Experimental Radioactivity Bench

This apparatus is designed to enable a comprehensive range of experimental investigations into the characteristics and properties of radioactive emission to be carried out. Although some experiments are suitable for lower levels, the majority are intended for 'A'-level physics students.

Additional equipment required:

A Geiger-Müller tube and holder
A compatible rate meter or counter
At least one radioactive source
Radioactive source handling tool

Caution
Although this apparatus does not contain any hazardous material, all investigations involve a radioactive source. Before acquiring or using such a source, refer to CLEAPSS document *L93: Managing Ionising Radiations and Radioactive Substances in Schools*.
This is a free download and can be viewed here:
http://www.cleapss.org.uk/download/L93.pdf

Equipment Detail

The bench is a steel tube with plastic end inserts. A millimetre scale is mounted on a plate attached to the side of the bench. This acts as a guide to align the slotted plastic carriages which clamp magnetically to the bench.

The slot on each carriage can accommodate any of the absorption plates, and has a nut so the plate can be held securely upright.

There are two source holders. The first has three horizontally collinear holes. The central hole is for alignment with the GM-tube, and the holes off-centre are used with the collimator for experiments involving magnetic defection of β particles. The second source holder is angled so that the sealed source can be placed beneath the GM tube for back-scattering experiments.

Aluminium Absorbers

Lead Absorbers

1st Source Holder

2nd Source Holder

Collimator

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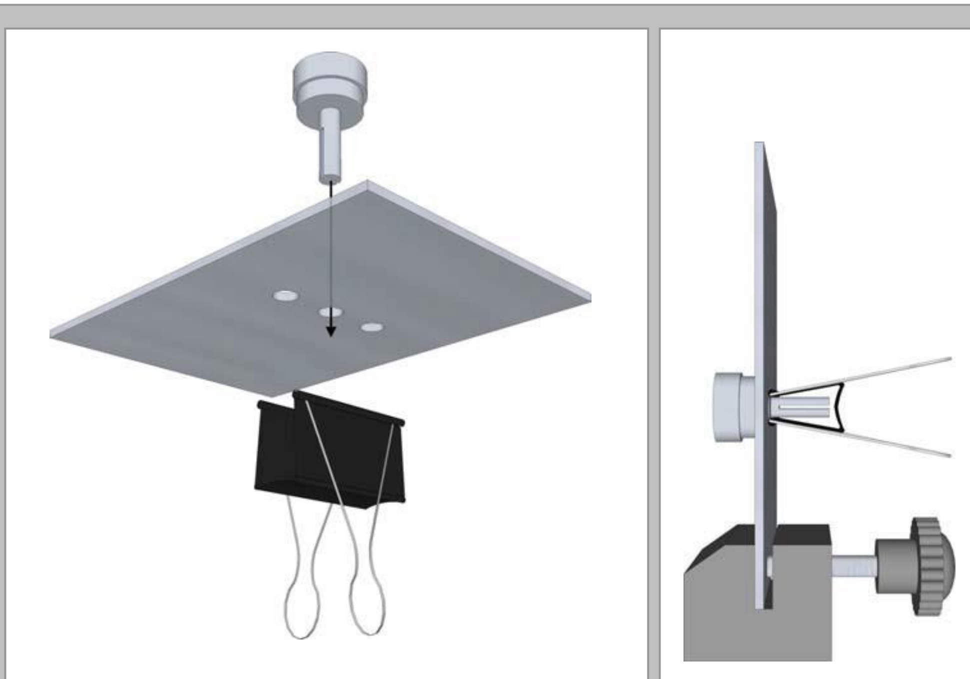
General Information

Two "Bulldog" clips are provided to secure the sealed sources in their holders. The holder should be held horizontally, and using a source handling tool, the source should be dropped in to the required hole, then the bulldog clip attached to the back.

Once secured in the holder, it can be turned so the source is horizontal, and then placed in a carriage.



The sealed source is placed in the holding plate, and secured with the bulldog clip. It can then be placed in a carriage.

When setting the voltage on the EHT, 400V is recommended. However, each tube is slightly different, and a higher or lower voltage may be required to obtain optimum response from the tube.

