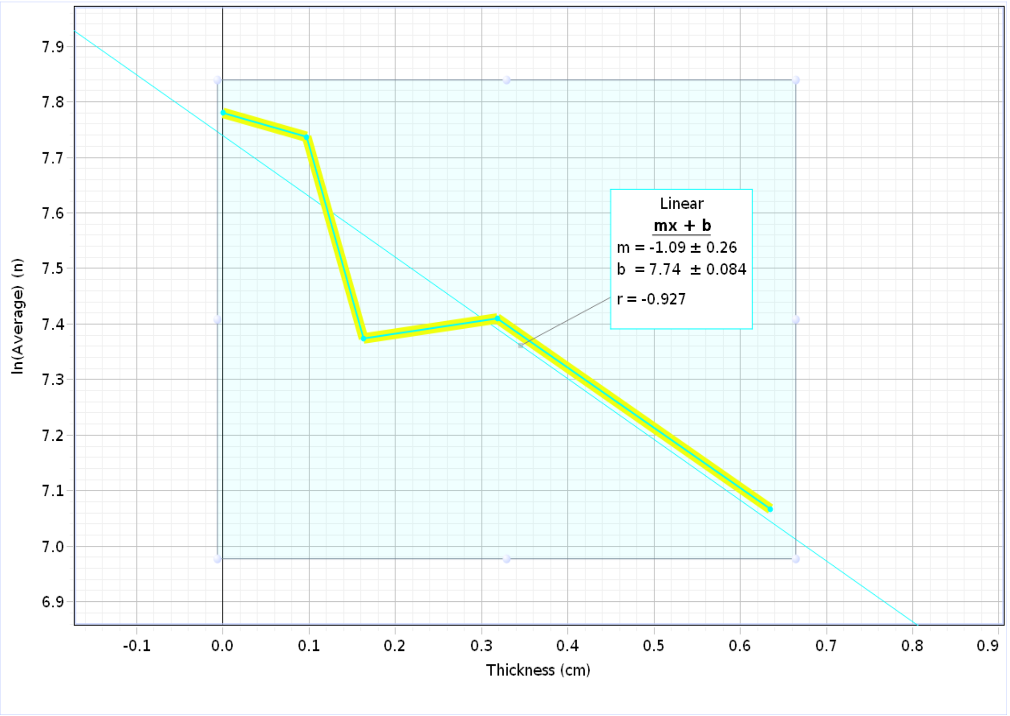


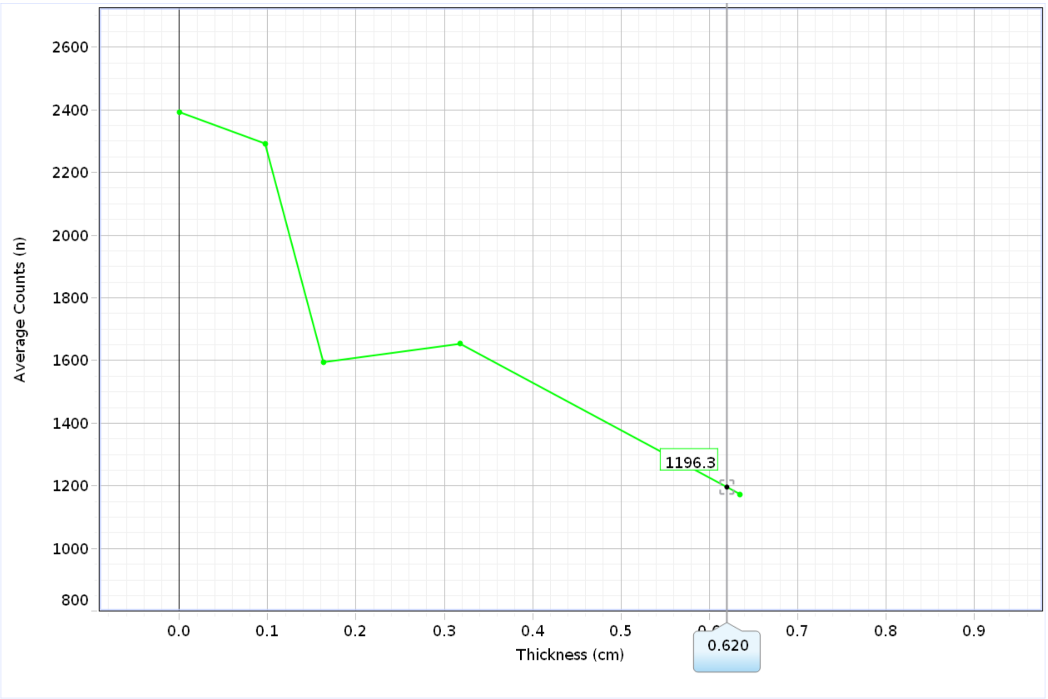


Results: Summary of Paramet

- GM Counter plateau
  - Optimal Voltage: 1200V.
- Background Radiation
  - ~30 counts per minute.
- Resolving time
  - 20 μ.s (1-100 μ.s)
- Efficiency
  - 1.33% (0-10%). 0.12% for gamma source.

