Gamma Ray Spectroscopy with Beta Particles in Magnetic Fields

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This report dissects Gamma rays and it's related spectrum's for various sources and how the intensity is affected by different materials. A look into the properties of Beta Particles in Magnetic Fields allow the decay curves of various sources to be produced. In deeper analysis, it is found that banana chips that are coated in honey may contain Caesium as well as Potassium due to the testing of atomic bombs during the Cold war.

1 Introduction

Gamma ray spectroscopy is a quick and non destructive analytical technique that can be used to identify various radioactive materials. Spectroscopy is the study of the emission and absorption of electromagnetic waves related to the dependence of the wavelength of the radiation emitted[5]. In this report, gamma rays are being investigated. Gamma rays are part of the electromagnetic spectrum. They have the shortest wavelength (100pm) and the highest energy. They have a frequency of around 10^{19}Hz[1]. Gamma rays are produced by four different types of nuclear reactions. Nuclear fusion, fission, alpha decay and gamma decay. They are created by the disintegration of radioactive atomic nuclei and in the decay of some sub atomic particles[4].

Gamma rays were first observed by French Chemist Paul Villard in 1900. Mostly going unnoticed in the scientific community, Paul Villard was an unsung hero of the second scientific revolution. Whilst doing investigations with radiation from radium he noticed them. It was only after this that the Curies and Rutherford started their experiments. Ernest Rutherford was a scientist from New Zealand and a few years after Villard, he coined the term 'Gamma Rays' for the phenomenon he witnessed in 1914.[6]

Gamma ray spectroscopy is a very useful tool in the modern world. It's used in uranium exploration, geological mapping, mineral exploration and environmental monitoring. In 2006 phosphorous deposits in Syria were found by air borne Gamma ray surveying. It shows that useful products for the continuation of the world can be found, without destroying the land we live on in the process.[5]

Another form of radiation is Beta Particles. Discovered by Ernest Rutherford in 1899 these high energy electrons are very useful in today's world. Also known as positrons, Beta particle velocity is incredibly high. They reach speeds close to the speed of light. They are much less ionising than alpha particles as well. Beta decay occurs in nuclei that have too many neutrons to achieve stability. These excess neutrons turn into protons and electrons. However the proton stays and the electron is ejected. Beta Particles have a mass of around one thousandth the mass of a proton.[8][9]

These particles are used extensively in modern society. They are common in factories for quality control. Their penetration ability allow for detection of thickness to be useful. They can be used for the treatment of eye and bone cancer. In medical apparatus, it's also used as an aid in PET scans as a tracer. In a more obscure case, it is used in emergency lighting for buildings.[8][9]

In this investigation both of these topics will be researched. In the Spectroscopy experiment a scintillation counter will be used to detect gamma rays from a variety of different radioactive materials. In the Beta experiment, an investigation into the origins and properties of beta particles will take place. Putting these particles into magnetic fields demonstrate the properties and will also allow the energy spectrum to be calculated. With the aid of error and data analysis these concepts will be accurately recorded and ultimately discussed.

2 Theory

2.1 Gamma Ray Spectroscopy

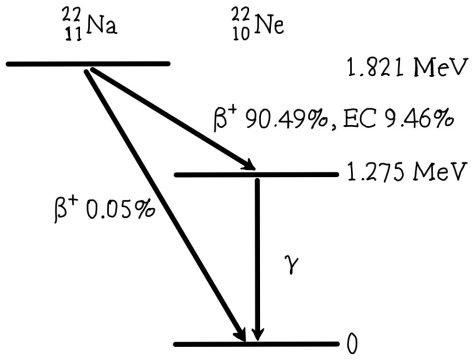
Gamma rays are produced in the disintegration of radioactive atomic nuclei. They are also produced in pair annihilation in which an electron and a positron vanish and two photons are created. These photons emitted are travelling in opposite directions and must have an energy equivalent to the rest mass energy.[3] When trying to understand what different atoms produce when disintegrating, a decay scheme is very useful. A decay scheme allows for a detailed 'route' of how an atom will transform from one atom to another via a decay. These decays will need the excretion of gamma ray, beta particle or alpha particle. In this experiment gamma rays are being discussed so materials where these are produced will be investigated.

The way these particles are measured is using a scintallator. A scintillator works by using a material called a phosphor to react with the emitted gamma rays. The phosphor when struck, releases electrons in the form of photons due to the excitement of the material due to the gamma ray interacting with it. The photons are then detected by a photo-multiplier tube that then converts this into an electric pulse. Through a multi channel analyser it turns the electrical pulse into a signal that can then be fed into the computer software. From the pulse height spectroscopy is done. The current pulses are proportional to the kinetic energy of the incoming particle. From this, a spectrum is produced showing peaks from the source placed above it.[14]

Na-22 is one of the materials being tested. In Na-22 it has a decay scheme that requires positron

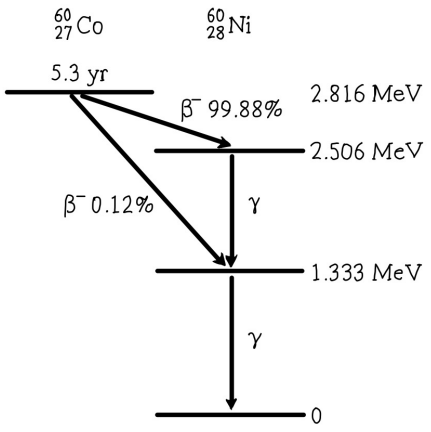
emission. This results in Ne-22 being formed. The production of this emits a 1.275 MeV gamma ray. As well as this, some of the positrons produced annihilate and as discussed before this produces two 511 KeV gamma rays as well that are fired off in opposite directions.[1] The decay scheme is shown on figure 1:

Figure 1: Na-22 decay scheme



The second material is Co-60. It initially decays by β^- but these particles don't reach the detector due to the low energy it has. If it had a higher energy, it could emerge from the sealed container that holds the radioactive source.Co-60 decays into Ni-60. This nucleus relaxes to it's ground state and produces two gamma rays having energies of 1.173 MeV and 1.333 MeV. These rays are emitted almost simultaneously.[1] The decay scheme is shown on figure 2:

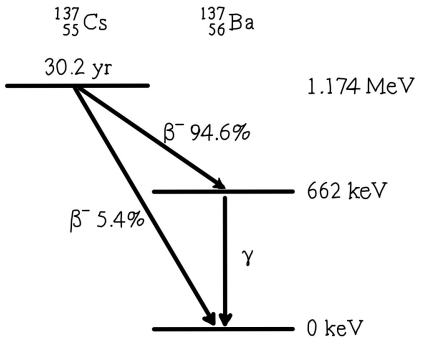
Figure 2: Co-60 decay scheme



The final material being studied is Cs-137. This decays by β^- as well and excites to a state of

Ba-137. This emits a 662 KeV gamma ray so it can reach it's ground state. As discussed before the β^- particles don;t have enough energy to protrude through the sealed container it is in.[1] The decay scheme is shown on figure 3:

Figure 3: Cs-137 decay scheme



Another important piece of theory needed for this experiment is how the spectrum will be read. Using a Gaussian fit method it will calculate the peak of the curve. This peak will correspond to the intensity of the peak. The software used for the experiment can do this automatically. A Gaussian fit equation looks like:

$$f(x) = ae^{\frac{(x-b)^2}{2c^2}} \tag{1}$$

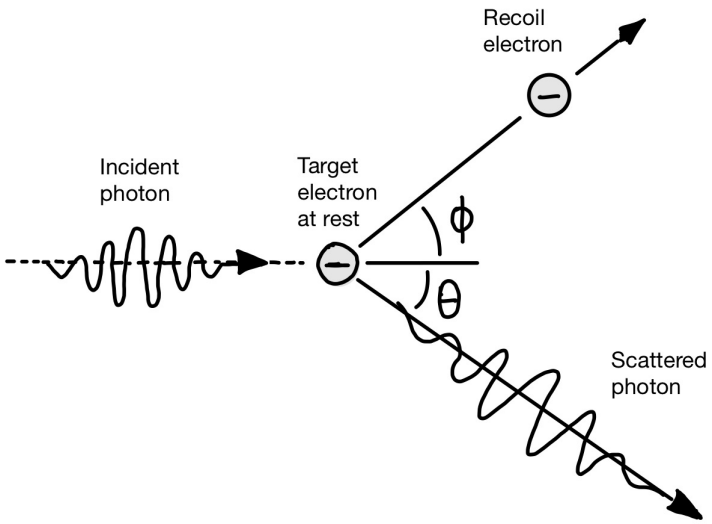
where a is the height of the curve, b is the position of the centre of the peak and c is the standard deviation. These intensities can then be plotted on a log plot to find the attenuation coefficient. This equation is:

$$I = I_0 e^{-\mu x} \tag{2}$$

where μ is the attenuation coefficient. Rearranging this it is clear that a plot of $\ln(\frac{I}{I_0})$ vs distance is needed. Then to calculate the attenuation coefficient, the gradient of this plot is calculated. Tools like python matplotlib features really help in this part of the process.

