Analyzing Negative Beta Decay Through Magnetic Spectrometry of Thallium-204

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ABSTRACT

The purpose of this experiment was to verify the negative beta decay spectrum of Thallium-204 by collecting counts at various angles in concordance with a magnetic spectrometer, culminating in a Kurie Plot for the isotope. This method of experimentation utilized a radioactive sample whose counts were measured at various angles by a Geiger-Muller (GM) tube. The GM tube was connected to a computer, where STX software was used in order to view the data. Manipulation of energy, momentum and magnetic field equations along with corrections for nuclear interactions allowed a Kurie plot to be developed. The Kurie plot displays counts, momentum, shape, and what is known as the Fermi Function plotted against the kinetic energy of the electron. The Kurie plot is useful in Nuclear Physics as its x-intercept is the Q value of a nuclear reaction. In the case of Thallium-204, the theoretical Q value of the decay process is 0.763 MeV (Mega Electron-Volts). The Kurie Plot created through this experiment displayed an x-intercept, or Q value at approximately 0.736 MeV, yielding a percent discrepancy of 3.5%. This result is not perfect but it is more than enough evidence to confirm the Negative Beta Decay process in Thallium-204. Possible errors in this experiment include the broad face of the GM Tube, background radiation, loose/malfunctioning connection wires, and random errors.

INTRODUCTION

Nuclear Physics is a relatively new branch of modern physics, being that it has only existed for about a century. However, the major strides that this field has made for the science community is arguably one of the most influential in all of science history. From the discovery of radioactivity by Becquerel in the late 1800s, to the work of the Curie family with radioactive elements in the early 1900s, to the classification of our modern atomic and nuclear structure, the advancements in this field have happened quite rapidly. It was of peak interest to scientists in the mid 1900s to identify and classify radioactive elements and properties, as these elements proved to be dangerous but also useful. The objective of my experiment was to verify the negative beta decay spectrum of a Thallium-204 isotope. This experiment was made possible by all of this prior research in the field. This experiment was atypical however, in that I verified the negative beta spectrum of the Thallium isotope through the use of a magnetic spectrometer with varying angle detection via a Geiger-Muller tube. Verifying this spectrum is vital to knowing about the element and its properties, the potential dangers of utilizing Thallium in technology or medicine, and the many other possible applications. In this paper, I will unpack some of the theory behind Beta decay and specifically, magnetic spectroscopy to analyze the decay process. I will go over the methods and materials necessary to conduct this experiment before showing and explaining the data I received. I will then walk through the analysis of the data and explain its significance before summarizing the experiment in conclusion.

THEORY

This experiment was based heavily on theoretical knowledge of electromagnetism and nuclear physics. The setup of the experiment was designed in a specific way as to obtain the results needed in the most feasible way possible given our lab equipment. To make the math calculations simple and feasible in an eight-week timeframe, it was essential that the magnetic field created be perpendicular to the path of the emitted electrons from the radioactive sample.

The next crucial part of the experiment was the decision to make measurements at various angles. This made the theoretical calculations for the radial path of the electron significantly more difficult; however, it allowed for the capturing of the full beta spectrum. In the end, this decision was pivotal to the success of the experiment.

The mathematical theory behind the project lay within a two-circle design: the radial path of the electrons and the circular shape of the coils used to create the magnetic field. The point of emphasis was where the path of the electrons, at a given angle, intersected with the coils. This allowed for the radius of that electron path to be calculated for use in some of the more basic theoretical equations.

The major equations that were utilized in this

1) $p = eBr$

2) $B = \dfrac{8\mu NI}{\sqrt{125}r}$

3) $N(p) \sim (p^2)(Q - Te)^2(F(Z, p))(|Mfi|^2)(S(p,q))$

4) $E = \sqrt{(pc)^2 + (mc^2)^2}$

experiment were as follows:

Equation one describes the momentum of the electrons emitted from the nuclear reaction at a given B, or magnetic field, and a given r, or radius. Equation 2 describes how to calculate the magnetic field at a given N, number of turns of wire, a given I, or current, and r, or radius of coils. Equation 3 describes the relationship that the number of radiation counts is proportional to the momentum of the electrons squared, the Q value minus the kinetic energy, the Fermi function for that given proton number and momentum, the nuclear matrix element for the specific isotope, and finally the shape factor for that given nuclear reaction. This is the fundamental relationship that the Kurie plot is based off of. Equation 4 describes the total energy of the electron being equal to the square root of the momentum squared plus the rest mass squared.