Precautions

The source should always be handled using the source handling tool. When using α or β sources, the grille should be pointed away from people at all times. It is recommended that people remain at least one metre away from the source when measurements are being taken. When not in use, the source should be returned to its lead "castle" in the hardwood storage box and kept in a locked cupboard away from permanently occupied places.

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Experiments

The following are examples of investigations that are possible with this kit.

Investigating the relationship between the intensity of γ rays at a point and the distance of that point from the source

Monitoring the distribution in space of the emission from a radiation source

Investigating the deflection of a stream of β particles in a magnetic field

Investigating back scattering of β radiation by solids

Gauging the foil thickness of aluminium foil by transmission of β particles

Gauging the level of a liquid or a powder by the transmission of β particles

Safety advice
This advice is not a replacement for a formal risk assessment, which should be carried out according to your school or LEA policy.

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Experiment 1 *Classifying radioactive and non-radioactive solids*

This is a simple investigation designed to introduce the fact that some materials emit radiation naturally, whereas others do not. It also demonstrates how this radiation can be detected using man-made devices.

Requirements

Rate meter
Geiger Muller tube and holder
Radioactive rock specimens
Normal rocks

Precautions

Although natural radioactive substances are not subject to regulations concerning holding of sources, care should be taken in storing and handling such materials. The rock specimens should be stored in the radioactive storage cupboard, and gloves should be worn when handling so no residue is left on skin.

Operating Procedure

1. Connect the GM tube holder to the rate meter
2. Mount the GM tube into its holder
3. Set the EHT supply on the rate meter to 400V, and the count range to $250s^{-1}$
4. Read and record the rate in the absence of a sample and the rate of click from the loudspeaker
5. Place each sample in turn in close proximity to the window of the GM tube.
6. Record the new count rate and the rate of clicking of the loudspeaker.
7. Classify the samples into radioactive and non-radioactive samples.

Example Results

Background count: $2s^{-1}$

Specimen	Pitchblende	Monazite	Slate	Concrete
Count rate (s^{-1})	84	71	2	3
Corrected count rate (s^{-1})	82	69	0	1

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Experiment 2 *Investigating the randomness of radiation emitted by a Cobalt-60 source*

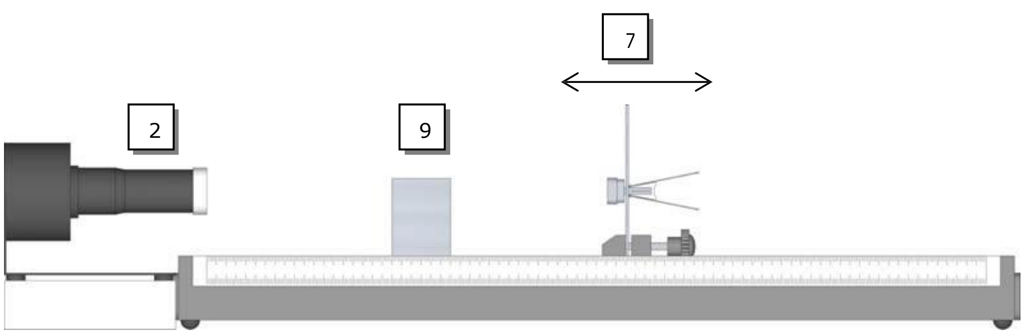
Requirements

Radioactivity Bench
Rate meter
Geiger Müller tube and holder
Source handling tool
Aluminium block
Lead block
Bulldog clip
5μCi cobalt-60 source
Stopclock

Before proceeding with this experiment, read the precautions on page 2.

Operating procedure

1. Connect the GM tube holder to the rate meter.
2. Mount the GM tube in its holder and place it at the zero end of the scale of the bench so that the window of the GM tube is vertically above zero on the scale.
3. Secure the source holder in a carriage with its line of holes horizontal, and the central hole in line with the GM tube window
4. Using the source handling tool, mount the cobalt-60 source in the central hole of the holder as illustrated on page 2, with the grille end facing the window of the GM tube
5. Set the EHT supply on the rate meter to 400V and set the range to $250s^{-1}$
6. Switch on and allow the rate meter to stabilise
7. Adjust the separation of the GM tube and source to give a reading on the order of $200s^{-1}$. Record the number of counts observed every 10 seconds, taking several 10 second samples.
8. Turn the loudspeaker on and listen to the clicks
9. Stand the aluminium block between the source and GM tube and observe the change to speaker output and count rate.
10. Replace the aluminium block with the lead block and again observe the changes.



