UNIVERSITY OF LIVERPOOL

Online Nuclear Physics Masterclass

Experiments 1 & 2 - Attenuation

June - July 2020

1 Introduction

In this workbook, along with our online software, you'll find all the necessary materials to investigate an important part of radiation protection: shielding. Experiments 1 and 2 are best done together in one session. Each activity comes with some more open-ended extension tasks. These don't have to be completed to achieve the aims of the sessions but will help you to gain extra knowledge and critical thinking skills which will be helpful to you in your university career and beyond. The answer boxes in this document should be editable, if not try opening the pdf with different software. In these first two experiments, we will be simulating the results we would get from a ^{99m}Tc source. This radioisotope is very useful for medical tracing due to its short radioactive half-life and easily detectable gamma rays.

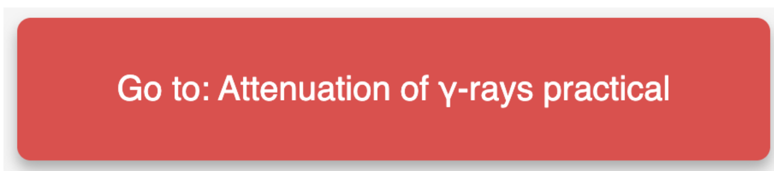
Throughout this workbook, you'll be asked lots of questions and given the space to answer them. These questions might ask you to explain your observations but they may also require some extra physics that isn't in this workbook, don't be afraid to use the internet! There's lots of excellent information out there on the web and it can be a wonderful tool for research. However, its important to be sure that you use a **credible** source. For example: if you're on Wikipedia, try to follow the links at the bottom of the page and get the information from the original source, rather than just quoting it from the wiki entry.

After the extension to Experiment 2, you'll also find a challenge which has been set by Jess Heaps (don't forget to watch her talk first on livnuclear.co.uk). You can send in your answers to this challenge to hello@livnuclear.co.uk .

Experiment 1 - Attenuation by lead

Preparation

In this activity, we will investigate how the intensity of the measured gamma-radiation changes depending on how much material is between the radioactive source and the detector. Throughout this section of the workbook, we will be using the **Attenuation Station** web-app that can be found on our website here. Alternatively it can be accessed from the main livnuclear.co.uk website with the red button, shown below.



At the end of this workbook, you'll find an example of a lab book for you to fill out as we go. You should sketch this out on to a piece of paper (or print it out if you're able to). Make sure to draw a picture of the diagram shown to you on the website and have a quick read of all of the instructions. Summarise them in the appropriate box in your lab book before you begin. Whilst you read, try to think about the risks which would be present if you were to do this experiment in a real lab. You can also start to make your table. For Experiment 1, you'll need two columns: one for the thicknesses of the material and another for the number of counts.

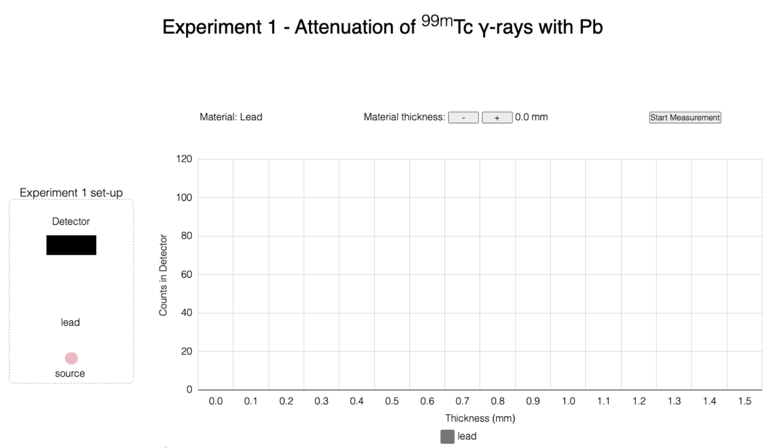
Experiment

In this part of the experiment, we will attempt to block the radiation which is emitted from a ^{99m}Tc source. For this first experiment, you'll be guided all the way through whilst you learn how to use the software.

