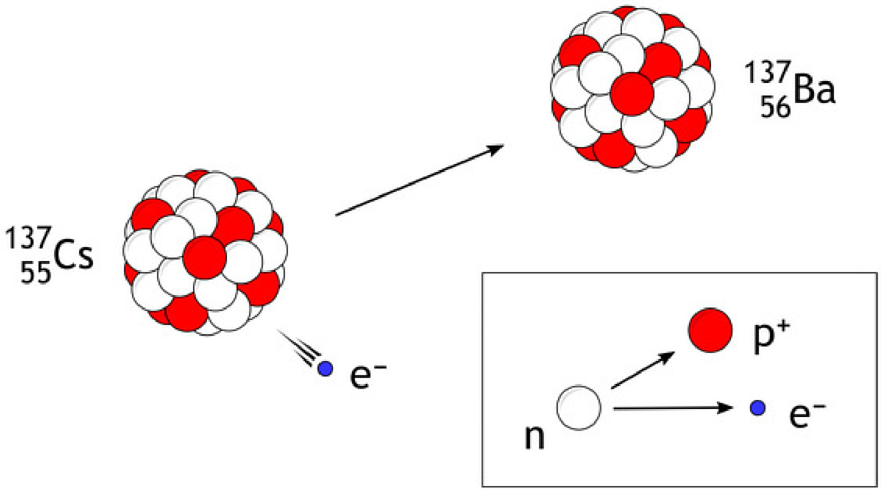
Experiment 1:

The beta spectrum



3rd Year of the Degree in Physics

Experimental Project

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7 of March 2025

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1 Introduction

In this experiment we aim to observe the beta decay of various radioactive atoms. We will be using a Geiger detector to count the amount of events and a magnetic field to deviate the beta particles. Then we will relate the number of events depending on the angle of the source and the detector.

The structure of the document is as follows. First, the theoretical principles behind this experiment will be explained. It will be followed by the experimental procedure and the results with their analysis. Finally, there will be the conclusions of the experiment, and we will answer some questions related to the experiment.

2 Theoretical Fundaments

Many of the atomic nucleus are not stable in their composition of protons and neutrons, that means that they are susceptibles to emit radiation that changes this structure to a more stable one.

This radiation can take three different forms as it can be alpha, beta or gamma radiation, each of them having a different emitted particle associated.

Of the three cases the one we will be interested in is the beta decay, this type of radiation is characterized by the electron that is emitted from the nucleus, turning a neutron into a proton and increasing the atomic number without altering the mass number.

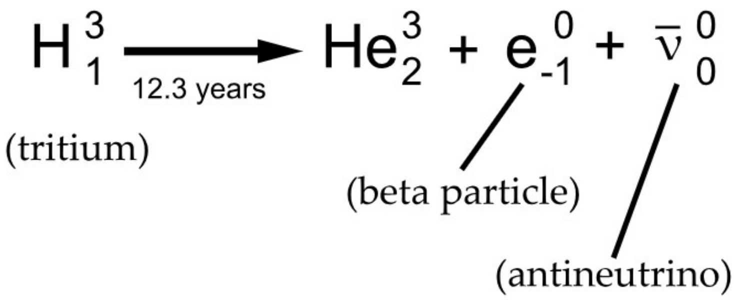

Figure 1: Beta Decay of the Tritium

As this emitted electrons have a negative charge that means that they can be deviated when a magnetic field is applied over them. This means that we can find the kinetic energy of these electrons by finding the angle of deviation, this is finding the angle that makes the detector count the maximum amount of events.

3 Experimental Procedure

In order to perform the experiment we must set the deflection system at a distance of $40mm$ to the detector. Then it is necessary to measure the background β radiation so we can subtract that effect from the measure of the sample.

Then we have to put the source of radiation, the radioactive element, in the deflection system so the β^- particles pass through the magnet. This magnet will deviate the particles with an angle. Finally, we will select a set of 5 angles between 40 to 140 and take measurements of the number of particles with the device attached to the Geiger detector. The radioactive elements that we will use are Po^{120}, Co^{60} and Sn^{90}.