Later on in the experiment, the Compton effect is used to understand the other peaks on the spectroscopy graph. This is the inelastic scattering of photons by electrons. It shows the process for relativistic scattering and shows the nature of particle photons.[10] This is very useful in this experiment because part of the decays produce photons. A simple Compton effect diagram is shown below in figure 4:

Figure 4: Compton Scattering Diagram



The energy of the scattered photon related to a the energy of the incident photon can be shown by equation 3 below[1]:

$$E = \frac{E_0}{1 + \frac{E_0}{m_0 c^2}(1 - \cos\theta)} \tag{3}$$

One last thing in this theory subsection is to briefly refer to the term internal conversion. For the decay scheme of Cs-137 (figure 3), the excited state has a long half life which allows other mechanisms for transitions. One of these mechanisms is internal conversion. It means when the excited state loses it's energy by ejecting an atomic electron. The removal of an electron creates a cascade of atomic electrons dropping down into vacant states to fill the excited atom shells. Doing this creates X-rays in the process.[1] This will be very useful to understand later on when understanding the peaks with minimal energy on the spectrum.

2.2 Beta Particles in Magnetic Fields

Beta particles are high energy,high speed electrons or positrons that are ejected from the nucleus during beta-decay. This normally happens in nuclei that have too many neutrons to achieve stability. Beta particles are interesting because they either carry a single negative charge or a single positive charge.

This means they can be quite volatile when entering for an example, a magnetic field. Beta minus particle emission happens when the ratio of neutrons to protons in the nucleus is too large. The excess neutron is turned into a proton and electron.[2]

In doing this, the element changes to a different one. Gamma ray emission discussed earlier accompanies the emission of beta particles because if the beta particle ejection doesn't get rid of the extra energy in the nucleus, it will release the excess energy in the form of a gamma ray.

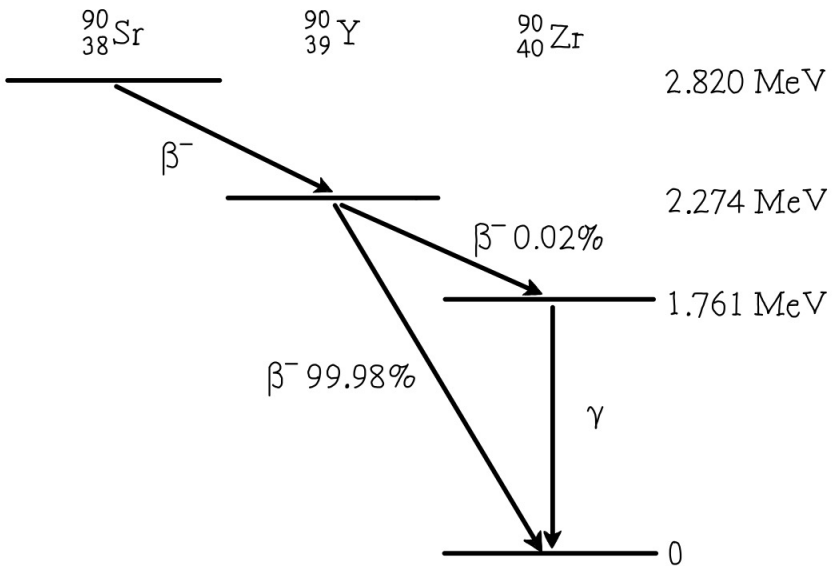
$$\beta^- = n \rightarrow e^- + p + \overline{\nu_e} \tag{4}$$

$$\beta^+ = p \rightarrow e^+ + n + \nu_e \tag{5}$$

Looking at these processes it is clear to see that they can be deflected by a magnetic field due to the charge on them. The strength of the magnetic field required to produce a certain deflection depends on the beta particles kinetic energy. This then helps the aid of this experiment as the you can use this to measure the energy spectrum of the particles.

The elements that will be focused on during this experiment will be Sr-90 and Na-22. The reason for this is that one emits an electron and one of them emits a positron. The Sr-90 half life is about 28.5 years. The supply of the β^- particles are controlled by the slower decay. The energy spectrum that should be produced should show a large curve. The decay scheme for Sr-90 is shown in figure 5 below.[2]

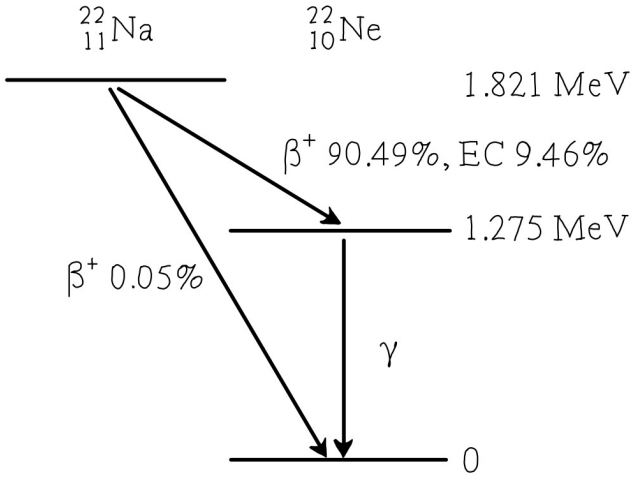
Figure 5: Sr-90 decay scheme



The decay scheme for Na-22 shows hints of electron capture as well as positron emission. The

Na-22 has a much lower half life of only 2.6 years. Over time this highlights that the Na-22 source will become weaker much faster than the Sr-90 one.[2] The decay scheme for Sodium is shown in figure 6:

Figure 6: Sr-90 decay scheme



The positrons and electrons emitted are then found in a beta spectroscope. This scientific instrument works by creating a magnetic field. When the beta particles enter through the aperture they are deflected by the magnetic field. There are a series of barriers inside the spectroscope so only the particles undergoing circular motion and with a specific radius aperture pass through the exit aperture[2]. The particles that make it through are met with a Geiger Muller tube. This works by detecting alpha,beta or gamma rays through a low pressure gas. The gas becomes momentarily conductive when ionised through the "Townsend avalanche effect" thus conducting a current through the gas. This event of conduction is measured per unit time as counts.[11]

In the calibration preliminary experiment, a hall probe is used to measure the magnetic field. A hall probe works detects the presence of a magnetic field compared to a predefined threshold for magnetic flux. When a suitable magnetic field is detected the switch turns on and when the field is removed the switch turns off.[12]

When the emitted electrons or positrons enter the magnetic field they undergo a Lorentz force of magnitude qvB perpendicular to both the velocity and field. The Lorentz force is defined as the "The force exerted on a charged particle moving with velocity though an electric and magnetic field."[13]

When undergoing circular motion the Lorentz force provides a centripetal force shown in equa-

tion 6 has a momentum of p = qbr.[2]

$$qvB = \frac{mv^2}{r} \tag{6}$$

The whole premise of this experiment is to plot the energy spectrum. The energy spectrum for beta decay can be shown that the number of beta particles per unit energy range is:

$$\frac{dn}{dE} \propto E\sqrt{E^2 - m_0^2c^4}(E_0 - E)^2 \tag{7}$$

This equation is formed using the relativistic relationship in equation 8 [2]:

$$E^2 = p^2c^2 + m_0^2c^4 \tag{8}$$

From this the kinetic energy of the charged particle can be written as [2]:

$$Q = \sqrt{(qBrc)^2 + m_0^2c^4} - m_0c^2 \tag{9}$$

When the kinetic energy is calculated the counts vs the kinetic energy is plotted to give the energy spectrum of the graph where the calculation of the initial kinetic energy can be discovered.

3 Methods

3.1 Gamma Ray Spectroscopy

To start the sources of radiation should be kept as far away as possible from the scintillation counter to reduce anomalies in the results. Even if the source is kept sealed in a container there is still a small chance that it could have some affect on the results. When setting the source into the holder it should be at a known distance away from the counter. This will allow consistency when testing the other sources.

