PHYS3113 Laboratory 2 – BDS

J.J. Whittaker (z5363798)[1,2]
[1] *Thursday A 2-6 Class*
[2] *Word count: 1506 words*

(Dated: 22:00 Wednesday 10th June 2024)

This experiment successfully shows the beta decay spectrum of Sr90 and Na22 and moderately successfully finds values for their decay products total kinetic energy, Q. Q for Sr90 was found to have a value of $Q_{Sr90} = 2075\ keV$ which has a percent accuracy to the theoretical of 26.5%. and Q for Na22 was found to have a value of $Q_{Na22} = 746\ keV$ which has a percent accuracy to the theoretical of 36.7%. The uncertainties of these values are not given as there was not successful error propagation through the report. The values should be taken as trends only.

INTRODUCTION

Beta decay occurs when its energetically favourable for a nucleon to exist in a different state. The beta decay has two forms, beta + and beta – denoted by $\beta^{\pm}$. They have the form;

$$\beta^-: \quad n \to p + e^- + \bar{\nu}_e, \tag{1}$$

$$\beta^+: \quad p \to n + e^+ + \nu_e. \tag{2}$$

The kinetic energy of the decay can be assumed to be spread mostly between the electron/position and the neutrino/antineutrino as they are significantly lighter than the nucleus of the decay atom. As there are 2 products, the kinetic energy of the particles are not definite and can take on a spectrum of values. This is the beta decay spectrum. The total kinetic energy takes the form Q and is equal to the lost rest mass of the products compared to the reactants which for beta decay is;

$$Q = (m_P - m_D - m_e - m_\nu)c^2. \tag{3}$$

where $m_P =$ mass of parent and $m_D =$ mass of daughter.

If one places the decay products in the path of a magnetic field, the path the beta particle will take is proportional to the kinetic energy of the particle. By varying the magnetic field, the path of the particle changes and can be detected. As the decay kinetic energy of the particle is not discrete, theoretically, the beta particle could have up to all the decay energy or it could have none thus the expected distribution of counts is statistical and would be a Poisson's distribution.

Using a Kurie plot, the spectrum of Beta particles can be described as;

$$(Q - K_e) \propto \sqrt{\frac{n_e(p)}{p^2 F(Z', p)}}. \tag{4}$$

If this relation is graphed against kinetic energy of the beta particle, the theoretical maximum kinetic energy Q can be found and this will be the goal of this report.

METHOD

1. Place the Geiger counter in the apparatus.
2. Measure the background radiation for 15 mins.
3. Place the hall probe within the electromagnet.
4. Slowly increase the current in the electromagnet and record the produced magnetic field.
5. Repeat step 4 until the spectrum up to 2.5 A is achieved.
6. Place the Sr90 sample in the apparatus.
7. Starting at 0 A record the counts for 60 seconds.
8. Increase the current by 0.1 A and record the counts for 60 seconds.
9. Repeat step 8 until the counts plateaus.
10. Remove the Sr90 sample and replace with Na22 sample.
11. Repeat steps 7 – 9 but record the counts for 200 seconds.
12. Remove the Na22 source from the apparatus.

RESULTS & ANALYSIS

The background radiation was calculated by letting the detector run for 15 min without the sample. The counts for the 15 min interval were;

$$(N_{15min})_{bg} = 275, \quad [5]$$

thus, the average counter per second from background radiation is;

$$R_{bg} = 0.306 \pm 0.018, \quad [6]$$

where the uncertainty is calculated by;

$$\Delta R_{bg} = \frac{\sqrt{n_{bg}}}{T_{bg}}. \quad [7]$$

The relationship between current applied to the solenoid and the magnetic field produced was calculated using the fit function in MatLab. The uncertainties are taken from 95% confidence intervals. The linear relationship is;