Many other equations were used and derived in this experiment, however these four are fundamental to the success of the experiment and the knowledge of these equations must be engrained before moving on to the other equations.
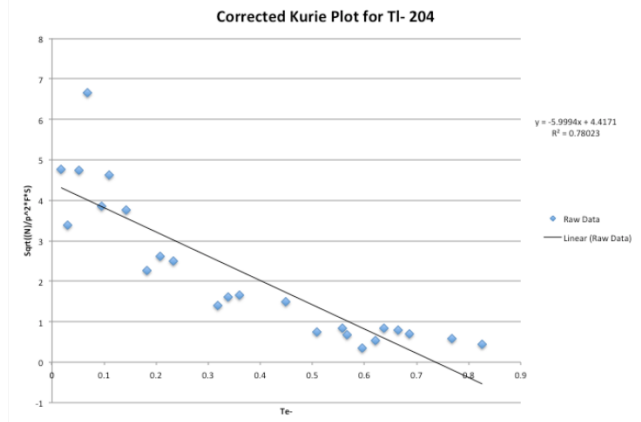
MATERIALS AND METHODS

This experiment utilized a Thallium-204 isotope source, a Geiger-Muller tube, a Spec Tech Counter, a DC Power Supply, two 0.5A (Amps) coils of known turn number, STX software, multiple sets of banana wires, and various other common lab items such as rulers, glue, etc. The Thallium sample is essential as that is the isotope that the negative beta decay spectrum is being confirmed for. The GM tube is needed as it counts the electrons that are emitted during the beta decay process for Thallium. The Spec Tech Counter connects the GM tube to the STX software that stores the numbers of counts as data into the computer for later use. The DC power supply is necessary, as it allows current to be pumped into the two coils, in turn creating a magnetic field perpendicular to the path of the emitted electrons. This is all vital to the experiment as the equations laid out in the theory section only work out if the magnetic field generated by the coils is perpendicular to the path of the emitted electrons. Banana-banana wires were used to connect the power supply to the coils

and various other lab items were used to make certain measurements easier or feasible.

The experiment to confirm the negative beta decay spectrum for Thallium-204 was done by placing a Thallium-204 sample in between two 0.5A coils of a known turn number. The coils were connected to a DC power supply and a known amount of current was placed into them, thus generating a magnetic field perpendicular to the path of the electrons being emitted by the source. The GM tube was place at varying detection angles in order to pick up emitted electrons at different energy levels and radii of curvatures. The GM tube was connected to the Spec Tech counter, which was connected to the STX software on the lab computer. This sent all of the data for the collected counts straight to the computer for analysis. Data analysis was then conducted using the known values based on the experimental setup and data collected in order to construct a Kurie plot. The Kurie plot was used to visually verify the negative beta decay spectrum based on literature on what the decay scheme should look like. The Kurie plot from this experiment looked exactly as expected. The Q value, or total energy of the nuclear reaction, can be associated with the x-intercept of the Kurie plot based on multiple literature sources and by derivation of the equations used in the plotting process. The theoretical Q value for the Thallium 204 decay was compared to the Q value found from my experiment. These values were measured in MeVs, or Mega Electron-Volts.

DATA

Table II: 0.12 A

Current (A)	r(m) coil	B (T)		pc_low (MeV)	pc_high		A_low (m)		A_high (m)	X (m) - high	X (m) - low	θ (degrees)	θ (degrees)
0.12	0.043		0.084	0.56391		1.17139	0.022377381		0.04648373	0.04286985	0.03521722	85.54103784	54.9853173

Counts	Elapsed (s)	Approximate Angle,θ		Background Counts	Average Background Count Angle		Avg. Counts	
398	200	0		227	284		0	103.6
360	200	0		318			15	84.2
354	200	0		224			30	82.4
389	200	0		323			45	84.4
437	200	0		328			60	81.8
353	200	15					75	68.2
359	200	15					90	62.6
328	200	15		Reverse Calculations for Kurie	x(m)		A(m)	B(T)	pc (MeV)	F-graphic	Fermi Corr.	Shape Corr.
386	200	15				0	#DIV/0!	0.084	#DIV/0!			#DIV/0!
415	200	15				0.011129219	0.326617427		8.23075916	16.13817302	13.7331477	472.7517071
351	200	30				0.0215	0.160478185		4.04405026	7.976921712	14.8251213	104.155407
306	200	30				0.030405592	0.103811183		2.61604182	5.216207984	16.0517871	39.77484679
327	200	30				0.037239092	0.074478185		1.87685026	3.806595692	17.4852856	18.65940814
418	200	30				0.041534811	0.056038691		1.41217501	2.938914601	19.2375897	9.613814894
430	200	30				0.043	0.043		1.0836	2.344509242	21.4966371	5.155270838
376	200	45										
414	200	45				E_tot	#DIV/0!	T_e-	#DIV/0!	qc	W (MeV)	Counts/ p^2FS
328	200	45							#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
387	200	45				8.246606411	7.735606411	0.01584725	16.138173	0.013836127	7.73560641	0.013836127
337	200	45				4.076206995	3.565206995	0.03215674	7.97692171	0.057122476	3.56520699	0.057122476
365	200	60				2.66548228	2.15448228	0.04944046	5.21620798	0.13898265	2.15448228	0.13898265
382	200	60				1.945170399	1.434170399	0.06832014	3.80659569	0.266785199	1.4341704	0.266785199
400	200	60				1.501785361	0.990785361	0.08961035	2.9389146	0.430011883	0.99078536	0.430011883
317	200	60				1.198044223	0.687044223	0.11444422	2.34450924	0.693596933	0.68704422	0.693596933
365	200	60										
405	200	75										
361	200	75										
347	200	75										
323	200	75										
325	200	75										
322	200	90										
346	200	90										
373	200	90										
350	200	90										
342	200	90										