4 Experiment Data and Final Results

4.1 Kurie Plot and determination of E_{max}

First, we need a table of the angles and the experimental N, in which we have removed the background effect being $N_o = 174,33$. We will see that for some angles, the amount of particles is so lower than the background that the result of subtracting them is negative. Since these values don't have any physical meaning, we will discard them from the data treatment :

Po^{120}				
Angle (º)	Measurement 1	Measurement 2	Measurement 3	N
40	2,666666667	-10,33333333	-49,33333333	2,666666667
60	-19,33333333	59,66666667	-19,33333333	7
80	96,66666667	33,66666667	58,66666667	63
100	74,66666667	111,6666667	58,66666667	81,66666667
120	62,66666667	94,66666667	97,66666667	85
140	-41,33333333	14,66666667	21,66666667	18,16666667

Table 1: Polonium beta decay

Co^{60}				
Angle (º)	Measurement 1	Measurement 2	Measurement 3	N
40	102,6666667	215,6666667	194,6666667	171
60	176,6666667	225,6666667	157,6666667	186,6666667
80	240,6666667	271,6666667	208,6666667	240,3333333
100	353,6666667	315,6666667	322,6666667	330,6666667
120	466,6666667	464,6666667	387,6666667	439,6666667
140	911,6666667	1058,666667	977,6666667	982,6666667

Table 2: Cobalt beta decay

Sn^{90}				
θ(º)	Measurement 1	Measurement 2	Measurement 3	N
40	-17,33333333	-23,33333333	-15,33333333	0
60	94,66666667	176,6666667	176,6666667	149,3333333
80	282,6666667	322,6666667	314,6666667	306,6666667
100	127,6666667	230,6666667	179,6666667	179,3333333
120	14,66666667	74,66666667	71,66666667	53,66666667
140	25,66666667	-33,33333333	10,66666667	1

Table 3: Cobalt beta decay

Now we have to calculate some physical quantities that will be used in the Kurie Plot. First we will obtain the energy of the $\beta-$ with the following formula:

$$E = m_o c^2 \cdot \left(\sqrt{\left(\frac{e \cdot B \cdot R}{m_o c \tan(\theta/2)} \right)^2 + 1} - 1 \right)$$

Where m_o is the mass of the electron $9.11 \cdot 10^{-31} kg$, B is the intensity of the magnetic field, being $310 mT$, and R the radius $15 mm$ of the magnet. Then, because $E(\theta)$ isn't linear, because of being fixed in angle intervals instead of energy ones, we will divide the counts by $|\frac{dE}{d\theta}|$, which will return us N'. It is obtained with this equation:

$$|\frac{dE}{d\theta}| = \frac{1}{2} m_o c^2 \frac{b^2}{\sin^2(\theta/2)\sqrt{b^2 + \tan^2(\theta/2)}}$$

Being b:

$$b = \frac{e \cdot B \cdot R}{m_o \cdot c}$$

And finally, we will calculate the Kurie function K(E) using the next equation:

$$K(E) = \sqrt{\frac{N'}{\sqrt{E^2 + 2E m_o c^2} \cdot (E + m_o c^2)}}$$

All the results from these formulas will be displayed in the following tables, one for each radioactive element:

Po^{120}			
E (keV)	$\lvert\frac{dE}{d\theta}\rvert$	N'	K (keV)
3354,95332	3,47368E-13	7,67678E+12	14,25803972
1958,022471	1,60421E-13	4,36353E+13	76,24165677
1227,693771	9,48275E-14	6,64364E+14	599,1948438
765,7429165	6,40083E-14	1,27588E+15	1685,698701
442,4621383	4,61335E-14	1,84248E+15	4611,975838
209,1289429	3,2697E-14	5,55606E+14	7794,034026

Table 4: Kurie plot magnitudes of the Polonium

Co^{60}			
E (keV)	$\lvert\frac{dE}{d\theta}\rvert$	N'	K (keV)
3354,95332	3,47368E-13	4,92274E+14	114,1756544
1958,022471	1,60421E-13	1,16361E+15	393,7102226
1227,693771	9,48275E-14	2,53443E+15	1170,32046
765,7429165	6,40083E-14	5,166E+15	3391,975808
442,4621383	4,61335E-14	9,53031E+15	10489,12669
209,1289429	3,2697E-14	3,00537E+16	57322,85148