$$B = (103.9 \pm 0.9)I + (1.2 \pm 1.1) \quad [mT] \quad [8]$$

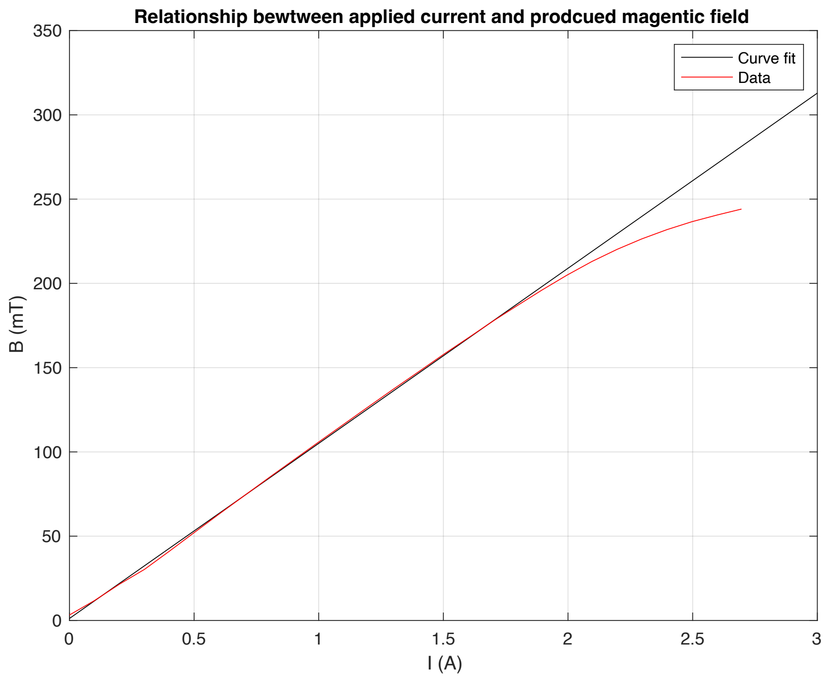

Figure 1: Curve fit data of relationship between current and magnetic field.

The current data taken for both Sr90 and Na22 can be converted to a magnetic field using this relationship. The magnetic field can then be converted into a kinetic energy using the relationship found in the pre-work question 3;

$$KE = \sqrt{(reBc)^2 + m_e^2c^4} - m_ec^2, \quad [9]$$

where the uncertainty for each data point is propagated by the formula; (presuming 100% accuracy for constants)

$$\Delta KE = \Delta B\left(\frac{\partial KE}{\partial B}\right). \tag{10}$$

The counts can be converted to counts per second using the relationship;

$$R_{tot} = \frac{n}{T} \pm \frac{\sqrt{n}}{T}, \tag{11}$$

where for Sr90, $T_{\mathrm{Sr90}} = 60s$ and for Na22, $T_{\mathrm{Na22}} = 200s$. The values can then be corrected using the measured background radiation;

$$R_{source} = R_{tot} - R_{bg}, \tag{12}$$

where as (I hope) they're independent, the error propagates using the formula;

$$\Delta R_{source} = \sqrt{\left(\frac{\sqrt{n}}{T}\right)^2 + \left(\frac{\sqrt{n_{bg}}}{T_{bg}}\right)^2}. \tag{13}$$

By plotting the corrected counts vs the beta particle kinetic energy in keV, the Beta spectrums for both sources can be observed;