Question 1.1. What type of radiation is emitted by ^{99m}Tc?

Answer 1.1:

The Attenuation Station software allows you to investigate the effect of different materials on radiation. To start with we'll experiment with lead. For this experiment, you'll be using this part of the web page.



You can use the + and - buttons to add or remove material in your setup. To start with we want a measurement without any lead so that we know where we're starting from. Make sure the thickness is set to 0 mm and press 'Start Measurement'.

Question 1.2. How many counts did you observe? Record this information in the table in your log book too.

Answer 1.2:

Now, let's use the + button to add some material. Increase the thickness by one step and take another measurement.

Question 1.3. What do you notice?

Answer 1.3:

Repeat this process at least 8 more times (so you'll have at least 10 measurements in total, including the ones you've already done). You're aiming to have a range of data up to the point where your counts are 20% of the original number. Don't forget to record this data in your lab book.

Question 1.4. What do you notice?

Answer 1.4:

This type of trend is known as **exponential decay** and it exists all over the place in nature: your cup of coffee cooling down, pressure decreasing as you increase in altitude and the capacitors charging and discharging in your electronic devices just to name a few. In an exponential decay, the rate at which the quantity decreases is **proportional** to its current value. The particular phenomenon we observe in this experiment is known as **attenuation of radiation** and the material is known as an **attenuator**.

Data Analysis

Now we're going to draw some conclusions from our data. Take a look at the graph you've built up in your browser.

Question 1.5. At what thickness of lead are your number of counts half the number they started at? What about a quarter? What about an eighth? What do you notice about these numbers?

Answer 1.5:

Extension

Understanding that there is a limit to how well we can conduct an experiment is fundamental to being a scientist. Even if the experiment we're conducting is a small tabletop one or if we're using the Large Hadron Collider, there will always be errors. Anything we do potentially introduces errors in both our set up and the measurements we take. By trying to fully understand these errors, we can take steps to ensure that our measurements are as good they can possibly be and therefore make our results **reliable**. Have another read through the instructions and think about the experiment you've just done.

Extension 1-I. Imagine you were in a real lab, what are the potential sources of error? Write them in the corresponding box in your lab book too.

Answer 1-I:

Extension 1-II What effect could these errors have on our final conclusions?

Answer 1-II:

Extension 1-III How would we combine the errors in this experiment?

Answer 1-III:

Extension 1-IV How could we improve this experiment to account for statistical error?

Answer 1-IV:

Experiment 2 - Comparing attenuators

Preperation

In this section, we're going to investigate the effect that different materials have on the attenuation of gamma rays. We've already investigated lead but now we're going to investigate aluminium, copper and tin too. To start with, we're going to make a hypothesis. This is where we write down what we think will be the result of the experiment and therefore give us an aim to the measurement. Having an aim is a key part to any experiment, we need to know what question we're going to try to answer before we're able to investigate it! Don't forget to fill out the necessary parts of your lab book before you start and as you go.

To begin this part, simply scroll down on the website to Experiment 2.

Question 2.1. Of the four materials (aluminium, tin, lead and copper), which do you think will cause the most attenuation? Why? How about the least?

Answer 2.1:

Hopefully you still have your results from the first experiment, if not quickly repeat those steps now.

Experiment

Use the drop down box to choose another material. With the thickness at 0 mm, start a measurement. Record the data in your table. Now increase the thickness and take another measurement.

Question 2.2. What do you notice? How does this compare with lead?

Answer 2.2:

Take measurements with other thicknesses of your chosen material until you're satisfied with your results. Whilst doing this, decide a suitable range of thicknesses to get the results you require. You might need to increase the thickness by more than one step each time, try to find a balance between the number of measurements you're going to take to get a good picture of what's happening and the time it will require you to do so. Remember that you want a range of thicknesses up to the point where your number of counts are at least 20% of the original counts. (You might not be able to do this for all of them, just get as low as you can.)

Question 2.3. What are your findings?

Answer 2.3:

Repeat the measurements with the rest of the materials.

Question 2.4. At first glance, how do the materials compare?