Results: Procedure One





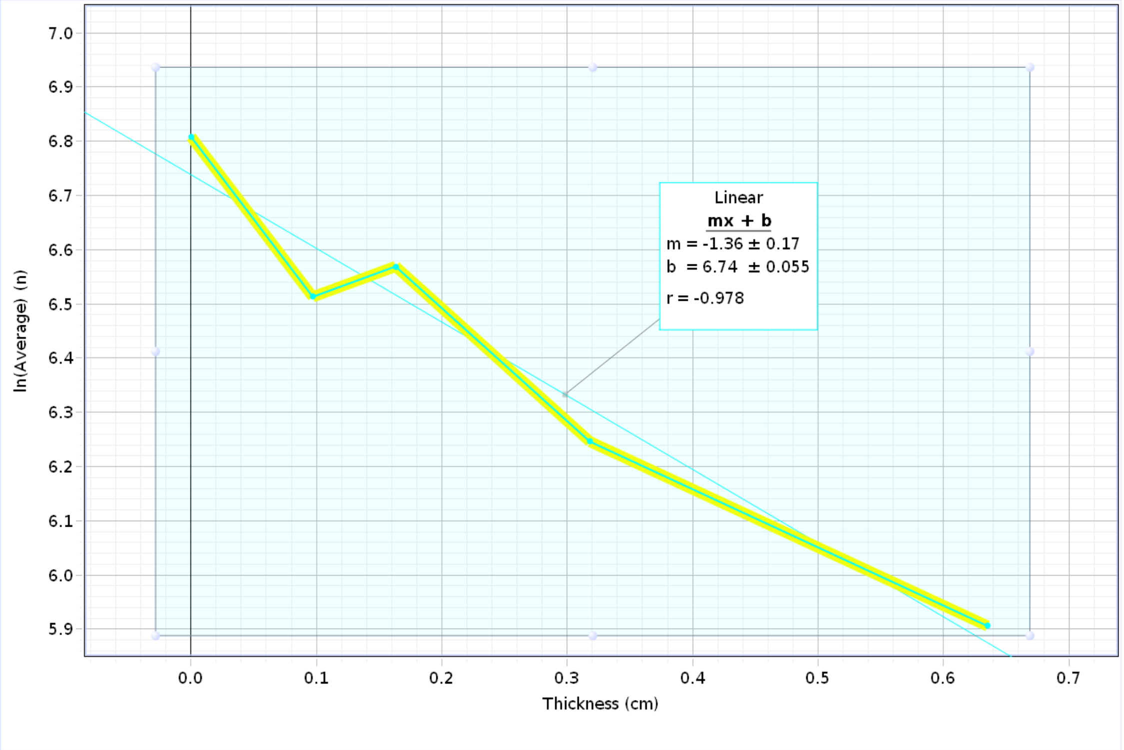
μ_{1slope} = 1.09 ± 0.26 cm^{-1}

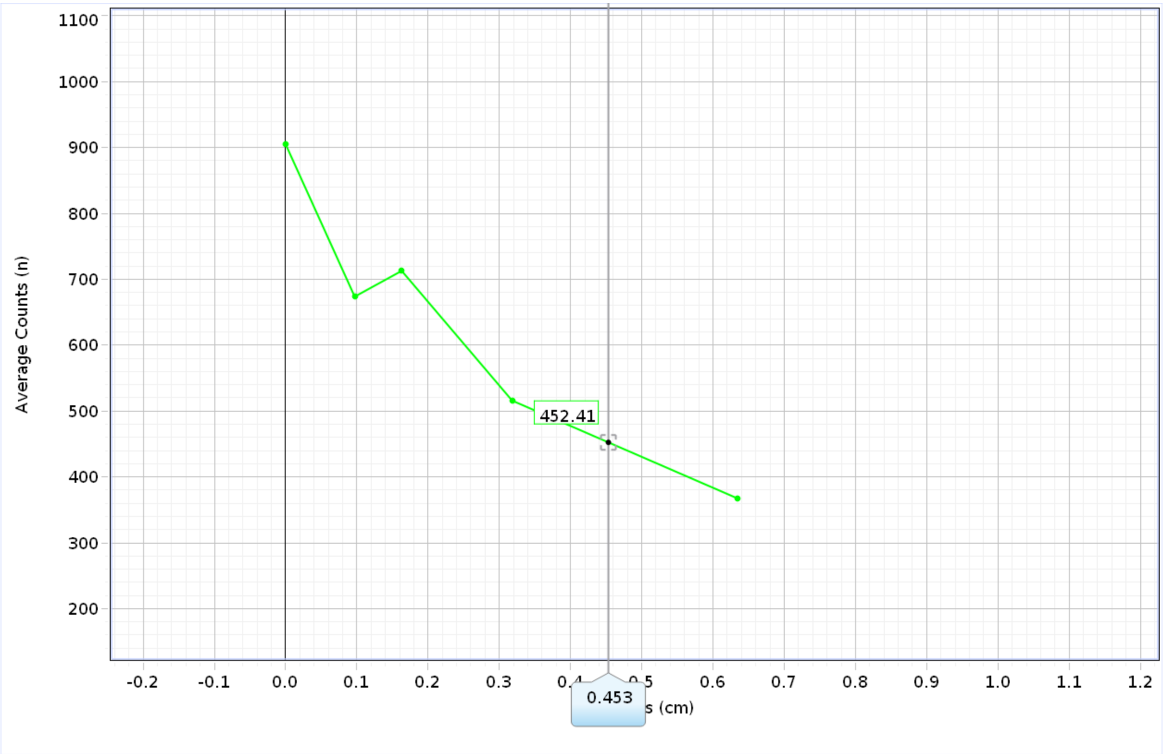
(μ/ρ) of 0.096 ± 0.023 g/cm^2

$X_{1/2}$ (1196 counts) was 0.62 cm, $\mu_{1(X1/2)}$ = 1.12 cm^{-1}

(μ/ρ) of 0.099 g/cm^2.