3.2 Gamma Ray Spectrum Calibration

Cassy Lab software is used to measure the counts and plot a spectrum. However, when turning on the software it isn't calibrated to an ideal position for the variables that are being tested. To calibrate, a source with known peaks is measured and then the peaks are then shifted using the online software. For this report the calibration of Na-22 was conducted. There are two transitions/peaks that are observed. This when changed will shift the peaks into the correct places on the spectrum. When measuring energy this is very important.

As well as a peak calibration there needs to be a voltage calibration as well. Too little voltage and the peaks won't appear and too much voltage and the peaks won't appear. There needs to

be a 'sweet spot' that needs to be found. Using Co-60, conduct tests by altering the voltage on the power supply until all the important peaks are in view. The important peaks can be found by checking with an accurate spectrum of the source you are measuring. Co-60 is used as this has the furthest peak on the spectrum so if that source is visible the other sources will also be seen. Once the system has been calibrated there are two last points before measuring data. The x axis should now read energy and the measurement time should be long enough to account for statistical noise and to accumulate enough counts. One hundred seconds is what is used in this experiment.

3.3 Gamma Ray Spectra and Peaks

Now that the system has been calibrated the measurements can begin. The first part is to measure the maximum peaks for each of the sources. Placing the sources into the holder and running the counter will produce a gamma ray spectra. After the timer has finished Cassy-Lab has functions where it can read the peaks. It can find it using integration, a manual pointing option or a Gaussian fit. Integrating the peaks can cause a series of errors due to background radiation so a Gaussian fit using equation one works the best. When this is measured the standard deviation should also be recorded. Once Na-22, Co-60 and Cs-137 have all been recorded, a spectra has been produced and the peaks have been calculated refer to the theoretical values to check how accurate they are. If they aren't accurate then the calibration step may not have been done correctly or there is a fault in the setup. If they are similar then this proves the calibration step was a success.

3.4 Attenuation of Gamma Rays

This part of the experiment focuses on how different materials affect the attenuation of gamma rays. The same process as the previous experiment happens but each source is repeated for four different materials. These are Lead, Steel, Aluminium and Bronze. These metals are in the form of thin square sheets that can be placed on top of a holder that the scintillator is under. This in turn creates a barrier where the gamma rays have to pass through to reach the counter and therefore decreasing the energy of the gamma rays. Adding a new sheet of the material being tested and finding the peak allows the attenuation coefficient to be calculated. Once this has been completed for each material and source there should be a series of tables that have thickness and the number of counts recorded at that given thickness for the peak on the spectrum. As well as this the standard deviation is also calculated again for each measurement.

Once these values have been recorded graphs can be plotted on python. Using equation two a log plot can be produced to calculate the attenuation coefficient. This rearrangement of the equation has the the x axis being thickness and the y axis being $log(\frac{I_0}{I})$

$$log(\frac{I_0}{I}) = \mu x \tag{10}$$

Plotting a graph for each of the materials and sources and finding the gradient of each one will give the attenuation coefficient for each of the materials and sources. This creates a large data set that can be used in practice to understand how different materials work better at blocking oncoming hazardous gamma rays or any ionizing radiation.

3.5 Further investigation on the mixed source spectrum

The last part of the experiment doesn't involve any measurements but is more of a way to understand the different peaks in the mixed source. It is clear that Cs-137 is in the mix but what else is creating the other peaks? Using equation 3, two of the peaks can be calculated. Using the angle on Compton scattering that creates the smallest energy will give one of the peaks. Then with this a calculation of $E_0 - E$ can be calculated which is another peak. E_0 is the energy peak of Cs-137 calculated in part 2.

In the theory section the idea of internal conversion was mentioned. This was where during a decay, the excited state loses it's energy by ejecting atomic electrons. This results in a cascade of electrons returning to the vacant states and emitting X-rays. These X-rays are what the peaks furthest to the left on the spectrum are.[2] One last part of the mixed spectrum is the plateau region after the X-ray section and before the peaks of Cs-137 etc. The scintillator can pick up background radiation so this is the main cause of this plateau. This part of the experiment now makes the mixed source easier to understand as all the peaks are a known variable. With all these part of this experiment the gamma ray spectrum's have been calculated and tested using different outside variables such as materials being placed in front of them.

3.6 Beta Particles in Magnetic Fields

3.7 Calibrating the Electromagnet

The main reason that calibrating the electromagnet is necessary is to prove that whatever polarity the equipment is, it will still give the same results, except one will be negative and the other positive. The way this is achieved is by measuring the magnetic field vs current. Starting at two Amperes the magnetic field is measured using the hall probe. After two amperes go down in 0.1 Amperes until zero Amperes. After switch the polarity and go from zero Amperes to two Amperes. The magnetic field is measured in 'mT'. Once this data has been calculated, using Python, plot the currents vs magnetic field. This should produce a linear line of best fit. This proves that the electromagnet is calibrated and this means that for the next part of this experiment measurements can be done in one polarity. This is useful as it shows when measuring a positron emitter later on, it doesn't alter the results.

3.8 Measurements of Radioactive nuclei

Strontium and Sodium are measured in this part. Set up the electromagnet and the holder to put the radioactive nuclei. With the open hole in the spectroscope the source is placed in the hole. Now with the Geiger Muller counter, make sure the gate time is at one hundred seconds for maximum absorption. Like the calibration experiment, measure from zero to two amperes. Starting at zero press the start button on the counter and measure the counts. Once this has been measured repeat at 0.1 intervals up until two Amperes. For strontium it has a negative charge on the electron so the polarity needs to positive for attraction of the source. For sodium it emits a positron so the polarity needs to be switched to negative for the same reason.

From the calibration experiment magnetic fields were measured at different currents. Using these you can convert magnetic field to kinetic energy using equation 9. q is the charge, B is the magnetic field, r is the radius, c is the speed of light. m_0 is the mass. Once kinetic energies have been calculated the decay curve of kinetic energy vs counts are plotted. From this you can calculate the max kinetic energy the particle has. From this compare to theoretical graphs.

4 Gamma Ray Spectroscopy Results

4.1 Gamma Ray Spectrum Calibration

Starting with the Na-22 spectrum first, the two peaks were reading at 760 KeV and 1760 KeV. These peaks were shifted to fit the theoretical spectrum peaks. These were altered to 511 KeV and 1274 KeV. Once this is done the voltage calibration was completed. Trials were done at 0.65kV,0.70kV,0.75kV,0.80kV,0.85kV but the final chosen value was 0.90kV. Once these calibration steps were completed, the source spectrum's were perfectly aligned. This is shown here:

Figure 7: Na-22 Calibrated Spectrum

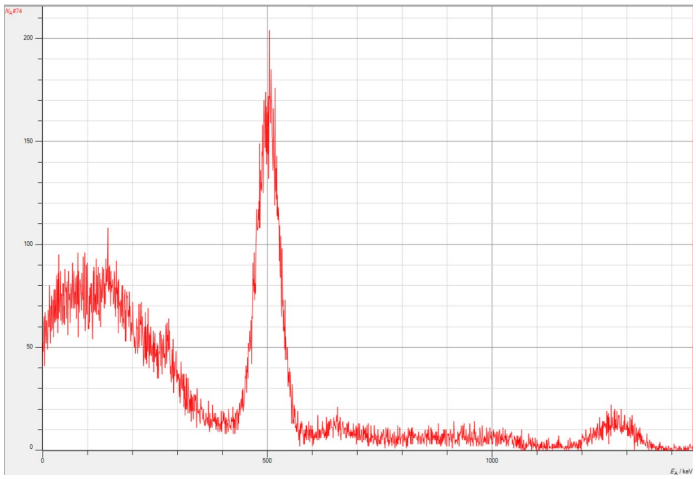


Figure 8: Co-60 Calibrated Spectrum

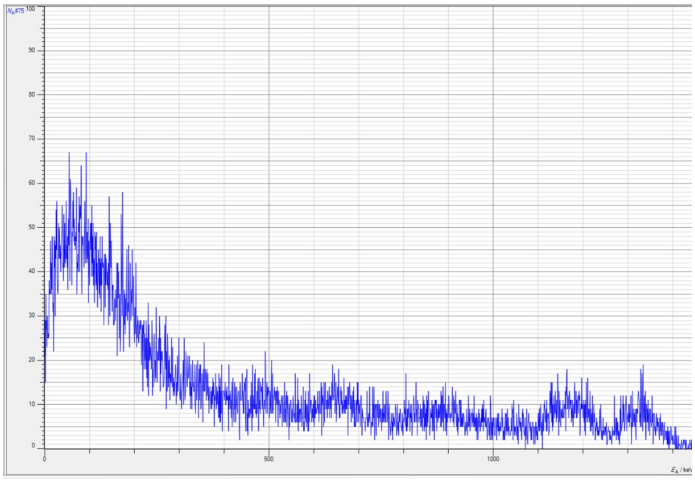
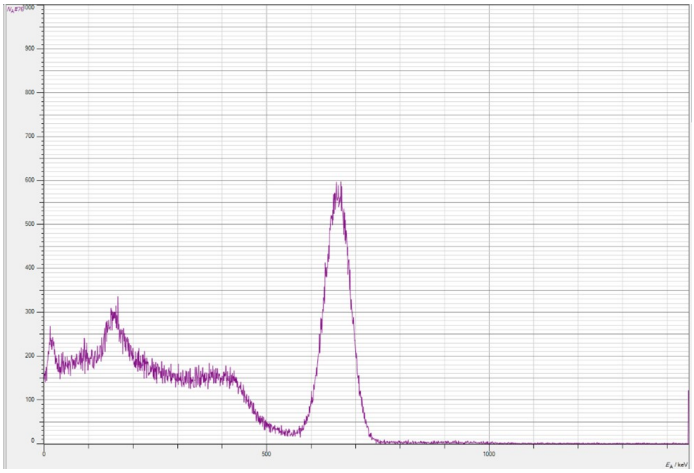


Figure 9: Cs-137 Calibrated Spectrum



4.2 Gamma Ray Peaks

This section of the results will show the values of the peaks on the spectrum's. These as discussed before were found using the Gaussian fit function. These values can then be compared to theoretical literature values and then can be used for resulting investigations on this experiment. These values are shown in the table below. The standard deviations will be calculated in the error analysis where a discussion on how accurate the data is to the theoretical data will also take place. Having these values will now aid in the attenuation experiment.

Table 1: Table of peaks for each spectrum with Theoretical values

PEAKS FOR SOURCES(KeV)		
Na-22	Co-60	Mixed Source (Cs-137)
507.9	1179.4	663.4
1277.8	1325.9	N/A
THEORETICAL PEAKS FOR SOURCES(kEv)		
Na-22	Co-60	Mixed Source(Cs-137)
511	1173	662
1275	1333	N/A

4.3 Attenuation of Gamma Rays

There is a lot of data in this section. For the ease of reading I have refrained from putting in all my graphs that show the calculations for the attenuation coefficient. The tables for sodium cobalt and the mixed source for each material is shown below:

Table 2: The Thickness intensity relations for Sodium

SODIUM							
LEAD		STEEL		ALUMINIUM		BRONZE	
Thickness (cm)	Intensity	Thickness (cm)	Intensity	Thickness (cm)	Intensity	Thickness (cm)	Intensity
0.00	297.5	0.00	304.9	0.00	299.9	0.00	196.6
0.10	198.2	0.10	228.1	0.044	243.1	0.05	150.5
0.20	172.2	0.20	214.2	0.099	237.6	0.1	144.2
0.30	146.8	0.30	202.6	0.141	238.1	0.15	140.1
0.40	128.1	0.40	187.7	0.185	233.8	0.2106	135.0
0.50	113.7	0.50	174.6	0.231	229.0	0.2701	129.5

Table 3: The Thickness intensity relations for Cobalt

COBALT							
LEAD		STEEL		ALUMINIUM		BRONZE	
Thickness (cm)	Intensity	Thickness (cm)	Intensity	Thickness (cm)	Intensity	Thickness (cm)	Intensity
0.00	20.1	0.00	19.1	0.00	19.0	0.00	13.0
0.10	17.7	0.10	18.8	0.045	18.5	0.0595	12.6
0.20	17.0	0.20	18.4	0.091	17.7	0.195	12.6
0.30	16.9	0.30	17.3	0.135	19.4	0.245	12.2
0.40	16.0	0.40	17.0	0.180	18.9	0.295	12.0
0.50	13.9	0.50	16.4	0.222	17.5	0.345	11.9

Table 4: The Thickness intensity relations for the mixed source

MIXED SOURCE (Cs-137)							
LEAD		STEEL		ALUMINIUM		BRONZE	
Thickness (cm)	Intensity	Thickness (cm)	Intensity	Thickness (cm)	Intensity	Thickness (cm)	Intensity
0.00	743.5	0.00	749.9	0.00	756.6	0.00	740.2
0.10	684.9	0.10	712.1	0.045	745.3	0.0595	718.5
0.20	609.9	0.20	675.8	0.091	735.8	0.1201	702.6
0.30	547.7	0.30	641.9	0.156	722.2	0.1701	675.4
0.40	499.6	0.40	613.2	0.172	731.7	0.2201	659.2
0.50	451.0	0.50	575.7	0.216	718.6	0.2701	631.2

From these values being documented Python was used to find the attenuation coefficient using the log plot graphs. These can be found in the appendix but an example of what they look like is shown below:

Figure 10: Attenuation Coefficient Graph Example 1

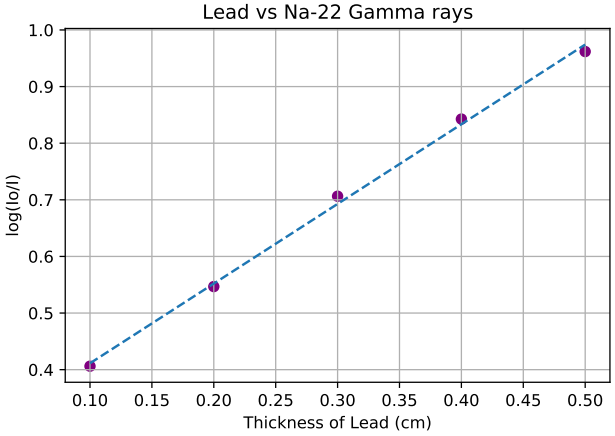
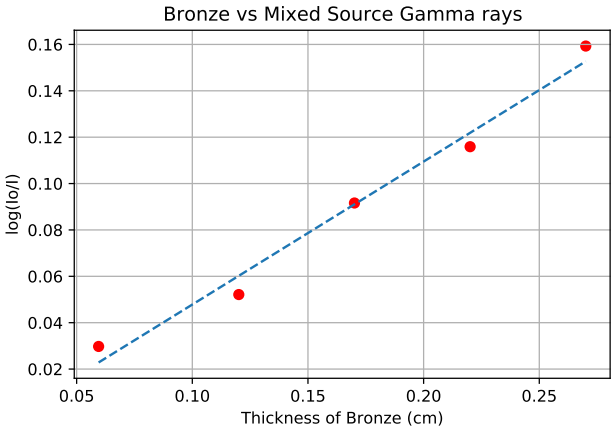


Figure 11: Attenuation Coefficient Graph Example 2



From these graphs the attenuation coefficient can be calculated by finding the gradient. The table below shows the value that was obtained from the experiment: These values obtained

Table 5: Attenuation Coefficient Values for Different Sources and Metals

SODIUM (507.9 KeV)			
LEAD	STEEL	ALUMINIUM	BRONZE
Obtained Value(1/cm)	Obtained Value(1/cm)	Obtained Value(1/cm)	Obtained Value(1/cm)
1.407	0.667	0.296	0.664
COBALT(1179.4 KeV)			
LEAD	STEEL	ALUMINIUM	BRONZE
Obtained Value (1/cm)	Obtained Value(1/cm)	Obtained Value(1/cm)	Obtained Value(1/cm)
0.544	0.352	0.264	0.220
MIXED SOURCE (Cs-137) (663.4 KeV)			
LEAD	STEEL	ALUMINIUM	BRONZE
Obtained Value(1/cm)	Obtained Value(1/cm)	Obtained Value(1/cm)	Obtained Value(1/cm)
1.035	0.522	0.197	0.617

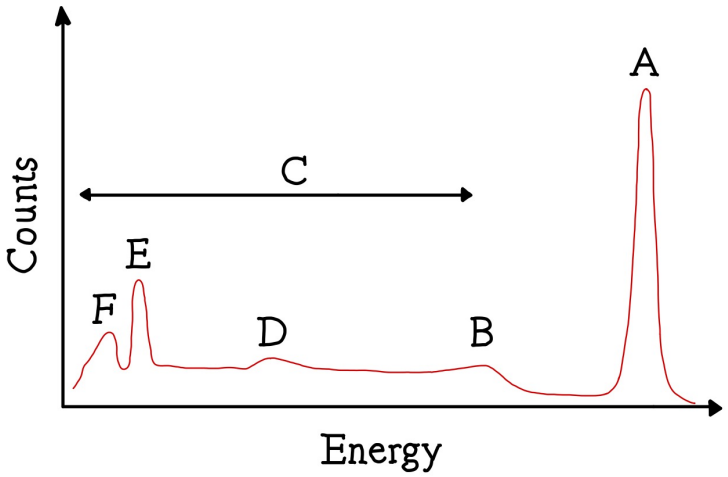
show how drastic materials can change alter the intensity of the gamma rays to pass through.

