γ-spectroscopy

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1 Introduction and Theory

We had several objectives in this experiment. Firstly, we wanted to calibrate the scintillation detector so that CASSY LAB outputted γ-ray energy spectra; plots of the number of γ-ray photons reaching the detector; set time interval versus photon energy. We wanted to use the calibrated detector to then identify an unknown source by analysing its characteristic energy spectrum. Next we aimed to investigate the relationship between the transmission of γ-rays through an absorptive medium and the thickness of the medium. We hoped to do this by calculating the at attenuation coefficient μ for both lead and aluminium, thus verifying Lamberts Law. From this we also wanted to estimate the mean free path of γ-ray quanta in the two media. Finally we wanted to estimate the activity of a weak radioactive sample.

There are three routes by which unstable nuclei can decay; via the emission of an α-particle, a β-particle or a γ-ray photon. γ-rays are a type of electromagnetic radiation of extremely high frequency and are produced mainly by the spontaneous decay of atomic nuclei as they transition from a high energy state to a low energy state. γ-rays have a wide range of energies; from 10keV to 10MeV. In this experiment, γ-ray spectroscopy is used to identify different γ-ray sources and to investigate the way in which γ-radiation interacts with matter.

Most radioactive sources will emit γ-rays, as they often accompany α and β radiation. These emissions can be detected and analysed with a spectroscopy system, and a γ-ray energy spectrum can be produced. This consists of a graph of detected intensity versus γ-ray photon energy and consists of a number of peaks (spectral lines), usually in the shape of a gaussian distribution. Every γ-emitting nuclide has its own characteristic spectrum as different nuclides will produce γ-rays of different energies. Thus the spectra can be used to determine which emitters are contained in any source.

The energies of the emitted γ-rays are determined using a scintillation counter. This piece of apparatus emits light when γ-rays interact with the atoms in the crystals. These emitted light pulses are transformed into voltage pulses by a photomultiplier, where the intensity of the light produced is proportional to the energy deposited in the crystal by the γ-ray. CASSY LAB 2 is used to create the energy spectra. A plot of channel number versus number of events per set time interval is outputted by the programme. This can be calibrated to output energies on the x axis instead of channel number. This is achieved by inserting a known source into the detector so that the discrete energies of the emitted gamma rays are known. The spikes in the spectrum can be analysed, and the channel number that corresponds to the peak of the spike can be found. The energy that corresponds to this channel number is known and this is used to calibrate the spectrum.

Using an energy calibrated scintillation counter, the energies of the γ-rays emitted by any source can be measured and read directly from the outputted characteristic spectrum. As a result, unknown sources can be put in the detector and the energy associated with the spikes of the spectrum can be found, and thus used to identify the γ-ray source.

The way in which gamma rays interact with matter can also be investigated using a similar experimental setup and by placing sheets of aluminium and lead of known thicknesses between the γ-ray source and the detector. This investigation can tell us much about the material being used as the absorber, as well as the relationship between absorber thickness and the intensity of the transmitted gamma radiation. The absorption of γ-radiation when it passes through matter is the way in which the energy of the gamma photon is taken up by the matter. The electromagnetic energy is transformed into the internal energy of the absorber and the resulting reduction in the intensity of the γ-rays as they propagate through the matter by the absorption of some of the photons is known as attenuation. The permeability of the absorber is characterised by the transmission

$$T = \frac{R}{R_0}, \tag{1}$$

where R_0 is the initial count rate and R is the count rate when the absorber is placed between the source and the detector. The greater the transmission, the smaller the attenuation effect. It has been found that the transmission depends of the thickness of the absorber, x, and that as the thickness of the absorber increases, the transmission decreases. The relative decrease of the transmission is proportional to the absolute increase in absorber thickness;

$$\frac{\mathrm{d}T}{T} = -\mu \mathrm{d}x, \tag{2}$$

where μ is the constant of proportionality called the linear attenuation coefficient. Integration of this equation leads to the Lambert law:

$$T = \exp\left(-\mu x\right). \tag{3}$$

The transmission can also be given by

$$T = \frac{\eta}{\eta_0}, \tag{4}$$

where η is the area under the peak on the gamma energy spectrum of a radioactive source (^{137}Cs in this experiment). Thus, a plot of absorber thickness versus area under the peak on the energy spectrum should result in a graph clearly illustrating exponential decay, and from which the attenuation coefficient can be estimated. The attenuation coefficient of a material characterises how easily it can be penetrated by a beam of light, sound etc. A large attenuation coefficient means that the beam is quickly attenuated (weakened) as it passes through the medium, and a small attenuation coefficient means that the medium is relatively transparent to the beam. The attenuation coefficient is related to the mean free path for the gamma quanta in the absorbing material by

$$\mu = \frac{1}{\lambda}, \tag{5}$$

where λ is the mean free path. From this the mean free path of a material can be estimated.