Results: Procedure Two





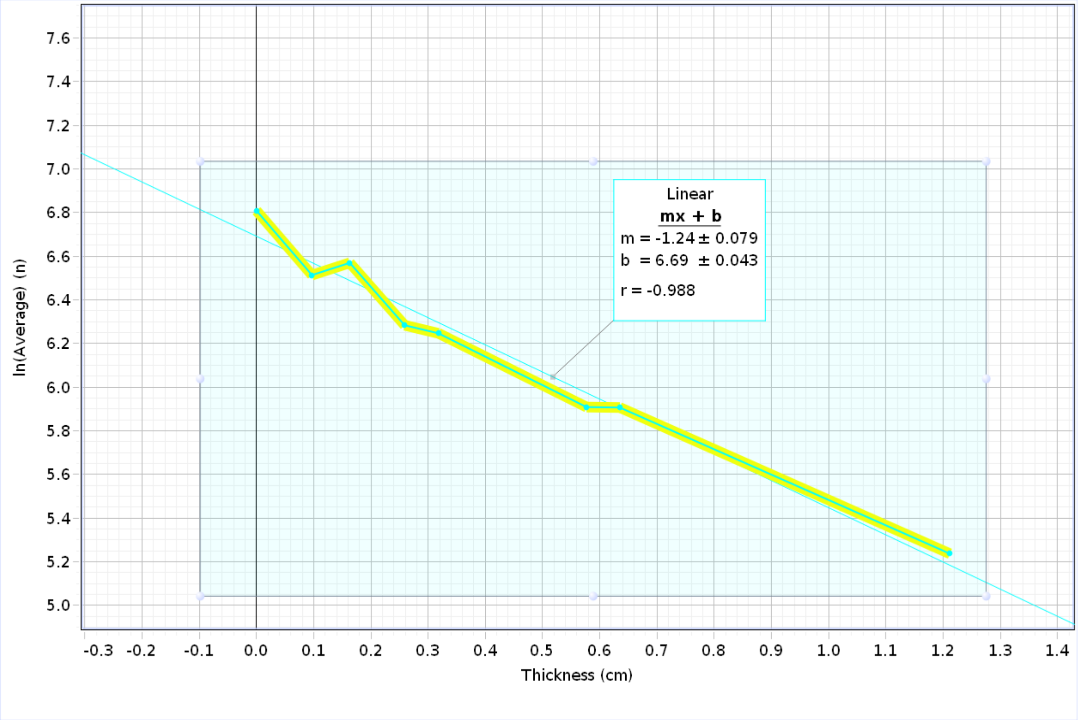
μ_{2slope} = 1.36 ± 0.17 cm^{-1}

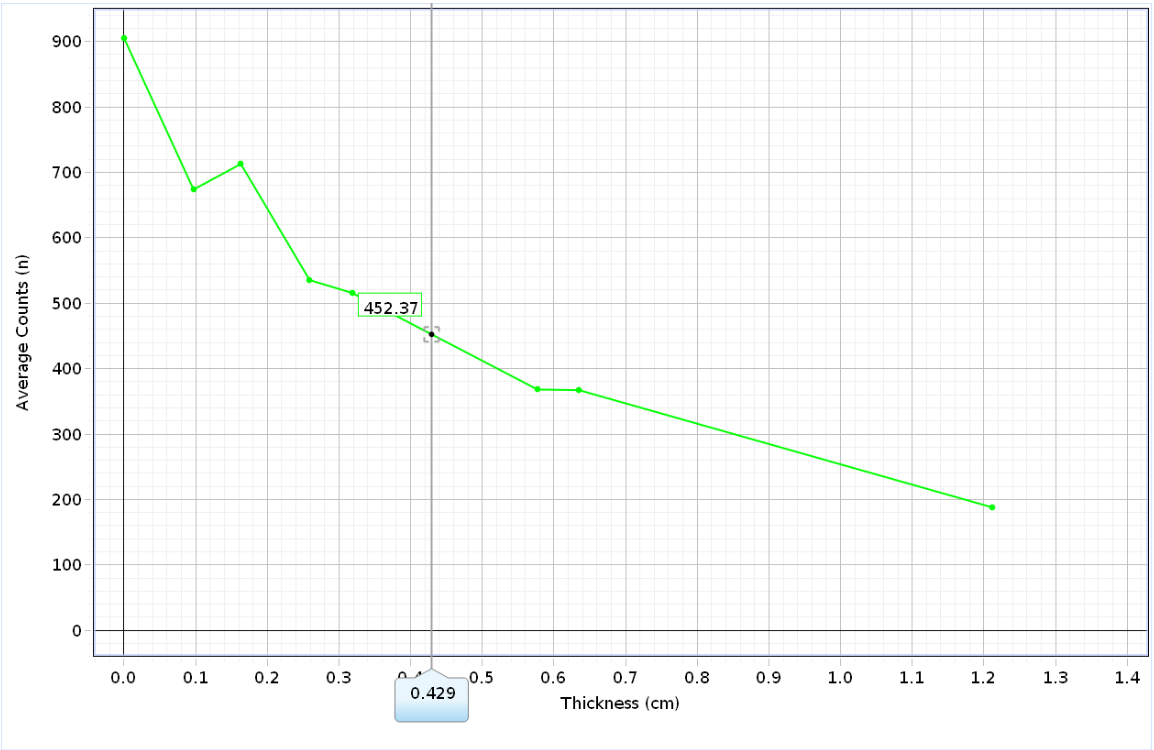
(μ/ρ) of 0.120 ± 0.015 g/cm^2

$X_{1/2}$ (452 counts) was 0.453 cm, $\mu_{1(X1/2)}$ = 1.53 cm^{-1}

(μ/ρ) of 0.135 g/cm^2.

Results: Procedure Three





μ_{3slope} = 1.24 ± 0.079 cm^{-1}

(μ/ρ) of 0.109 ± 0.007 g/cm^2

$X_{1/2}$ (452 counts) was 0.429 cm, $\mu_{1(X1/2)}$ = 1.62 cm^{-1}

(μ/ρ) of 0.142 g/cm^2.