Theory

The radiation emitted from this source is random in nature; it is not possible to predict when any given atom in the source will decay. The laws governing the emission are statistical laws which apply when there are a very large number of random events.

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Extension

This investigation can be extended to investigate the variation in count rate and to determine the standard deviation of a series of observations from the mean count rate.

11. Carry out the experiment as detailed in steps 1 to 7 and note the maximum and minimum reading of the rate meter over a period of 5 minutes. Split the range identified into five unit modules.
12. Record the number of counts observed in 50 times 10 second intervals and draw up a tally of the number of observations falling in each unit module.
13. Calculate the mean value (x_m) of the count rate and the deviation (σ_x) of each observation from that mean value.
14. Calculate the variance (σ^2) and the standard deviation (σ).
15. Plot a histogram of the frequency of a given range of observations against that range of observations.

Theory

The **mean value** (x_m) of a series of observations is the ratio of the sum of those observations to the number of observations *N*:

$$x_m = \frac{\Sigma x}{N}$$

x: specific observation

The **deviation** (σ_x) of an observation from the mean value is the difference between that observation and the mean value:

$$\sigma_x = x - x_m$$

The **variance** (σ^2) of the series of observations is the mean of the squares of the deviations of a series of observations from the mean value:

$$\sigma^2 = \frac{\Sigma \sigma_x^2}{N}$$

The **standard deviation** (σ) is the square root of the mean of the squares of the deviations:

$$\sigma = \sqrt{\frac{\Sigma \sigma_x^2}{N}}$$

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Example Results

Range	Tally	Frequency	Deviation (σ_x)	σ_x^2	$\Sigma\sigma_x^2$
200-204	|||	3	-16	256	768
205-209	|||	3	-11	121	368
210-214	~~||||~~	5	-6	36	180
215-219	~~||||~~ ||||	9	-1	1	9
220-224	~~||||~~ ~~||||~~ |||	13	4	16	208
225-229	~~||||~~ ~~||||~~ ||	12	9	81	972
230-234	~~||||~~	5	14	196	980