4.4 Further Investigation of the Mixed Source

After all of these experiments there were parts of the spectrum's that weren't identified. Parts that could be linked to background radiation but also could be due to other things. In this subsection these parts will be discussed in detail with the use of the Compton effect.

During this experiment there has been focus on just the sharp total absorption peak. In a spectrum there is a lot of peaks that can be linked to other sources. Here is an example image of what a standard mixed source spectrum should look like:

Figure 12: Example of a standard Mixed Source Spectrum



So far peak A has been identified. Peak E is another source listed as Am-241 as this has a theoretical value of 59.5KeV. The rest of the peaks in the list are actually to do with the decay of peak A (Cs-137). In the theory section there was discussion of the Compton effect. This is described as the inelastic scattering of photons by electrons. To understand what Peak D is the use of the Compton scattering equation is used (equation 3). To find D we need to find the minimum value of E. This is when the scattering of photons has an angle of 180 degrees. E_0 in this equation is the value of peak A. The equation is shown below:

$$E = \frac{663.4}{1 + \frac{663.4}{511}(1 - \cos 180)} \tag{11}$$

The value of E is 184.5 KeV. This is then Peak D on the graph above. To find peak B the max kinetic energy acquired by an electron is need to be found. This is simply Peak A - Peak D which is:

$$663.4 - 184.5 = 478.9KeV \tag{12}$$

Now Peaks A,B,D and E have been found. C on the example graph is a plateau region where the counts dies down before the large peak at point A. This is due to the scintillator being sensitive to both gamma rays and high energy electrons. It shows the electron dispersion instead of gamma rays. It could also be due to anomalies in the scintillator counter as Compton scattering takes place anywhere that gamma rays pass through.

The only peak left to discover is Peak F. In theory section the topic of internal conversion was discussed. Due to an unusually long half life other transitions can be possible. This peak is consequently a X-ray peak. So all the peaks in a mixed source mean something. Not only background radiation but also due to mechanisms by electrons and the Compton effect. This just shows that it is useful to not just focus on one peak when investigating a mixed source as you could just find something you didn't expect.

5 Beta Particles in Magnetic Fields

5.1 Calibrating the Spectroscope

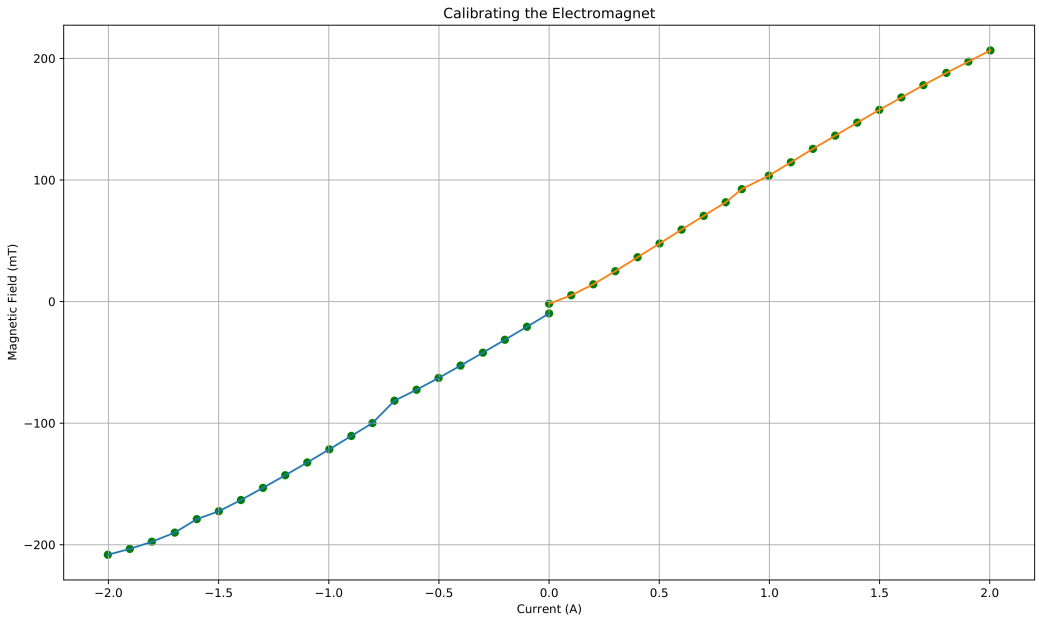
The calibration of the spectroscope is done by calibrating the electromagnet. This is done by calculating the dependence of the magnetic field on current. The figure below shows the current in two different polarities and it shows they are fairly similar. This allows the kinetic energies to be calculated later on in the report as the kinetic energy equation requires it. When calibrating the experiment it was very important that values were written down to the highest order of accuracy. This was done to make sure there wouldn't be any rounding errors before using the calculated value in a further calculation for kinetic energy. When calibrating, the hall probe was fully inserted into the electromagnet and carefully moved around to avoid any damage to the actual device.

Table 6: Magnetic field dependence on current

I (Amps)	B (mT)		I (Amps)	B (mT)
2.0033	-208.2		2.0034	206.2
1.9033	-203.4		1.9034	197.4
1.8033	-197.5		1.8034	188.1
1.6991	-190.0		1.6991	178.0
1.5991	-178.9		1.5991	167.9
1.4991	-172.4		1.4991	157.7
1.3988	-163.2		1.3988	147.2
1.2988	-153.2		1.2988	136.5
1.1976	-142.8		1.1975	125.6
1.0976	-132.3		1.09749	114.6
0.99757	-121.5		0.99747	103.6
0.89759	-110.5		0.89748	92.5
0.80187	-99.9		0.80175	81.7
0.70187	-81.5		0.70174	70.5
0.60165	-72.5		0.60153	59.2
0.50159	-62.8		0.50151	47.8
0.40178	-52.6		0.40170	36.5
0.3005	-42.0		0.30049	25.01
0.20069	-31.4		0.20068	14.23
100.56 mA	-20.7		100.56 mA	5.2
0.0084 mA	-9.74		0.0084 mA	1.76

Error bars were too small to be seen on this graph due to the high precision of the multi-meter so this will be discussed later. From these data points, Python can be used to graph the values. Using a negative axis for the negative polarity, the current may appear to be negative but in fact it is positive. This was done to get two linear lines that connect near the origin.

Figure 13: Beta Decay Calibration



5.2 Beta Decay Schemes

From now on in this report, the values from the positive magnetic field measurements will be used. There were tests for two sources. Sr-90 and and Na-22. Na-22 releases a positron so the polarity has to be switched when measuring this compared to the Sr-90 source. The table below shows the two sources and how the counts are affected by the current:

Table 7: Count dependency on Current

Sr-90			**Na-22**	
I (Amps)	Counts		I (Amps)	Counts
2.0029	155		2.0031	59
1.9030	195		1.9032	69
1.8030	210		1.8031	54
1.6989	281		1.6989	63
1.5989	391		1.5989	64
1.4989	435		1.4989	64
1.3986	623		1.3986	62
1.2987	900		1.2986	55
1.1974	1097		1.1974	61
1.09735	1445		1.0974	63
0.99735	1800		0.99732	61
0.89736	2007		0.89734	54
0.80165	2259		0.80163	72
0.70162	2464		0.70162	50
0.60144	2554		0.60144	77
0.50142	2320		0.50139	104
0.40159	1942		0.40160	171
0.30042	1444		0.30036	249
0.20058	823		0.20056	232
100.489 mA	408		100.437 mA	136
0.79 mA	242		0.76 mA	103

Now with the counts being measured and the magnetic field being measured earlier, the kinetic energy can be obtained. Using equation 9 this is calculated. For the purpose of the lab report the mathematical expression below shows the way the kinetic energy is obtained for one of the values:

$$Q = \sqrt{(q * 206.2 * 50 * c)^2 + m_0^2 c^4} - m_0 c^2 = 4.96 \times 10^{-10} \quad (13)$$

This is then done for every magnetic field recorded and current and graphs are plotted. The decay curves look different due to the energy that the particles leave the source. The Geiger-Muller counter was set to a gate time of 100 seconds to allow as many counts to be read. Increasing the time increases the accuracy of the results. As well as this it provides a clearer graph to read and take readings of off. The graphs shown below are extrapolated after to get the max kinetic energy of the beta particles that are emitted. If more time permitted and there was a chance to repeat the experiment, there could be a possibility to find the max kinetic energy properly by doing more readings and using those.