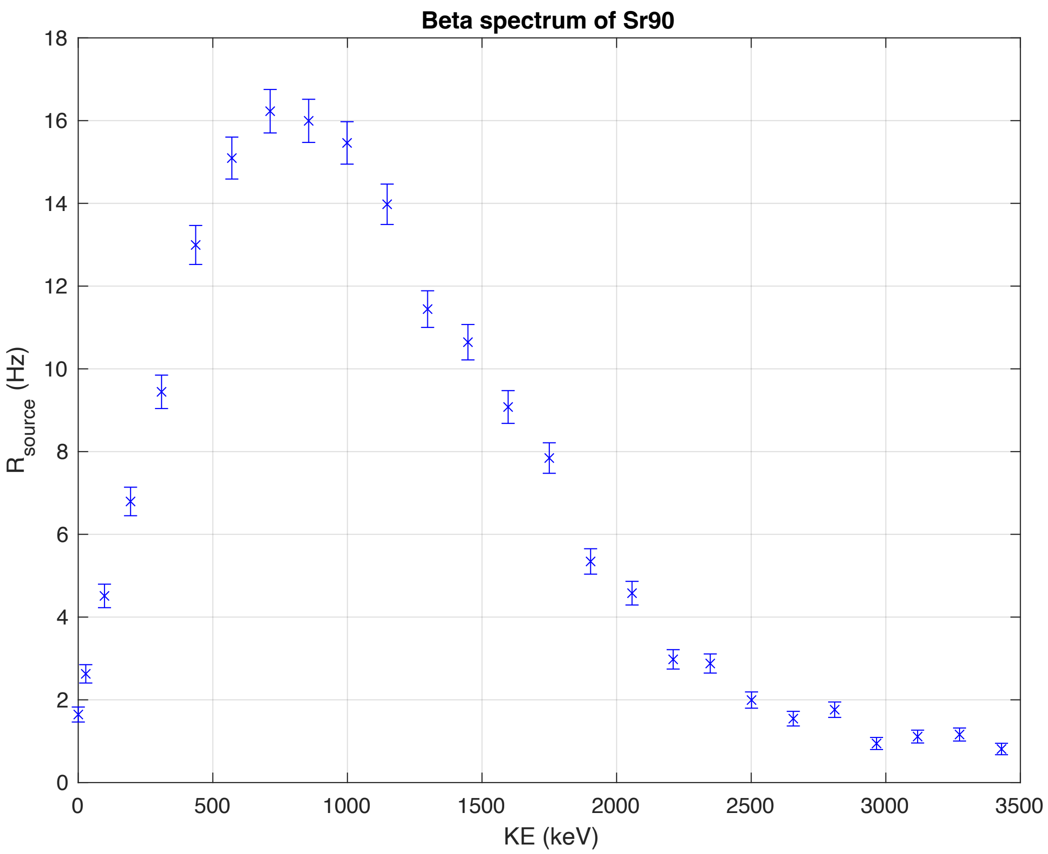

Figure 2: Plot of corrected counts vs beta particle kinetic energy's showing beta decay spectrum of Sr90.

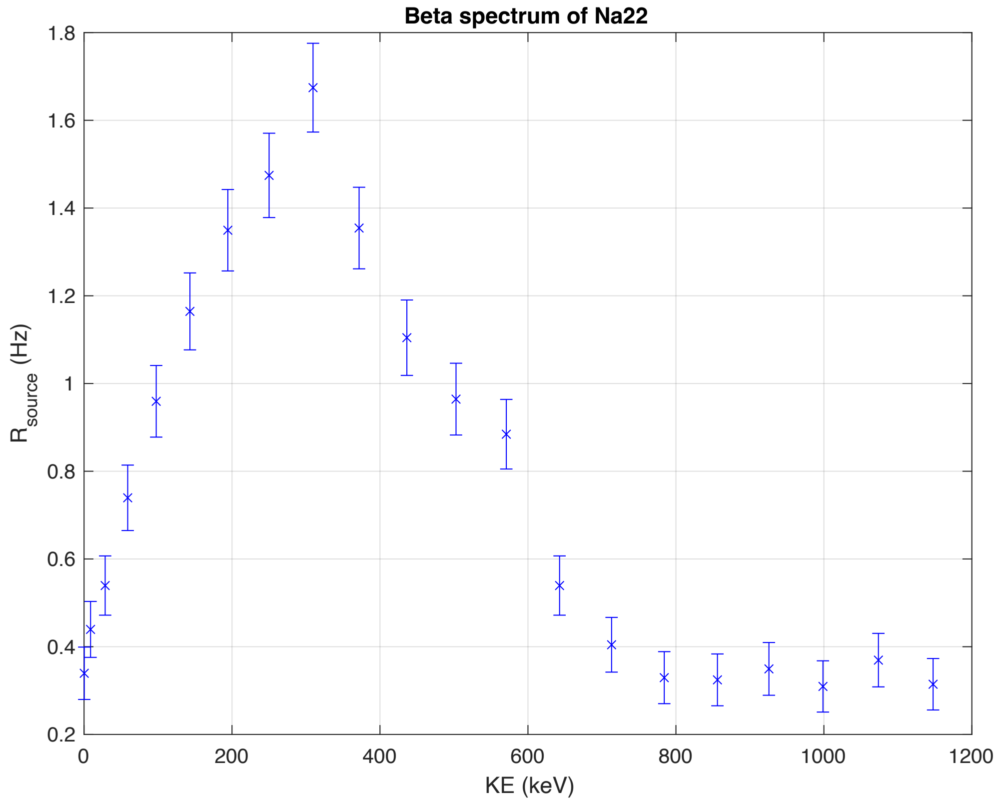

Figure 3: Plot of corrected counts vs beta particle kinetic energy's showing beta decay spectrum of Na22.