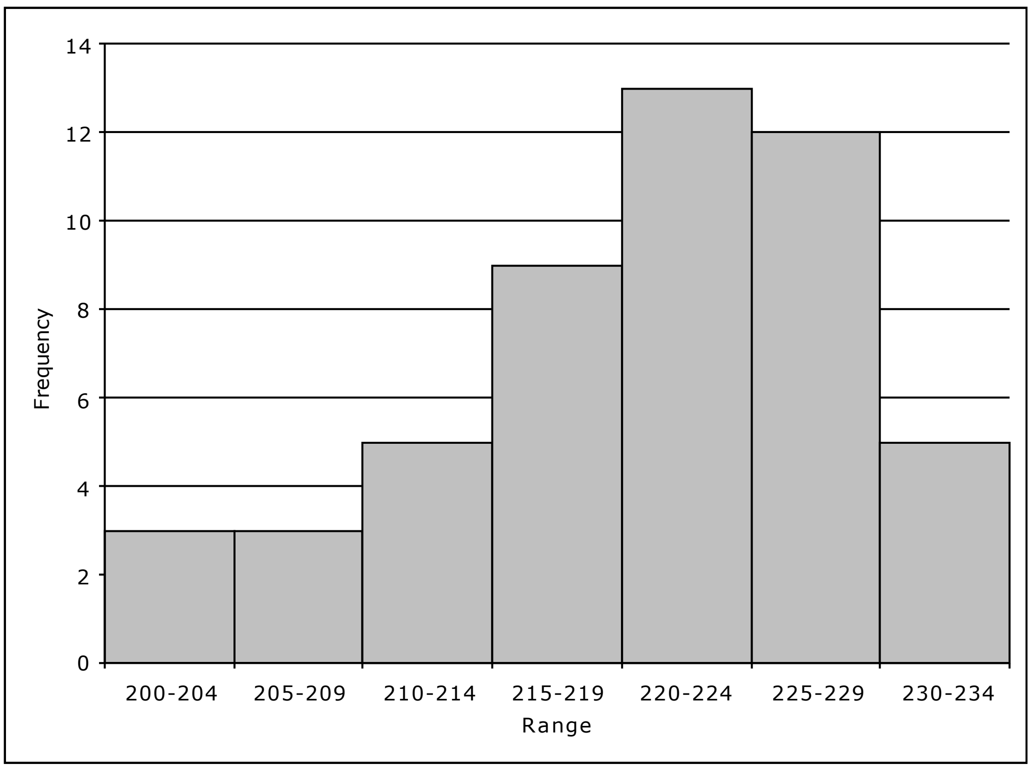
Sum of observations $= 10910$

Mean value $= \frac{10910}{50} = 218$

Sum of squares of deviations $= 3485$

Mean square deviation $= \frac{3485}{50} = 69.7$

Root mean square deviation $= \sqrt{69.7} = 8.3$



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Experiment 3 *Comparing the activity of emitters*

Requirements

Radioactivity bench
Rate meter
Geiger Müller tube and holder
Source handling tool
Bulldog clip
5µCi cobalt-60 source
5µCi strontium-90 source
5µCi americium-241 source

Before proceeding with this experiment, read the precautions on page 2.

Operating Procedure

1. Connect the GM tube holder to the rate meter.
2. Mount the GM tube in its holder and place it at the zero end of the scale of the bench so that the window of the GM tube is vertically above zero on the scale.
3. Secure the source holder in a carriage with its line of holes horizontal, and the central hole in line with the GM tube window.
4. Using the source handling tool, mount one source in the central hole of the holder as illustrated on page 2, with the grille end facing the window of the GM tube.
5. Set the EHT supply on the rate meter to 400V and set the range to 250s^{-1}
6. Switch on, allow the rate meter to stabilise, and take a note of the activity.
7. Repeat steps 1-6 with each source.
8. Identify the most active of the three sources, and mount it in the holder as before.
9. Adjust the distance between the source and the tube so that the meter reading is the maximum for that source.
10. Using this separation, determine the count rate for the other sources.

Example Results

Background count: 2s^{-1}

Source	Cobalt-60	Strontium-90	Americium-241
Count rate (s^{-1})	240	135	2
Corrected count rate (s^{-1})	238	133	0

Note: when placed 6mm from the GM tube window, the count rate recorded from americium-241 was 250s^{-1}.

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Experiment 4 *Reducing the intensity of radiation emitted by a source*

Requirements

Radioactivity bench
Rate meter
Geiger Müller tube and holder
Source handling tool
Bulldog clip
5μCi cobalt-60 source
5μCi strontium-90 source
Set of solid blocks

Before proceeding with this experiment, read the precautions on page 2.

Operating Procedure

1. Connect the GM tube holder to the rate meter.
2. Mount the GM tube in its holder and place it at the zero end of the scale of the bench so that the window of the GM tube is vertically above zero on the scale.
3. Secure the source holder in a carriage with its line of holes horizontal, and the central hole in line with the GM tube window.
4. Using the source handling tool, mount one source in the central hole of the holder as illustrated on page 2, with the grille end facing the window of the GM tube.
5. Set the EHT supply on the rate meter to 400V and set the range to $250s^{-1}$
6. Switch on, allow the rate meter to stabilise, take a note of the activity.
7. Adjust the separation of the GM tube and source to give the maximum possible reading on the rate meter.
8. Record the count rate.
9. Place each solid block in turn between the source and GM tube, with the block in close proximity to the source.
10. Record the count rate for each solid.

Example Results

Background count: $1s^{-1}$

Block	None	Polystyrene	Wood	Aluminium	Lead
Count rate (s^{-1}) Co_{60}	240	150	7	5	2
Count rate (s^{-1}) Sr_{90}	240	190	3	1	1

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Extension

The relationship between the activity from a source and the source-counter separation can be investigated.