Figure 14: Beta Decay of Sr-90 (KE= eV)

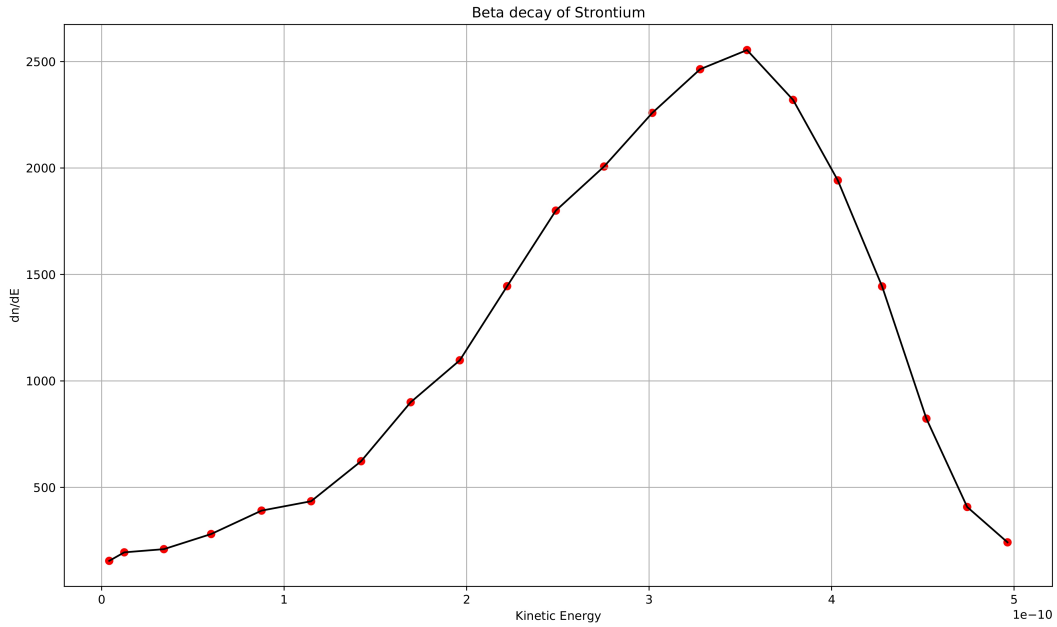
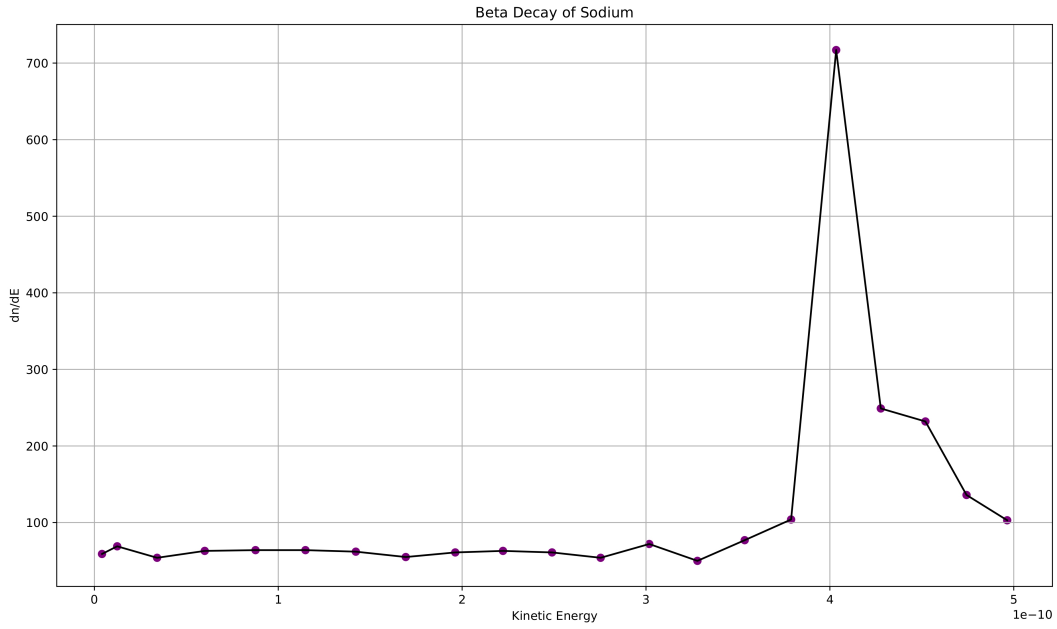


Figure 15: Beta Decay of Na-22 (KE= eV)



From the graphs there is clear evidence that Strontium has a much nicer peak. Strontium however is supposed to have two peak not one but the second one is not visible. This is due to the y axis being calibrated for much lower energy. The second peak is expected at 2.274 MeV. It would need a larger current and magnetic field to get these values visible. From these graphs as well it is clear that the positron graph doesn't have a great decay pattern to visualise compared to an electron decay pattern.

Before the peak on the sodium graph there is a lot of background radiation due to the annihilation of particles. This occurs when a subatomic particle collides with it's anti-particle to produce another source of radiation. In this case if an electron and positron collided then two photons would be produced.

The last part of this results section show what the theoretical values of Q_0 would be if the graphs were extrapolated. The Q_0 for the Strontium peak would be 566KeV and the Q_0 for the sodium graph would be around 588KeV. These are close to the theoretical values of 544KeV for Na-22 and 546KeV for Sr-90.

6 Radioactive Source Breakdown of Honey Coated Banana Chips

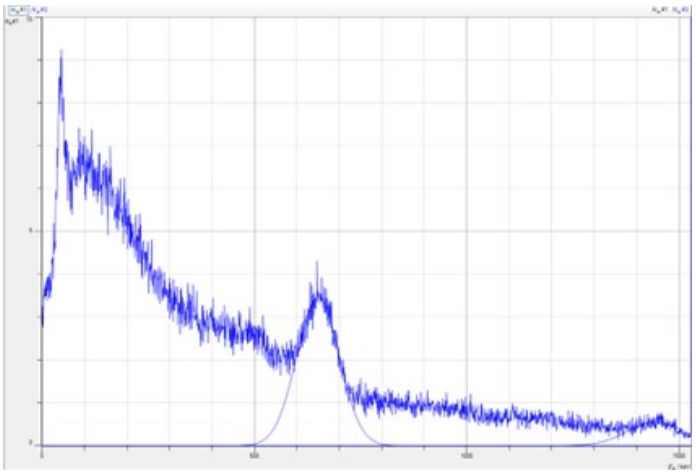
It is time to delve deeper into an application of Gamma Ray Spectroscopy. Using a real world object we encounter everyday, this part of the report will highlight how radiation is present in most things without us even knowing. Even if it such small radiation, the fact that they contain these sources are fascinating. This trial involved food. Food that can be preserved for a long time were used as if needed the same food source could be tested multiple times if needed to get an understanding if the results calculated were authentic or not.

This method is the same as the Gamma ray spectroscopy but this time there is more apparatus needed to allow for the accuracy of the experiment. When researching radiation in food, it was clear that there was going to be a small amount of radiation being emitted. These foods aren't harmful to us, otherwise they wouldn't be for sale. To combat the small value of radiation emitted, the scintillator described earlier in this report, will be lined in lead. Lead cylinders will surround the scintillator. This will create a barrier where the gamma rays emitted will not escape. They will be able to accumulate inside the lead container, creating a better spectrum on Cassy-Lab.

Brazil nuts were first tested but there was no luck. They were kept in the lead container for 5 hours and there was no radioactive peaks present. From this evidence it was clear that the soil the fruit and vegetables grow in make a massive impact in the amount of radiation present. The soil gives the plants nutrients so this would increase the radioactive potential.

The next fruit tested was Banana chips. These banana chips were coated in honey and were sold in bags of 125g. The whole bag was placed into the lead lined scintillator apparatus and was left again for five hours. This time there were results. It was possible to even fit a Gaussian peak on these parts of the spectrum. The spectroscope showed clear signs of radiation being emitted. This spectrum looked like this:

Figure 16: Spectrum of the accumulated Honey Coated Banana Chips



It is clear that there is a Potassium peak. The far right of the graph dictates that. That was expected but what wasn't expected was the other peak. There shouldn't be anything else being emitted from the banana chips. It's a well known fact that bananas contain Potassium. Potassium is required in our bodies to aid the normal fluid level in cells. Bananas are a great way to get this mineral in. The other peak was unexpected.