Table 5: Kurie plot magnitudes of the Cobalt

Sn^{80}			
E (keV)	$\lvert\frac{dE}{d\theta}\rvert$	N'	K (keV)
3354,95332	3,47368E-13	0	0
1958,022471	1,60421E-13	9,30886E+14	352,1451285
1227,693771	9,48275E-14	3,23394E+15	1321,998855
765,7429165	6,40083E-14	2,80172E+15	2497,974771
442,4621383	4,61335E-14	1,16329E+15	3664,627795
209,1289429	3,2697E-14	3,05838E+13	1828,625087

Table 6: Kurie plot magnitudes of the Cobalt

From these tables, we can make the Kurie plot and get the maximum energy by looking at the cut-off points. We can see that the high-energy points won't follow a linear function because of their big uncertainty and our data doesn't adjust well with a low R^2.

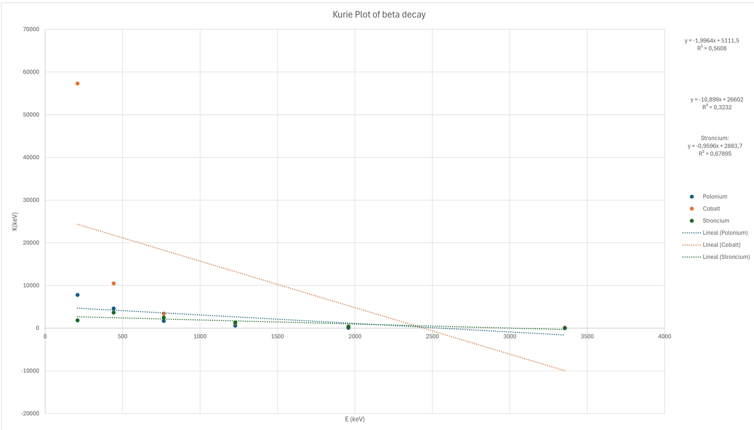

Figure 2: Kurie plot

We see that each deflection can be adjusted as a linear equation. By calculating the x that makes y zero, we can obtain the E_{max}.

For Polonium:

$$y = -1.9964x + 5111.5$$

$$E_{max} = \frac{5111.5}{1.9964} = 2560.35$$

For Cobalt:

$$y = -10.899x + 26602$$

$$E_{max} = \frac{26602}{10.899} = 2440.77$$

For Strontium:

$$y = -0.9596x + 2883.7$$

$$E_{max} = \frac{2883.7}{0.9596} = 3005.1$$

4.2 Theoretical spectrum

Now we will calculate the theoretical spectrum of beta decay and compare it with the experimental values. For it we have to use the following equation for N_{theo}:

$$N_{theo}(E) = C\sqrt{E^2 + 2E \cdot m_o c^2} \cdot (E_{max} - E)^2 \cdot (E + m_o c^2) \cdot F(Z, E)$$

Where $F(Z, E)$ is the Fermi function:

$$F(Z, E) = \frac{2\pi\nu}{1 - e^{-2\pi\nu}} \left(\alpha^2 \cdot Z^2 \cdot \omega^2 + \frac{1}{4}(\omega^2 - 1)\right)^S \tag{1}$$

With Z the atomic number of the element, $\alpha = \frac{1}{137}$ is the fine structure constant and the other terms are: $\nu = \alpha \cdot Z \cdot \frac{E+m_oc^2}{\sqrt{E^2+2E\cdot m_oc^2}}$, $\omega = \frac{E}{m_oc^2} + 1$, $S = \sqrt{1-\alpha^2 Z^2} - 1$.
By last we have to adjust the constant C, that is a normalization constant, until N_{theo} has the best agreement with N'. In order to do the adjustment of C we will do a linear regression in excel with the N_{theo} unadjusted as the independent variable and N' the dependent. We will show directly the N_{theo} adjusted with the obtained value of their respective variables.