Operating Procedure

1. Connect the GM tube holder to the rate meter.
2. Mount the GM tube in its holder and place it at the zero end of the scale of the bench so that the window of the GM tube is vertically above zero on the scale.
3. Secure the source holder in a carriage with its line of holes horizontal, and the central hole in line with the GM tube window.
4. Using the source handling tool, mount one source in the central hole of the holder as illustrated on page 2, with the grille end facing the window of the GM tube.
5. Set the EHT supply on the rate meter to 400V and set the range to 250s^{-1}
6. Switch on, allow the rate meter to stabilise, and take a note of the activity.
7. Adjust the separation of the GM tube and source to give the maximum possible reading on the rate meter.
8. Record the count rate.
9. Increase the source-counter separation in 50mm steps and record the corresponding count rates.

Example Results

Background count: 1s^{-1}

Separation	100	150	200	250	300	350	400
Count rate (s^{-1}) Co_{60}	240	137	98	57	37	27	20
Count rate (s^{-1}) Sr_{90}	240	87	52	33	22	16	12

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Experiment 5 *Determining the range of α particles in air*

Requirements

Radioactivity bench
Rate meter
Geiger Müller tube and holder
Source handling tool
Bulldog clip
5μCi americium-241 source
Tissue paper

Before proceeding with this experiment, read the precautions on page 2.

Operating Procedure

1. Connect the GM tube holder to the rate meter.
2. Mount the GM tube in its holder and place it at the zero end of the scale of the bench so that the window of the GM tube is vertically above zero on the scale.
3. Secure the source holder in a carriage with its line of holes horizontal, and the central hole in line with the GM tube window.
4. Using the source handling tool, mount one source in the central hole of the holder as illustrated on page 2, with the grille end facing the window of the GM tube.
5. Set the EHT supply on the rate meter to 400V and set the range to $250s^{-1}$
6. Switch on and allow the rate meter to stabilise.
7. Carefully remove the grille from the end of the GM tube
8. Adjust the separation of the GM tube and the source to get the maximum count rate on the rate meter. Do not allow the source to be brought too close to the unprotected window of the GM tube, as it is very delicate.
9. Increase the source/tube separation in steps, and record the reading from the rate meter against the distance of the source from the tube, changing the range on the counter if necessary

NOTE: Remember to replace the protective grille on the end of the GM tube at the end of this experiment.

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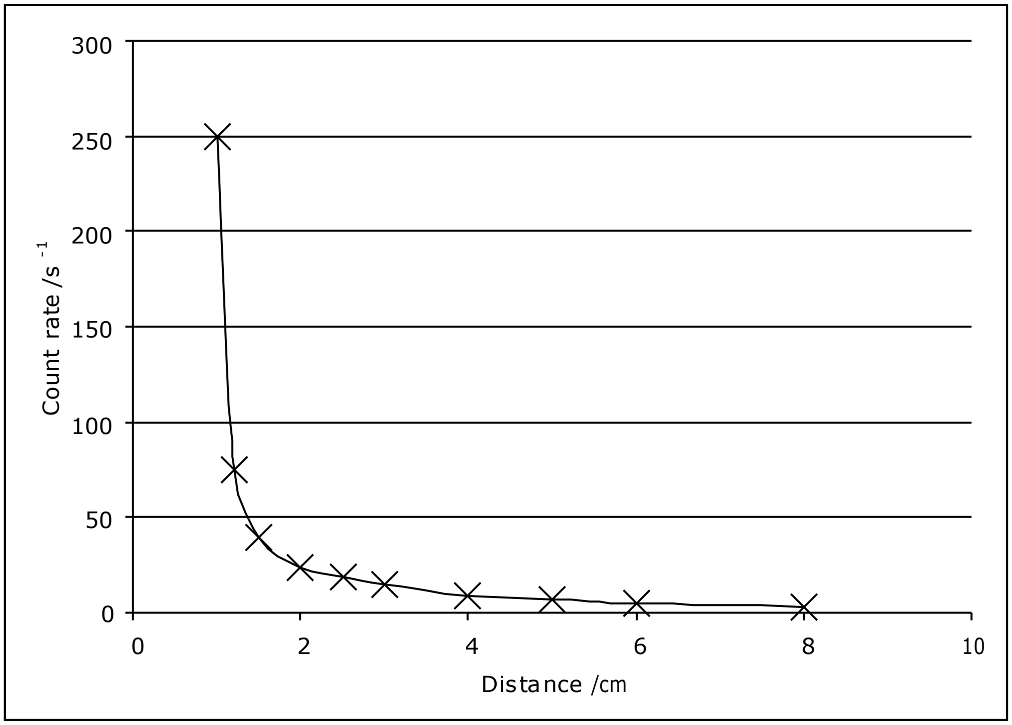
Example Results

Background count: 1s^{-1}

Source-tube separation (cm)	1.0	1.2	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0
Count rate (s^{-1})	250	75	39	24	19	15	9	7	5	3
Corrected count rate (s^{-1})	249	74	38	23	18	14	8	6	4	2



Theory

α particles cause heavy ionisation of the air as they pass through it, losing their energy after travelling a relatively short distance (i.e. they have a very short range in air).