The data needs to be manipulated into the form of a Kurie plot which for the spectrum of beta particles has the form;

$$(Q - K_e) \propto \sqrt{\frac{n_e(p)}{p^2 F(Z', p)}}. \qquad [14]$$

Through assumptions outlined in section 2.3.1 of the BS Student notes, $F(Z', p)$ can be considered constant thus the function takes the form of;

$$\sqrt{\frac{n_e(p)}{p^2}} = C(Q - K_e), \qquad [15]$$

where C is some proportionality constant. Momentum can be expressed as $p = Bre$ but as r and e are constant, they can be pulled into C. Thus the final relationship is;

$$\sqrt{\frac{n_e(B)}{B^2}} = C(Q - K_e), \qquad [16]$$

which when $\sqrt{\frac{n_e(B)}{B^2}}$ is plotted against K_e, the x-intercept should be Q. The values for B and for $n_e(B)$ are known and thus when plotted, the linear part of the plot can be estimated linearly and the value for Q read off the graph. The plots and linear fits are;

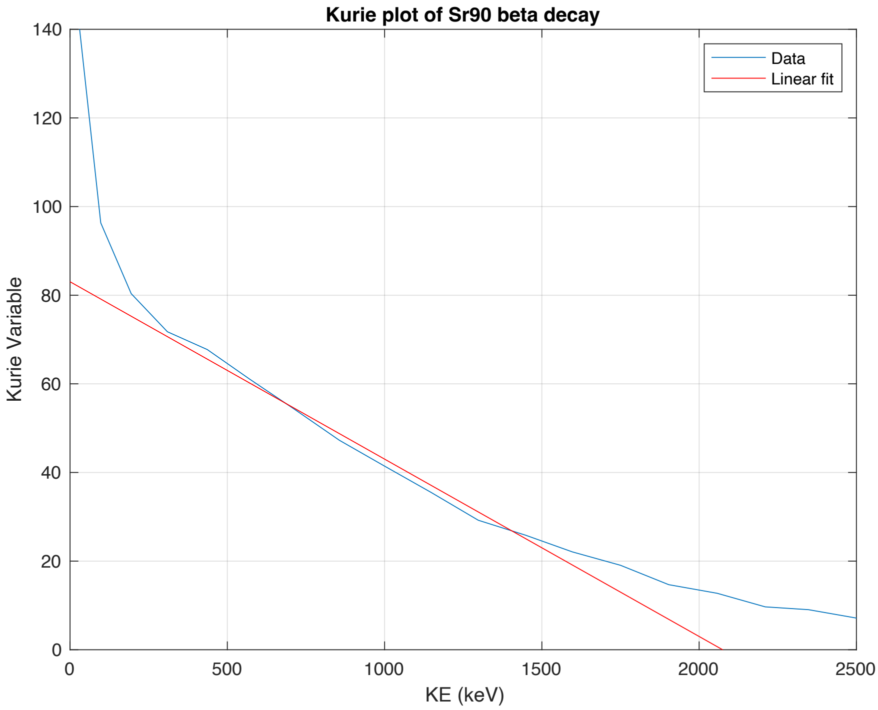

Figure 5: Kurie plot of Sr90 beta decay spectrum showing linear fit.

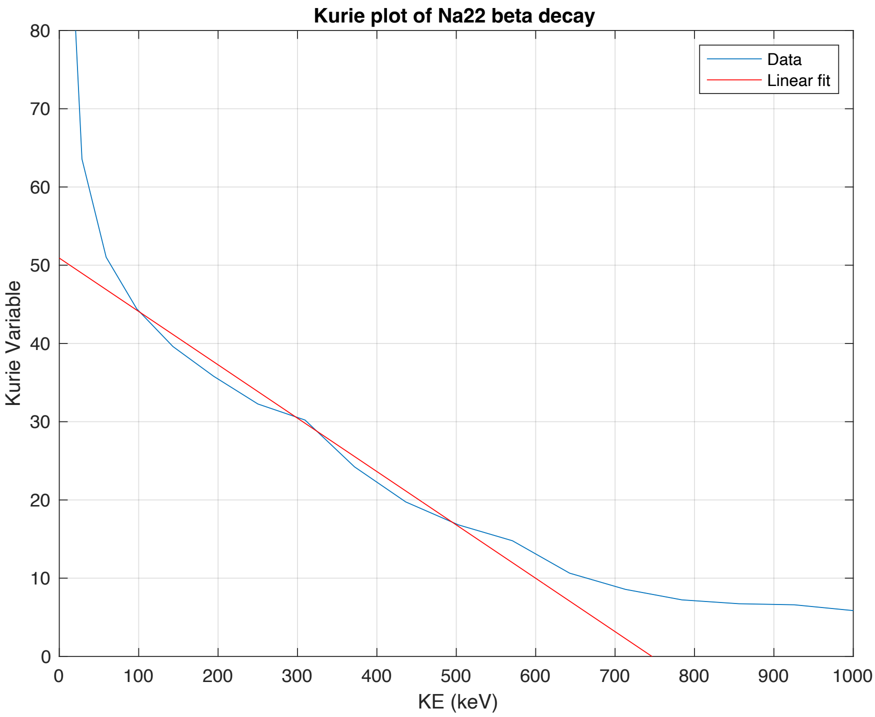

Figure 4: Kurie plot of Na22 beta decay spectrum showing linear fit.