T_e-	Counts/p^2FS	T_e-	Counts/p^2FS
0.637757075	0.829237426	0.637757075	0.829237426
0.207788982	2.605017303	0.207788982	2.605017303
0.095674063	3.860990264	0.095674063	3.860990264
0.051282053	4.737729782	0.051282053	4.737729782
0.029630163	3.385919682	0.029630163	3.385919682
0.017647049	4.756403275	0.017647049	4.756403275
1.609190621	0.21037942		
0.621813932	0.536095483	0.621813932	0.536095483
0.318970285	1.406312498	0.318970285	1.406312498
0.182744499	2.256774277	0.182744499	2.256774277
0.110096524	4.62041091	0.110096524	4.62041091
0.067366501	6.648590141	0.067366501	6.648590141
2.617548762	0.068403792		
1.089296975	0.255603262		
0.595125113	0.355462809	0.595125113	0.355462809
0.141871597	3.752764122	0.141871597	3.752764122
3.63598325	0.059462181		
1.574595027	0.243885981		
0.893293308	0.467101805		
0.557532976	0.844829326	0.557532976	0.844829326
0.360596562	1.653463706	0.360596562	1.653463706
0.233760525	2.507737728	0.233760525	2.507737728
4.658542187	0.038697978		
2.067669429	0.165508228		
1.202018232	0.26257287		
0.768501343	0.576833923	0.768501343	0.576833923
0.508862895	0.741309793	0.508862895	0.741309793
0.337403538	1.618166377	0.337403538	1.618166377
5.683183273	0.025467688		
2.564782606	0.089287479		
1.516483185	0.248773093		
0.986519572	0.412628801		
0.664959194	0.796750932	0.664959194	0.796750932
0.449001193	1.492984535	0.449001193	1.492984535
6.709020086	0.02167013		
3.064250264	0.095669135		
1.834380461	0.182055153		
1.208908796	0.368078831		
0.826146094	0.443602905	0.826146094	0.443602905
0.566083758	0.668745796	0.566083758	0.668745796
7.735606411	0.013836127		
3.565206995	0.057122476		
2.15448228	0.13898265		
1.434170399	0.266785199		
0.990785361	0.430011883		
0.687044223	0.693596933	0.687044223	0.693596933

Corrected Kurie Plot for Tl- 204

$y = -5.9994x + 4.4171$
$R^2 = 0.78023$

ANALYSIS AND DISCUSSION

The results of this experiment were a success, as the Kurie plot made confirmed the negative beta decay scheme for Thallium-204. Using the fundamental equations above in concordance with the derived equations based on the specific setup used, a Kurie plot shows the square root of counts per the product of momentum squared, the Fermi function, and the shape factor versus the Kinetic energy of the emitted electrons. The expected result was a negative linear slope with an x-intercept of about 0.763 MeV, the Q value for Thallium-204.

The experiment was successful in that figure one visually represents a negative beta decay scheme. The x-intercept in figure one can be seen to be approximately 0.736 MeV, yielding a miniscule 3.5% discrepancy between the Q value from this experiment and the accepted theoretical value. This low percent discrepancy, again, proves that the decay scheme for Thallium-204 is negative beta decay.

CONCLUSION

The objective of this experiment was to confirm a negative Beta decay spectrum for a Thallium-204 isotope through the use of magnetic spectroscopy. The innovation in this experiment lay in the method of experimentation: the use of a GM tube, collecting electron counts at varying angles, in concordance with the magnetic spectroscopy. The results of this experiment were what was expected: the negative beta decay spectrum of Thallium-204 was verified. A Kurie plot was used to confirm the beta decay spectrum, where the x-intercept represents the Q value of the nuclear reaction. The theoretical Q value of the decay of Thallium-204 is accepted to be 0.763 MeV (Mega Electron-Volts). The result of my Kurie

plot using the data collected from this experiment yielded a Q value of 0.736 MeV, thus being close enough to confirm the beta decay spectrum based on the visual graph and its intercept. The results yielded a percent discrepancy of 3.5 percent from the theoretical Q value along with a strikingly similar Kurie plot. Future improvements to this experiment could include the following: a more precise GM tube that measures finer increments of angle, larger coils allowing for larger magnetic fields which would make displaying the full spectrum easier, a closed of room for experimentation with limited background radiation and other electronics for precise measurements, and many possible others. Future work could include other spectroscopy methods for radioactive decay, studying different types of radioactive decay, using a GM tube along with a scintillator in order to measure radioactive materials in a given location, and many other options in this ever-growing and innovative field.

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