The window of the GM tube is a very effective absorber of the energy of *α* particles and is equivalent to a few centimetres of air (depending on the type of GM tube being used).

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Extension

To investigate the absorption of α particle energy by tissue paper.

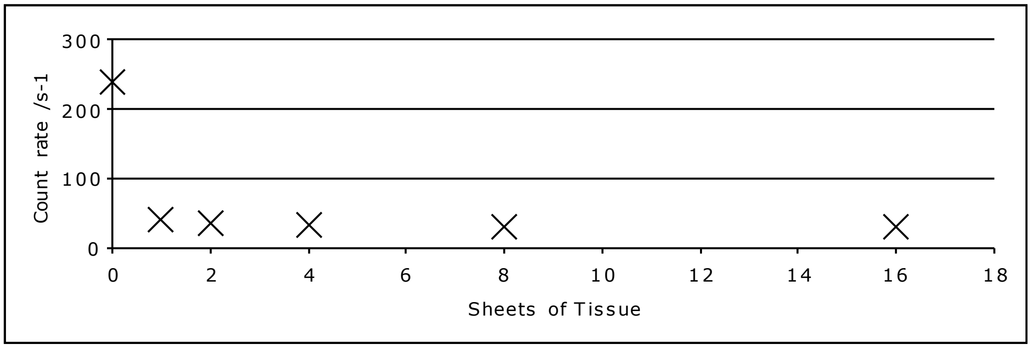
10. Adjust the separation of the GM tube and the source to get the maximum count rate on the rate meter. <u>Do not allow the source to be brought too close to the unprotected window of the GM tube, as it is very delicate.</u>
11. Introduce one thickness of a $10cm^2$ sheet of tissue paper between the source and the GM tube, and record the new rate meter reading.
12. Fold the tissue paper once, place two thicknesses of it between the source and GM tube again, and record the new rate meter reading.
13. Continue to fold the paper and place the new thickness between the source and GM tube.

<u>NOTE: Remember to replace the protective grille on the end of the GM tube at the end of this experiment.</u>

Example Results

Background count: $1s^{-1}$

Sheets of Tissue	0	1	2	4	8	16
Count rate (s^{-1})	240	41	37	35	33	33
Corrected count rate (s^{-1})	239	40	36	34	32	32



Note

1. The count rate falls significantly when a single thickness of tissue is placed between the source and the tube, but subsequent layers of tissue have little effect. This suggests that all α particle energy is absorbed by a single layer of tissue and the window of the GM tube, and that remaining incident radiation is not α radiation.
2. Americium-241 emits low energy γ rays as well as α particles.

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Experiment 6 *Investigating the absorption of β particles in metal*

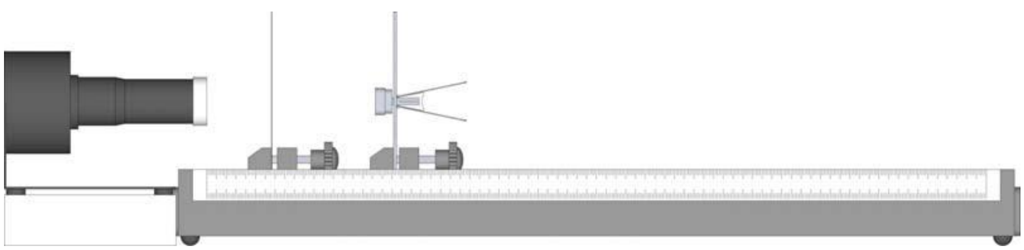
Requirements

Radioactivity bench
Rate meter
Geiger Müller tube and holder
Source handling tool
Bulldog clip
5μCi strontium-90 source
Set of aluminium plates
Micrometer
Stopclock

Before proceeding with this experiment, read the precautions on page 2.