The linear fit function for Sr90 is;

$$KV = (-0.0400 \pm 0.0040)KE + (83.0 \pm 4.3) \quad [17]$$

And for when $KV = 0$, $KE = Q$ thus the form of Q is;

$$Q_{Sr90} = \frac{(83.0 \pm 4.3)}{(0.0400 \pm 0.0040)} = 2075.0 \pm 5.0\ keV. \quad [18]$$

The error was propagated from linear fit to Q in the form;

$$\Delta Q_{Sr90} = \sqrt{4.3^2 + \left(\frac{0.004}{0.04^2}\right)^2}. \quad [19]$$

(This uncertainty is just so wrong, I can't figure out how to propagate KE or KV uncertainty through the linear fit of the Kurie Plot)

The theoretical value for $Q_{Sr90} = 2825\ keV$ thus the accuracy to theoretical is;

$$(Q_{Sr90})_{accuracy} = 26.5\%. \quad [20]$$

The linear fit function for Na22 is;

$$KV = (-0.0682 \pm 0.0095)KE + (50.9 \pm 3.2) \quad [21]$$

And for when $KV = 0$, $KE = Q$ thus the form of Q is;

$$Q_{Na22} = \frac{(50.9 \pm 3.2)}{(0.0682 \pm 0.0095)} = 746.3 \pm 3.8\ keV. \quad [22]$$

The error was propagated from linear fit to Q in the form;

$$\Delta Q_{Na22} = \sqrt{3.2^2 + \left(\frac{0.0095}{0.0682^2}\right)^2}. \quad [23]$$

(This uncertainty is just so wrong, I can't figure out how to propagate KE or KV uncertainty through the linear fit of the Kurie Plot)

The theoretical value for $Q_{Na22} = 546\ keV$ thus the accuracy to theoretical is;

$$(Q_{Na22})_{accuracy} = 36.7\%. \quad [24]$$

FINAL QUESTIONS

Question 8:

The beta spectrum is not discrete as the particles take on a range of kinetic energies. If the neutrino was not a decay product, the kinetic energy of the beta particle would be known and thus the spectrum would have defined peaks at the decay kinetic energy. This supports the conclusion in question 1 of the pre-work.

Question 9:

The values for Q for each decay source are within 40% of their theoretical value thus do show the general trend of both beta decay energies. The uncertainty that is shown at the final product is a vast understatement, so no conclusions are going to be drawn for if the final answer is within uncertainty.

Question 10:

a) It should be zero. This is not observed.

b) There are other decay products for each of the beta sources that are not considered. The other Sr90 decay products occur at a low probability but for Na22, the main decay product will be a high energy gamma ray which would significantly increase the background radiation.

c) Change the detector such that it only records beta particles.

Question 11:

I don't believe so. The main product observable would be an x-ray which is not picked up by the GM tube.

DISCUSSION

The results are somewhat depictive of the theoretical beta decay spectrum but how the error propagation was conducted in this report made it hard to find an exact quantitative answer. The error propagation was successful in finding the error in the actual spectrum which is observed in the error bars in Figure 2, Figure 3. When it came to propagating the error through the line of best fit of the Kurie plots in Figure 4, Figure 5 it failed. The error introduced by the linear estimation is found but not the error in the previous calculations of KE or the Kurie Variable.

CONCLUSION

The experiment was successful in showing the beta decay spectrum of Sr90 and Na22 and was moderately successful in finding values for their total decay products total kinetic energy, Q. Q for Sr90 was found to have a value of $Q_{Sr90} = 2075\ keV$ which has a percent accuracy to the theoretical of 26.5%. and Q for Na22 was found to have a value of $Q_{Na22} = 746\ keV$ which has a percent accuracy to the theoretical of 36.7%. The uncertainties of these values are not given as there was not successful error propagation through the report. The values should be taken as trends only.

REFERENCES

[1] UNSW, “Beta Decay Spectroscopy Student Notes”. 2018