This peak after comparing to previous spectrum's matched to the mixed source. It matched perfectly to the Cs-137 peak. That means that the Banana chips contain Cs-137 as well as Potassium. From this, research was done online to understand whether this was an anomaly or not. The initial solution to this unforeseen peak was that there must of been some residual radiation lingering from previous experiments. The lead lining may not have been closed correctly or even worse, the mixed source spectrum containing the Cs-137 may have been left near the scintillator without record.

After research, it turns out that honey is the cause for this peak. Honey from America contains Cs-137. This stems from the Cold War where atomic bombs were being tested as this involved Uranium and Plutonium. Years later, they have decayed into Cs-137. This is left in the soil where plants then rely on this to give them minerals and energy to grow. This means that when the bees pollinate the flowers (grown in the Cs-137 ridden soil), they are transporting Cs-137 with them to then make honey. This chain reaction from Uranium decaying has created another chain reaction in the production of honey. This honey is then sold worldwide. Even though the levels are so small that they aren't dangerous at all, it is still fascinating that the effects from the cold war are still having consequences in food in present day.[15]

In humans 18g worth of Potassium is considered a dangerous amount that requires immediate medical assistance.[16] In one bag of these banana chips only 670mg of Potassium are in them meaning 2687 bags would have to be ingested in a short period of time.This is without the Caesium being incorporated into it as well. The values of these peaks in figure 16 are shown on the next page.

Table 8: Peaks for the Spectrum of Banana Chips.

	Count rate (KeV)	Standard Deviation
Cs-137	160.5	49.9
Na-22	25.7	66.7

7 Error analysis

7.1 Gamma Ray Spectroscopy

When discussing error analysis on this part there is many factors that can be discussed. From the power supply to the height of the source in comparison of the scintillator. As well as this there is the human error in picking the best curve to do a Gaussian fit function.

1. Error in power supply reading = $\pm 0.05V$
2. Error in height from source = $\pm 1mm$
3. Error in Counts = ± 0.005
4. Error in Gaussian Fit = σ

All of these factors can contribute to an uncertainty in the final readings. As well as this there is uncertainty in the way the peaks are measured. Using integration, it can lead to the background radiation being incorporated into the final readings of the graphs. They way to alleviate that was to use a Gaussian fit function where it creates a curve best fit line and them uses the peak of that instead.

When measuring the peaks with a Gaussian fit function it creates a standard deviation. The standard deviation shows the variance of a sample. In this case it shows the distribution of the peak curve. It shows also how spread out it in comparison with the mean. The standard deviation for each measurement is shown below and is made up of previous tables used earlier (Table 2,3 and 4).

Table 9: SD = Standard Deviation in Kev

SODIUM											
LEAD			STEEL			ALUMINIUM			BRONZE		
Thickness (cm)	Intensity	SD	Thickness(cm)	Intensity	SD	Thickness(cm)	Intensity	SD	Thickness(cm)	Intensity	SD
0.00	297.5	26.1	0.00	304.9	26.1	0.00	299.9	27.2	0.00	196.6	27.2
0.10	198.2	27.0	0.10	228.1	26.6	0.044	243.1	26.9	0.05	150.5	27.1
0.20	172.2	27.7	0.20	214.2	26.9	0.099	237.6	27.0	0.1	144.2	27.6
0.30	146.8	28.0	0.30	202.6	26.9	0.141	238.1	27.3	0.15	140.1	27.7
0.40	128.1	28.3	0.40	187.7	28.1	0.185	233.8	27.5	0.2106	135.0	28.3
0.50	113.7	28.3	0.50	174.6	29.6	0.231	229.0	28.0	0.2701	129.5	29.2

Table 10: SD = Standard Deviation in Kev

COBALT											
LEAD			STEEL			ALUMINIUM			BRONZE		
Thickness (cm)	Intensity	SD	Thickness(cm)	Intensity	SD	Thickness(cm)	Intensity	SD	Thickness(cm)	Intensity	SD
0.00	20.1	57.6	0.00	19.1	53.3	0.00	19.0	50.4	0.00	13.0	45.4
0.10	17.7	55.0	0.10	18.8	72.8	0.045	18.5	54.3	0.0595	12.6	53.4
0.20	17.0	53.2	0.20	18.4	47.8	0.091	17.7	73.4	0.195	12.6	107.6
0.30	16.9	81.6	0.30	17.3	75.4	0.135	19.4	55.4	0.245	12.2	54.0
0.40	16.0	55.9	0.40	17.0	53.2	0.18	18.9	70.7	0.295	12.0	49.1
0.50	13.9	61.7	0.50	16.4	56.2	0.222	17.5	86.6	0.345	11.9	64.9

Table 11: SD = Standard Deviation in Kev

MIXED SOURCE (Cs-137)											
LEAD			STEEL			ALUMINIUM			BRONZE		
Thickness (cm)	Intensity	SD	Thickness(cm)	Intensity	SD	Thickness(cm)	Intensity	SD	Thickness(cm)	Intensity	SD
0.00	743.5	29.6	0.00	749.9	29.7	0.00	756.6	29.5	0.00	740.2	29.6
0.10	684.9	29.9	0.10	712.1	29.7	0.045	745.3	29.3	0.0595	718.5	29.7
0.20	609.9	30.0	0.20	675.8	29.8	0.091	735.8	29.7	0.195	702.6	29.8
0.30	547.7	30.2	0.30	641.9	30.6	0.135	722.2	29.5	0.245	675.4	30.0
0.40	499.6	30.3	0.40	613.2	30.2	0.18	731.7	29.7	0.295	659.2	29.9
0.50	451.0	30.7	0.50	575.7	30.8	0.222	718.6	30.2	0.345	631.2	30.1

7.2 Beta Particles in Magnetic Fields

This section involved more instrumental error. Reading errors to be more exact. These errors from the equipment can lead to errors in equations to which can lead to a bigger uncertainty than expected if the earlier uncertainties aren't taken care of properly:

1. Error in Voltage = ±0.0005
2. Error in Current = ±0.0005
3. Error in Magnetic Field = ±0.005

From these errors the uncertainty in Kinetic energy can be calculated. Using the Covariance matrix, the uncertainty in kinetic energy and counts can be found.

1. Covariance in Strontium Counts = 735311.75
2. Covariance in Sodium Counts = 21883.96
3. Covariance in Kinetic Energy = 2.55×10^{-20}

Error bars could be plotted but with such difficult values, it would be hard to distinguish them on the graphs so the graphs are without error bars for this specific reason.

8 Discussion

8.1 Gamma Ray Spectroscopy

From calibrating the apparatus, to finding attenuation coefficients there is a lot of success in this experiment. The equipment was calibrated correctly using example sources. The equipment was set up correctly, resulting in accurate data. The peaks were recorded using a Gaussian fit function which was tested over the other methods (integration) to allow for precise analysis of the recorded data. The attenuation coefficient method was performed accurately and there was a repeat of this part of the experiment to make sure that the values that were produced were correct. Using a micrometer, the thicknesses of the metal sheets for the attenuation experiment made the calculations much better. Best fit lines were measured and the standard deviation and uncertainties were measured for each of the recorded results. With a deeper look into the other peaks with the discussion of the Compton effect and other mechanisms the whole spectra was deconstructed and analysed.

With every experiment there are ways to improve it. In this case it would have been better to use even more materials and sources. Testing the attenuation with different sources and recording them can give a large data-set. With different materials, it can highlight objects that work better at stopping gamma rays than others. This knowledge could be useful for a repeat of this experiment as the cobalt source didn't work as well as expected. The intensity values would increase sometimes when they should decrease. As well as this, the interval time that was measured could be increased and a lining of thick lead could have been placed round the scintillator to try and alleviate any anomalies and increase in background radiation. Finally, if there was a repeat, I would plot the data for the spectra in Python and analyse the peaks on there as well to get multiple sources of the same calculations to understand anomalies in the work.

8.2 Beta Particles in Magnetic Fields

This part of the experiment performed exactly how I wanted it. The results that were gained, matched the theoretical values of what the decay schemes should look like. The calibration experiment proved that the polarity didn't affect the magnetic field as similar results were recorded for each. From this experiment, the magnetic field was obtained. Then when looking at the sources, the counts were measured accurately using the Geiger-Muller counter and was then plotted along with kinetic energy. The decay curves created were what was expected. It was known that Na-22 wouldn't have as good of a decay curve due to the positron emission. The annihilation of particles as well as the energy of the positron created a decay curve that wasn't as broad as the others. However, the Sr-90 produced a decay curve that was exactly needed. A large broad peak.