Operating Procedure

1. Connect the GM tube holder to the rate meter.
2. Mount the GM tube in its holder and place it at the zero end of the scale of the bench so that the window of the GM tube is vertically above zero on the scale.
3. Secure the source holder in a carriage with its line of holes horizontal, and the central hole in line with the GM tube window.
4. Using the source handling tool, mount the source in the central hole of the holder as illustrated on page 2, with the grille end facing the window of the GM tube.
5. Set the EHT supply on the rate meter to 400V and set the range to $250s^{-1}$
6. Switch on and allow the rate meter to stabilise.
7. Adjust the separation of the GM tube and the source to get the maximum count rate on the rate meter, and make a note of this rate.
8. Use the micrometer to measure the thickness of the aluminium plates.
9. Mount each plate in turn into a carriage, and place it between the source and the GM tube.
10. Record the rate on the rate meter against the thickness of the aluminium sheet (x).



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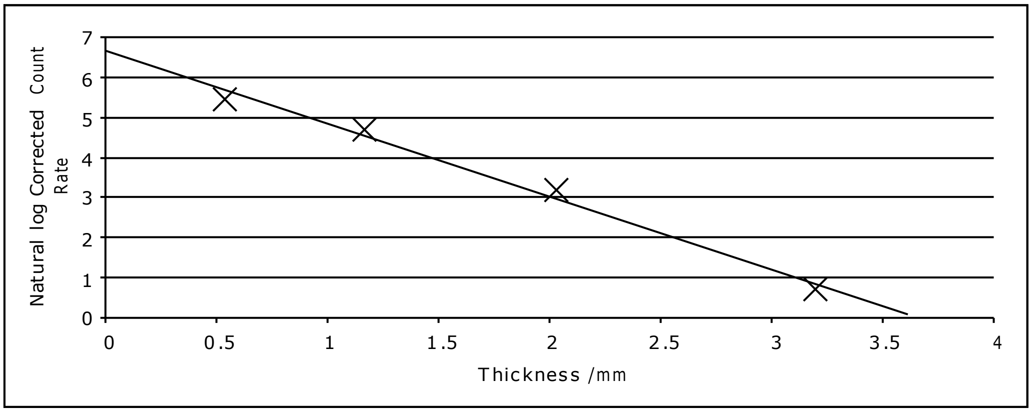
Example Results

Background count: 1s^{-1}

Thickness (mm)	0.54	1.17	2.03	3.20
Count rate (s^{-1})	237	110	25	3
Corrected count rate (s^{-1})	236	109	24	2
Natural log	5.46	4.69	3.17	0.69



Theory

The absorption of β particles is approximately exponential:

$$I = I_0 e^{-\mu x}$$

I: intensity of β particles
I_0: incident intensity
μ: absorption coefficient
x: thickness

I is the intensity of β particles passing through the aluminium.

Taking the natural log of this equation:

$$\ln I = \ln I_0 - \mu x$$

So the gradient of the graph above is $-\mu$.

The half thickness ($x_{½}$) is the thickness at which the intensity of the transmitted β particles is half the incident intensity, and is given by:

$$\tfrac{1}{2} I_0 = I_0 e^{-\mu x_{1/2}}$$

$$\ln \tfrac{1}{2} = \ln 1 - \mu x_{1/2}$$

$$x_{1/2} = \frac{\ln 2}{\mu}$$

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Experiment 7 *Investigating the attenuation of γ rays in lead*

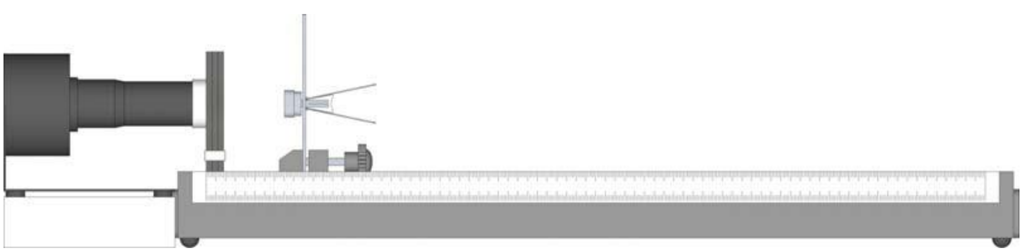
Requirements

Radioactivity bench
Rate meter
Geiger Müller tube and holder
Source handling tool
Bulldog clip
5μCi cobalt-60 source
Set of lead plates
Micrometer
Rubber band

Before proceeding with this experiment, read the precautions on page 2.