Po^{120}			
S = -0.21		C = 5,46553E-32	
ω	ν		N_{theo}
4,09191E+16	0,613138686	2,47757E+33	1,76076E+46
2,38812E+16	0,613138686	8,43894E+32	1,17378E+45
1,49737E+16	0,613138686	3,31767E+32	8,88074E+44
9,33947E+15	0,613138686	1,29068E+32	2,43738E+44
5,39654E+15	0,613138686	4,30928E+31	3,7841E+43
2,55066E+15	0,613138686	9,62677E+30	2,32753E+42

Table 7: Theoretical spectrum's variables of the Polonium

Co^{60}			
S = -0.019		C = 9,36804E-30	
ω	ν	F	N_{theo}
4,09191E+16	0,613138686	2,47757E+33	1,76076E+46
2,38812E+16	0,613138686	8,43894E+32	1,17378E+45
1,49737E+16	0,613138686	3,31767E+32	8,88074E+44
9,33947E+15	0,613138686	1,29068E+32	2,43738E+44
5,39654E+15	0,613138686	4,30928E+31	3,7841E+43
2,55066E+15	0,197080292	4,4064E+29	9,59755E+40

Table 8: Theoretical spectrum's variables of the Cobalt

Sn^{90}			
S = -0.068		C =8,66075E-31	
ω	ν	F	N_{theo}
4,09191E+16	0,364963504	5,68847E+32	7,83683E+44
2,38812E+16	0,364963504	1,93757E+32	8,14424E+44
1,49737E+16	0,364963504	7,61733E+31	3,62707E+44
9,33947E+15	0,364963504	2,96339E+31	8,71367E+43
5,39654E+15	0,364963504	9,89406E+30	1,27204E+43
2,55066E+15	0,364963504	2,2103E+30	7,55691E+41

Table 9: Theoretical spectrum's variables of the Strontium

Finally , the plot of the N_{theo} vs the kinetic energy E shows the linear relation between both variables:

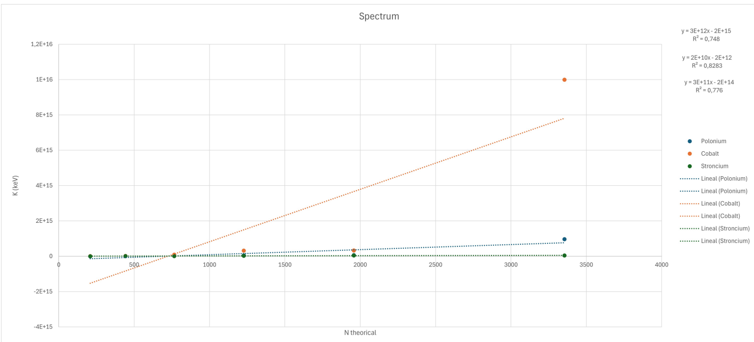

Figure 3: Theoretical spectrum of beta decay vs Kinetic Energy

5 Discussion and Evaluation

Compare the E_{max} found with the table value.

When comparing the maximum kinetic energy obtained for each element with the experimental energies, we can identify that their values are below the data from the tables.

E (keV)	E_{max}	Element
3354,95332	2560.35	Po^{120}
1958,022471	3005.1	Sn^{80}
1227,693771	2440.77	Co^{60}
765,7429165		
442,4621383		
209,1289429		

Table 10: Comparison between the E_{max} of each element and the kinetic energy E

This disagreement could be caused from the linear regression fit that was made in order to predict the maximum. As it was said before, the Kurie plot is highly sensitive at high-energies and has a high uncertainty at small angles.

Discuss the agreement between the experimental and the theoretical spectrum.

As we can see in the theoretical spectrum plot, the R^2 obtained are close to 0.9. Because this plot finds the correlation between the K function, which was calculated with the experimental data, and N_{theo}, it confirms that the normalization constant C, adjusted for each material, yields a strong agreement between the N' spectrum and the N_{theo}.

What is the relationship between uncertainty and the value of the angles? Why?

We can see that the kinetic energy depends on $\tan\theta/2$, because this function becomes very small at low angles this makes the energy calculation highly sensitive to small angle errors. Therefore, both the counts and energy become less reliable at lower angles.