Results: Summary of Attenuation

- GM Counter plateau
  - Optimal Voltage: 1200V.
- Background Radiation
  - ~30 counts per minute.
- Resolving time
  - 20 µ.s (1-100 µ.s)
- Efficiency
  - 1.33% (0-10%). 0.12% for gamma source.

- Average of *μ*/ *ρ* (*μ* from slope).
  - 0.108 ± 0.029 g/cm^2
- Average of *μ*/ *ρ* (*μ* function of half intensity distance).
  - 0.125 g/cm^2.

Error and Uncertainty

- Using the value of (μ/ ρ) obtained from the slopes of $\ln(I_0)$ vs Thickness (0.108 ± 0.029 g/cm^2) and the accepted mass attenuation coefficient (μ/ ρ) of 0.1136 g/cm2.

$$\%\text{Error} = \frac{|Accepted\ Value - Obtained\ Value|}{Accepted\ Value} \times 100\%$$

$$= \frac{|0.1136\ \text{g/cm2} - 0.108\ \text{g/cm2}|}{0.1136\ \text{g/cm2}} \times 100\%$$

$$= 4.93\%$$

- Uncertainty terms in the averaged values through error propagation gives;

$$\Delta(\mu/\rho) = 0.029\ \text{g/cm2}$$

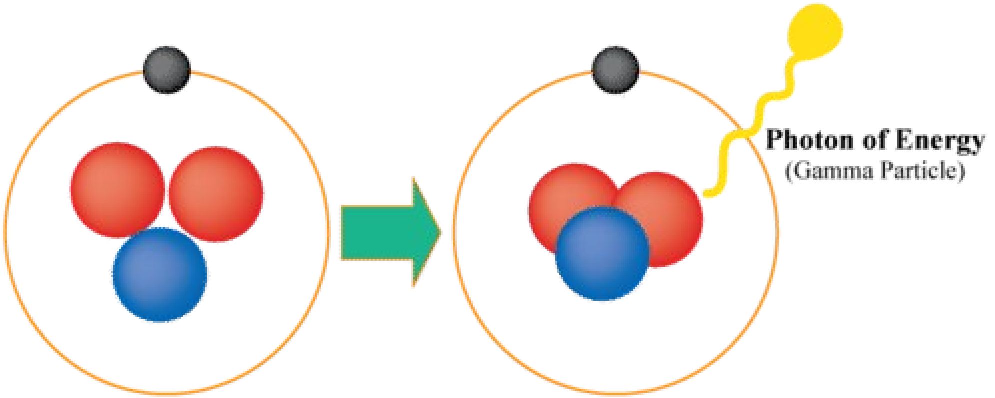
- Using the uncertainty to calculate the percentage fractional uncertainty gives;

$$\Delta(\mu/\rho)/(\mu/\rho) \times 100\% = 26.85\%$$

Which compared to the % error suggests the results are valid.

Conclusion

- Successfully determined the the mass attenuation coefficient of lead through two different approaches.
- Lead is indeed an efficient material to absorb, at least for low energy emissions.
- Could’ve used more varying density's of Pb as the most accurate procedure did use combinations.
  - The distance between the source and the varying leads could’ve been as issue.
- Better means of calculating the resolving time as adjusted times had 10-20 counts.
- Better analysis for error propagation.
- Discuss Slide 10 answers.



Citations

- [1] Encyclopedia Britannica. *Electromagnetic Spectrum*.
- [2] Wikipedia. Paul Villard. https://es.wikipedia.org/wiki/Paul_Ulrich_Villard#/media/File:Paul_Villard.jpg
- [3] WikiCommons. *Rutherford.*
- [4]https://en.wikipedia.org/wiki/Photoelectric_effect#/media/File:Photoelectric_effect.svg
- [5] Wikibooks. *Basic Physics of Nuclear Medicine*
- [6] NIST. *X-Ray Mass Attenuation Coefficients*
- [7] Lead. https://en.wikipedia.org/wiki/Lead
- [11] https://indico.cern.ch/event/593812/contributions/2499768/attachments/1466350/2268202/KDK_Cap_Congress_2017_Matthew_Stukel.pdf

Thank you.

Questions?