Operating Procedure

1. Connect the GM tube holder to the rate meter.
2. Mount the GM tube in its holder and place it at the zero end of the scale of the bench so that the window of the GM tube is vertically above zero on the scale.
3. Secure the source holder in a carriage with its line of holes horizontal, and the central hole in line with the GM tube window.
4. Using the source handling tool, mount the source in the central hole of the holder as illustrated on page 2, with the grille end facing the window of the GM tube.
5. Set the EHT supply on the rate meter to 400V and set the range to $250s^{-1}$
6. Switch on and allow the rate meter to stabilise.
7. Adjust the separation of the GM tube and the source to get the maximum count rate on the rate meter, allowing sufficient space to space between the GM tube and the source to introduce the two thickest lead plates between them.
8. Record the count rate without any lead plates.
9. Measure the thickness of the thinnest lead plate, mount it in a carriage, and place it on the bench between the source and GM tube in close proximity to the source. Record the new count rate.
10. Alternate the lead plates, to get various thicknesses. Measure the thickness, and secure the plates with a rubber band near the base. Carefully stand the plates between the source and GM tube and record the count rate for each thickness.
11. Remove the source and record the count rate to determine the background count.



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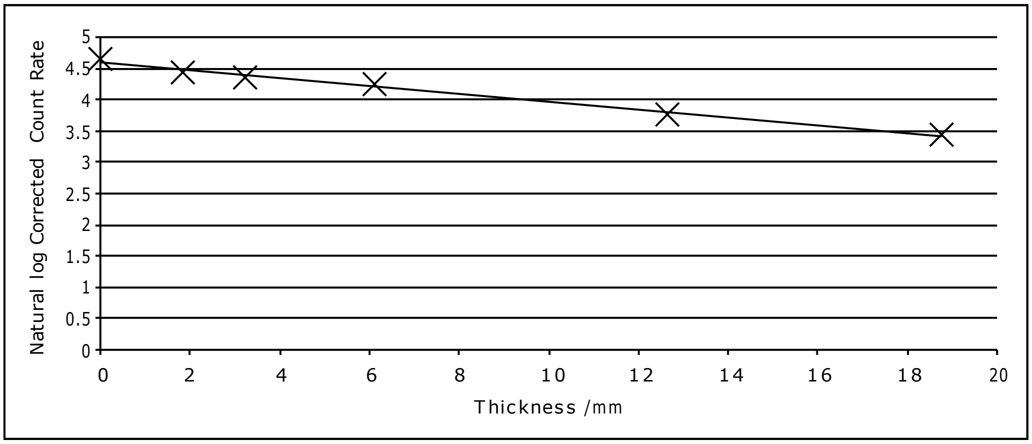
Example Results

Background count: $1 s^{-1}$

Thickness (mm)	0	1.85	3.21	6.10	12.65	18.75
Observed count rate (s^{-1})	105	85	78	70	44	32
Corrected count rate (s^{-1})	104	84	77	69	43	31
Natural log	4.64	4.43	4.34	4.23	3.76	3.43



Theory

The attenuation of γ rays through lead is approximately exponential:

$$I = I_0 e^{-\mu x}$$

I: intensity of γ rays
I_0: incident intensity
μ: attenuation coefficient
x: thickness

I is the intensity of γ rays passing through the lead.

Taking the natural log of this equation:

$$\ln I = \ln I_0 - \mu x$$

So the gradient of the graph above is $-\mu$.

The half thickness ($x_{½}$) is the thickness at which the intensity of the transmitted γ rays is half the incident intensity, and is given by:

$$\tfrac{1}{2} I_0 = I_0 e^{-\mu x_{1/2}}$$

$$\ln \tfrac{1}{2} = \ln 1 - \mu x_{1/2}$$

$$x_{1/2} = \frac{\ln 2}{\mu}$$

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