1.1 Detection of Weak Radioactivity Sample in a Marinelli Beaker

The beaker encloses the scintillation crystal detector completely to ensure well defined geometry of measurement. A different calibration is needed. A weaker radioactive sample is used as the detection probability of the sample depends on γ-ray energy. Although the effect of background radiation is minimised by the lead shielding placed around the measuring arrangement, it still has impact and first needs to be taken from the γ-ray spectrum of the weak source. It is worth noting that an x-ray peak may appear on the spectrum due to x-rays stimulated by interaction of γ-rays and the lead shielding.

2 Experimental Method

Figure 1: Experimental setup.

This experiment involves two similar setups, each with a separate scintillation counter for calibration. The CASSY LAB 2 data acquisition unit and appropriate software was used. A radioactive sample was set around the scintillation counter inside a lead shield. The scintillation detector was connected to the input of CASSY LAB 2 and a laptop with specific software installed was used to display and process the data.

The laptop, power supply of the CASSY LAB 2 unit and the high voltage power supply were turned on. CASSY LAB 2 was opened on the desktop. The measurement parameters were altered such that the measuring time was set to 200 seconds with 1 second increments. The voltage on the high voltage power supply was set to 0.65kV and tuned until the spectrum covered most of the channels.

The first setup contains a mixed radioactive source of ^{137}Cs. The most intensive spectral line corresponds to this isotope. A gaussian curve was fit to this spectral line using the fit function selection within the menu of actions in CASSY LAB 2. The centre of the spectral line and the line width were then outputted. Selecting settings→input A1→channel n_a and then going to the group box named energy calibration, a check mark was set in the line global for all channels. Two points were entered (0,0) and (the channel number corresponding to the centre of the peak, energy of gamma ray emitted by ^{137}Cs nuclide). This was used to calibrate the detector. The x-axis was renamed E_a and the spectrum was redrawn by the programme in the energy scale. For the second set up, a weak radioactive source was used for the calibration. When using a weak source, the source is put in a Marinelli beaker which encloses the scintillation crystal detector completely. The same process was applied for the calibration for part two.

The spectrum for the background radiation was recorded such that it could later be subtracted from all measurements as for a weak source, the background radiation has a considerable affect on the spectrum.

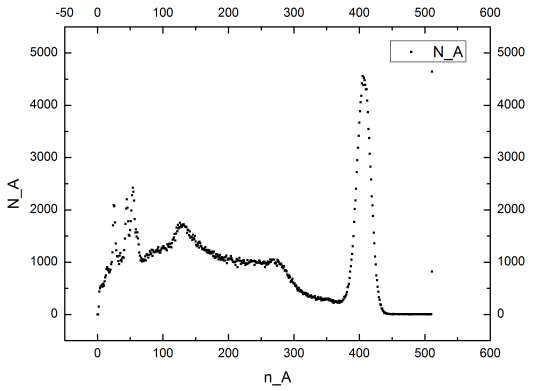
The second setup was used for the identification of an unknown γ-ray source. The known radioactive source was mounted in the Marinelli beaker around the detector and the gamma spectrum was measured in the pre calibrated scale. The peak was approximated by a gaussian curve and the central point and area were calculated. The energies of any spectral lines were estimated and the relative probabilities were found.

An unknown source was inserted mounted in the Marinelli beaker around the detector and any spectral lines were analysed i.e., the energies and areas were estimated. The results were used to identify the unknown source.

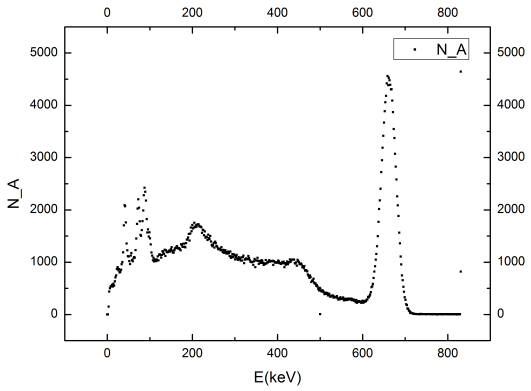
For the third part of the experiment, the energy spectra were recorded for aluminium and lead absorbers of varying thickness in order to verify Lambert's law. Sheets of aluminium and lead were used in combination with each other in order to obtain a series of values of the transmission T for different thicknesses.

3 Results and Analysis

The ^{137}Cs radiation source and the Marinelli beaker were both used for calibration. The spectra were obtained and are shown below. It is worth noting the peak at the end of each graph. The reason for the peak is because the experiment was carried out with a finite number of channels, and any gamma radiation corresponding to higher channels were all registered in the highest one.



(a) Calibration of the ^{137}Cs source.



(b) Calibration of the Marinelli beaker.

The spectrum of the unknown source was obtained and the spectral energy was determined. The unknown source was identified to be ^{40}K. The activity of the ^{137}Cs was taken to be 5kBq as read from the Marinelli beaker. From this the activity of the ^{40}K was measured to be 0.33kBq. Although this was only 11% of the activity, since the remaining activity takes the form of β-decay, so the activity of ^{40}K was determined to be 2.98kBq. The relative probability was determined to be 100%, since the other peak on the graph was not caused by ^{40}K, but by the lead shielding surrounding the scintillation counter.