The value of Q_0 was calculated by extrapolating the data and figuring it out using that but if there was a repeat of the experiment, a curved line of best fit would be plotted which would give the best result for the value trying to be calculated.

Furthermore, I would have liked to have tested other sources that emit beta particles to create a collection of curves to then try and decipher why they look so different. A larger spectroscope could have been interesting to research as well as this would create a large magnetic field. It would create a larger range so that more peaks could be seen on the decay curve, especially for Sr-90.

8.3 Radioactive Source Breakdown of Honey Coated Banana Chips

Delving deeper into the Gamma ray research I am really happy with what was discovered. Using a scintillator lead lined, there was a spectrum that showed not only Potassium in it but also Cs-137. The discovery of this lead to me realising just how long radioactive materials can affect our environment if abused and tested. With such a large half life the Cs-137 in the soil and in the honey will last for decades to come.

To extend this in a further research paper, there could be investigation into even more food and other things that are used on a daily basis by humans. Cigarettes and the presence of vape fluid could be tested to see if the substances that are being ingested are even worse for you than we already knew. I would've liked to have repeated this experiment several times to check the validity of the Cs-137 being in the honey and that it wasn't just an anomaly in the data.

9 Conclusions

Concluding this lab report, everything that has been discussed and experimented on can be used in the modern world to benefit us. From measuring the peak energy of gamma radiation to understanding how beta particles work in the presence of a magnetic field, this knowledge allows humanity to evolve and get a deeper understanding of the world we live in. With the banana chips research, this just shows how hazardous nuclear weapons can be on the future of our Earth. The lingering effects of nuclear radiation can be seen in so many subtle ways, even in the delicious honey coated banana chips we eat and are surrounded by on a daily basis in life.

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10 Appendix

10.1 Attenuation Coefficient Graphs

Figure 17: Sodium Intensity vs Thickness graphs

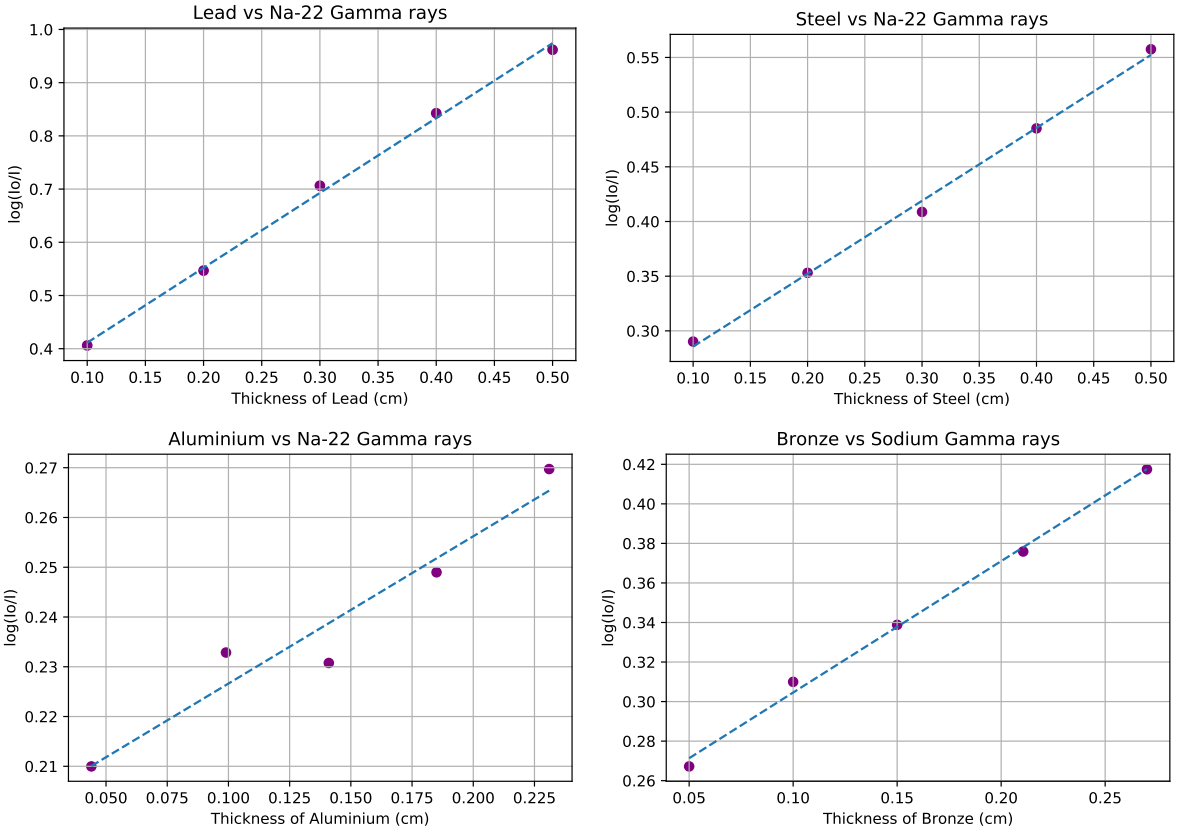

Figure 18: Cobalt Intensity vs Thickness graphs

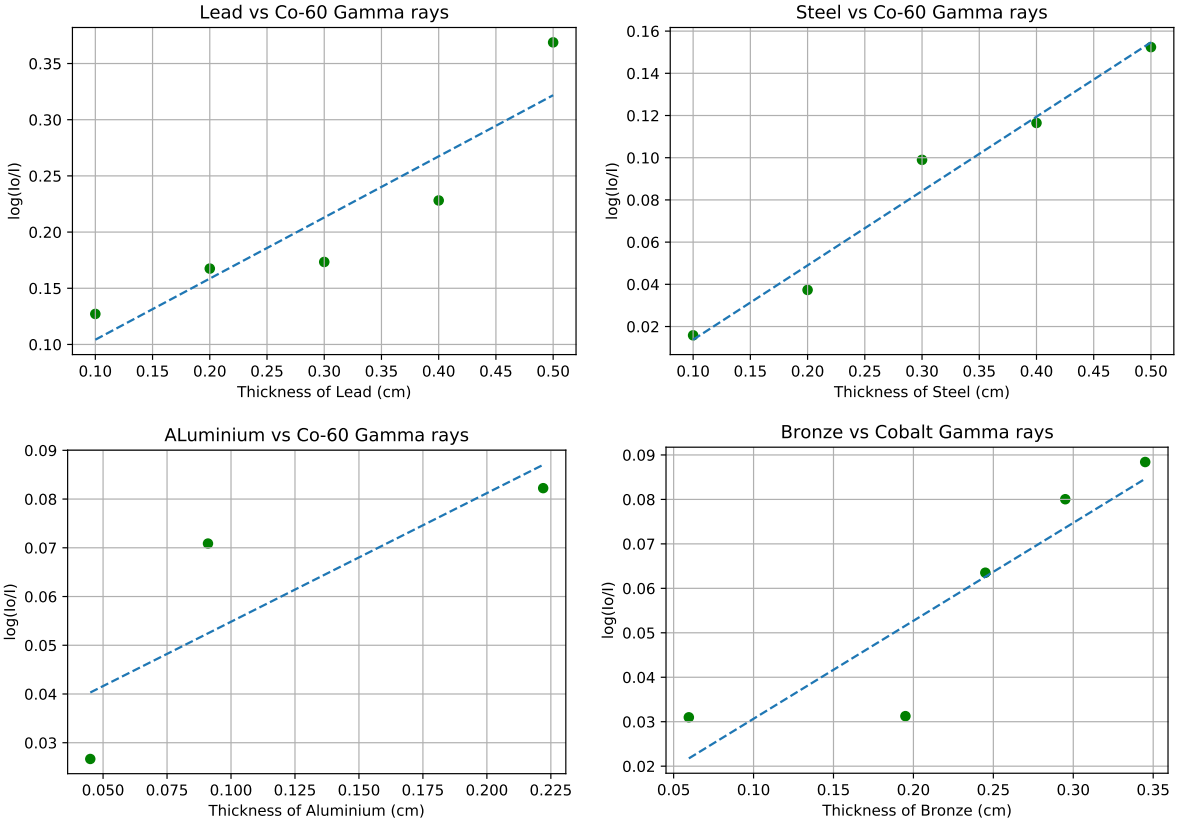

Figure 19: Mixed Source Intensity vs Thickness graphs