Core practical 15: Investigate the absorption of gamma rays by lead

Objectives

- To measure the count rate when different thicknesses of lead are placed between a gamma ray source and a detector
- To determine the half-thickness of lead for gamma rays of a particular energy

Safety

- This practical involves a radiation hazard. Local rules apply. See CLEAPSS Guide L93 for further advice.
- Students should carry out this work with due attention to safety in accordance with a risk assessment. Particular attention should be paid to the fact that radioactive materials are in use.

Specification links

- Practical techniques 1, 2, 3, 4, 5, 11, 12
- CPAC 3b, 4b, 5b

Procedure

Research

1. Look up the rules for handling radioactive materials in schools and the practices required for safety.
2. Write a plan for the safe conduct of the experiment. You should describe carefully how the readings are taken and how the count rate is calculated from them.

Practical

1. Carry out your experiment, paying particular attention to the management of safety. Each student should record their own results.

Notes on procedure

- If every student has produced a plan and associated risk assessment, the experiment can be carried out by a number of students at the same time. The activities are measuring the thickness of the lead sheets and determining the count rate. All students can measure a few of the sheets, and the readings can be pooled and uncertainties derived from these. Each student should have their own stop clock and a clear view of the counter. Each student can set or clear one of the lead sheets and the source can be manipulated by each student separately as an exercise. In this way each student should experience every aspect of the practical work in a relatively short time.
- CPAC 3b will be observed and should also be in students' reports on the work.
- CPAC 4b will be evidenced by students' results.
- For CPAC 5b, students' research should be evident.
- They should use ICT to plot their graph as software can subtract backgrounds and take logs very easily. If available, software which plots error bars and draws different lines of fit would be helpful.

Answers to questions

1. The gamma rays spread out with their intensity reducing according to the inverse square law, so doubling your distance from the source reduces your dose by 75%.
2. The decay is random and will naturally fluctuate over time. Repeating readings enables you to calculate an average and will give you an estimate of the uncertainty by taking the range of a set of repeats.
3. A datalogger would make it easier to calculate the rate, because most software programs can calculate this directly. Since the uncertainty in measuring the time by hand is very small and repeat readings are taken it is unlikely to be much more accurate because it will not be taking readings over a longer period.
   Other valid arguments should be considered.

Sample data

x/mm	C/s^{-1}
0.00	605
1.55	544
3.25	479
4.80	454
6.48	409
8.03	365
9.73	327
13.15	257

The graph of ln C against x for this data gives a gradient of $-0.0638\ \text{mm}^{-1}$.

The half-thickness is $\frac{\ln 2}{0.0638} = 10.9\ \text{mm}$.

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Safety

- This practical involves a radiation hazard and important rules must be followed. CLEAPSS Guide L93 gives information. Always follow your teacher's instructions carefully.
- You should carry out this work with due attention to safety in accordance with a risk assessment. Pay particular attention throughout to the fact that radioactive materials are in use.

All the maths you need

- Recognise and make use of appropriate units in calculations.
- Use calculators to find and use power, exponential and logarithmic functions.
- Use an appropriate number of significant figures.
- Find arithmetic means.
- Understand simple probability.
- Substitute numerical values into algebraic equations using appropriate units for physical quantities.
- Use logarithms in relation to quantities that range over several orders of magnitude.
- Translate information between graphical, numerical and algebraic forms.
- Plot two variables from experimental or other data.
- Understand that $y = mx + c$ represents a linear relationship.
- Determine the slope and intercept of a linear graph.
- Interpret logarithmic plots.
- Use logarithmic plots to test exponential and power law variations.

Equipment

- gamma ray source and handling tools
- GM tube and counter
- bench apparatus to support source and GM tube
- stop clock
- sheets of lead
- micrometer or callipers

Procedure

Research

1. Look up the rules for handling radioactive materials in schools and the practices required for safety.
2. Write a plan for the safe conduct of the experiment. You should describe carefully how the readings are taken and how the count rate is calculated from them.

Practical

1. Carry out your experiment, paying particular attention to the management of safety. Each of you should record your own results if working in a group.

Analysis of results

- Since a constant fraction of the radiation is absorbed for each thickness *x,* of absorber, the rate of absorption is exponential, so the measured count rate *C* will vary according to the formula $C = C_0 e^{-\mu x}$. Taking logs to the base *e* of each side gives $\ln(C) = -\mu x + \ln(C_0)$ which is similar to $y = mx + c$. Since the value of the gradient will be $-\mu$, which is a constant, the line should be straight with a negative constant gradient.

  The half-thickness is the thickness of lead that reduces the count rate to half the initial count.

1. Plot a graph of your results and use it to determine the half-thickness of lead for the source used.
2. Estimate the uncertainty in your readings and draw error bars on your plots. If you cannot do this using the graphing software, print off the graph and analyse the uncertainties by drawing error bars and lines of best fit by hand.
3. Draw two lines of best fit and use them to estimate the uncertainty in your value for the half-thickness.

Learning tip

- You do not need the origin on your graph. Choose your scales to make sure that the points spread out, occupying more than half of the paper along both axes.

Questions

1. Explain why you are safer the further away you stand from a gamma ray source.
2. Explain why repeating your readings will improve them.
3. The GM tube could be attached to a datalogger instead of a simple counter. Discuss whether using a datalogger would improve your results.

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Equipment per student/group	Notes on equipment
gamma ray source and handling tools	
GM tube and counter	These could be connected to a datalogger but total count must be displayed. A reset facility makes taking the measurements simpler.
bench apparatus to support source and GM tube	The sheets of lead must be placed between the source and the detector without varying the separation of source and detector.
stop clock	One per student
sheets of lead	These are placed between source and detector, and should each be a few millimetres thick to a total of approximately 20 mm, but this will depend on the energy of the gamma rays. The aim should be to reduce the count rate by 50% from that measured after the first absorber is in place. At least six count rates are required.
micrometer or callipers	This is to measure the thickness of the lead sheets.

Notes