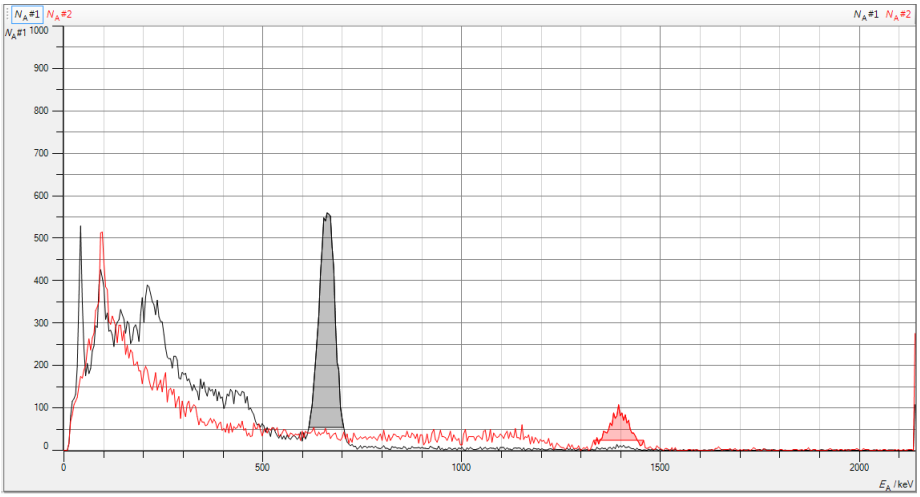


Figure 3: Spectrum of the unknown source.

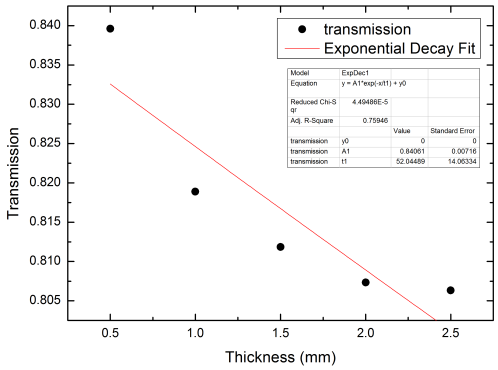
The γ-spectra for various thicknesses of aluminium and lead were then recorded. The area of the spectral peaks, η, was measured using CASSY LAB. The transmission T was plotted against the absorber thickness d in order to verify Lambert's law and determine the linear attenuation coefficient for aluminium and lead and hence determine the mean free path for the γ-quanta. It was observed that the energy of the γ-quanta did not change with the absorber thickness but the area of the spectral peaks did.

$d\,(\mathrm{mm})$	$\eta\,(\mathrm{a\,u})$	$T = \frac{\eta}{\eta_0}$
0	126609	
0.5	106310	0.8396
1.0	103678	0.81889
1.5	102788	0.81185
2.0	102218	0.80735
2.5	102090	0.80634

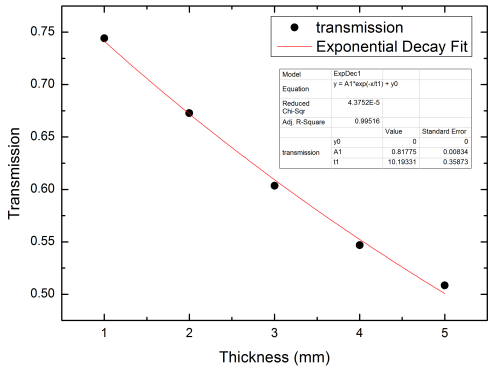
(a) γ-spectra for an aluminium absorber.

$d\,(\mathrm{mm})$	$\eta\,(\mathrm{a\,u})$	$T = \frac{\eta}{\eta_0}$
0	126609	
1	94211	0.74418
2	85185	0.67280
3	76424	0.6036
4	69231	0.54681
5	64379	0.50849

(b) γ-spectra for a lead absorber.



(a) Aluminium absorber.



(b) Lead absorber.

From the graphs linear attenuation coefficients of $\mu = 0.019 \pm 0.005\text{mm}^{-1}$ and $\mu = 0.098 \pm 0.003\text{mm}^{-1}$ were obtained for aluminium respectively, and hence the mean free paths were determined to be $\lambda = 52 \pm 4\text{mm}$ and $\lambda = 10.2 \pm 0.4\text{mm}$.

4 Discussion and Conclusions

The ^{137}Cs source was used for calibration purposes, and in doing so, the unknown source was successfully identified as ^{40}K. The activity of this source was determined to be 2.98kBq.

Values of $0.019 \pm 0.005\text{mm}^{-1}$ and $0.098 \pm 0.003\text{mm}^{-1}$ were obtained for the linear attenuation coefficient for aluminium and lead respectively, giving mean free paths of $52 \pm 4\text{mm}$ and $10.2 \pm 0.4\text{mm}$. The errors in the linear attenuation coefficient and mean free path for aluminium was larger than the errors for lead, possibly because a better fit was obtained for the data obtained for lead. One possible reason for this is that the aluminium was not made of perfect sheets. Small dents in the sheets could result in air gaps between the aluminium, reducing the accuracy of the experiment.