Answer 2.4:

Data Analysis

Question 2.5. At roughly which distances are your number of counts half of where they started for each material? If you couldn't measure that, what do you estimate it would be?

Answer 2.5:

Hopefully you can see that different materials have different attenuation effects. Now we're going to look at our results and draw some conclusions. Use your answer to Question 5 to help you with this next part.

Question 2.6. What conclusions can you make? How do these compare with your original hypothesis?

Answer 2.6:

Question 2.7. How does this help us with radiation protection?

Answer 2.7:

Extension

In order to try and quantify our findings, we're going to bring in a new quantity, the **Attenuation Length**. To find this, look at your graph for a material and find the point at which the number of counts is half the number where they started.

In the next step, we'll be bringing in a mathematical operator known as the **Natural Logarithm** or ln. You may not have heard of this before and if so don't worry - we're not going to quiz you on it! You can use it with the 'ln' button on your calculator. To calculate the attenuation length we will use the equation

$$= \frac{\ln(2)}{x_{1=2}}: \qquad (1)$$

Here, (the Greek letter mu) is the attenuation length and $x_{1=2}$ is the thickness of material at which the number of counts is half of where they started - the numbers you wrote down in Question 5.

Extension 2-I. What are the attenuation lengths for each material? What are the units?

Answer 2-I:

Another method of finding is with a straight line graph. For this method, follow these steps:

1. Work out $\frac{I}{I_0}$ for each of your measurements. That is, the number of counts you measured divided by the number of counts with no attenuator.
2. Take the natural log of this quantity, $\ln \frac{I}{I_0}$
3. Plot $\ln \frac{I}{I_0}$ on your y axis and the thickness on your x axis

You can do this plotting on the graph paper we've provided at the end of this worksheet, excel or a similar spreadsheet program, or you can use FooPlot. To add points rather than a function, simply use the drop down menu in the yellow box on the right hand side and click 'points'. You can then add rows of x,y data as a column. An example of the data format is provided on the site.

Extension 2-II. Do you have a correlation? If so, what type of correlation do you have? If not, why not?

Answer 2-II:

If x is the thickness of your material, the equation of your graph is

$$\ln \frac{I}{I_0} = - \, x: \tag{2}$$

This means that the gradient of your graph should be $-$! To get this value we will need to draw a line of best fit. To do this with FooPlot, you can add a function in the form $mx + c$ and change the values of m and c until you get a line you think fits the trend well.

Repeat this process for your other materials.

Extension 2-III. What are the attenuation lengths of your materials?

Answer 2-III:

Now we have our two results, we need to assess which of the two methods we think is more **reliable**. Exercises like these will really help to build your critical thinking ability and your skills as a scientist.

Extension 2-IV. How do the two methods compare? Is one more reliable?

Answer 2-IV:

Extension 2-V. Why do some materials make better attenuators than others?

Answer 2-V:

Extension 2-VI. What other factors are important when deciding which material to use in order to shield a person from radiation? In which circumstances would they be important?

Answer 2-VI:

Extension 2-VII. Based on the mathematics you've been given, why would the gradient of your straight line graph be ?

Answer 2-VII:

Challenge courtesy of Jess Heaps

A manufacturer wants to conduct radiography on metal components in order to produce images so they can diagnose weld defects. They are building a new radiography booth and have asked you to provide radiation protection advice as part of the design stage. The radiography source to be used is ^{169}Yb with activity 185 GBq. When unshielded, the source produces a gamma dose rate of 4.8 mSv/hr at 1 metre [source: radprocalculator.com]. The source will be positioned at a minimum distance of 2 metres from the walls of the radiography booth. You have been asked to provide advice on the thickness of lead shielding required in order to reduce dose rates outside the external walls below 7.5 Svh/hr.

You can send your challenge answers in to us at hello@livnuclear.co.uk

Date:

Title:

Diagram of your setup

List of equipment + risks

Description of your method

Table of results

Sources of error

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73#8-($#41%'6%9#8-(.''0%:520-*(%;"1$#2$%<('5.=%:7;>??=%
:7;>@%*3,%;A:B