

PHYS 403

Lab Report (100 pts) Grading Method

Names _____ Ben Chrysler and Eric Yu _____

CRITERIA	Eugene	Alexey
Science overview (20)	20	20
Procedures (30)	30	30
Results / Analysis (30)	30	30
Technical quality of the report: graphs, figure captions, tables, references, check spelling etc. (20)	20	20
Final Totals (100)	100	100

OTHER COMMENTS: Great job!

100

Excellent report. One small comment - take care about number of significant digits (see your graphs) - no deduction (ec)

Angular correlation of gamma rays in sodium-22 and cobalt-60 beta decay

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Abstract

Measuring the angular correlation of successive gamma rays emitted when an excited nucleus decays to its ground state is used as a probe to study the structure of excited nuclear states. We perform angular correlation measurements using scintillation detectors and coincidence counters on the decay products of ^{22}Na and ^{60}Co . For ^{22}Na , we study the pair of gamma rays created through pair annihilation and find that the angular correlation follows a gaussian centered at $\theta \approx 180^\circ$ with a width dependent on the angle the detector covers, as expected.. For ^{60}Co , we find that the angular correlation is consistent with spin states of $J_3, J_2, J_1 = 4, 2, 0$ and quadrupole-quadrupole transitions.

Introduction

When radioactive isotopes undergo β decay, the resulting nucleus of the new element is in an excited nuclear state. Upon deexciting to the ground nuclear state, a gamma ray is emitted. For example, ^{22}Na undergoes β^+ decay to an excited nuclear state of ^{22}Ne , which then deexcites to its ground state and emits a gamma ray (Fig. 1(a)). Sometimes, the nucleus will deexcite to an intermediate state before fully exciting to the ground state and in turn emit two successive gamma rays. An example of this is ^{60}Co , which undergoes β^- decay to ^{60}Ni which emits two gamma rays as it passes through an intermediate excited state as it deexcites to its ground nuclear state (Fig. 1(b)) [1]. When two gamma rays are emitted in a single process, there might be a correlation between the directions the gamma rays are emitted in. This correlation can be described by the angular correlation function $W(\theta)$, which gives the probability that the second gamma ray is emitted at an angle θ from the first [5].

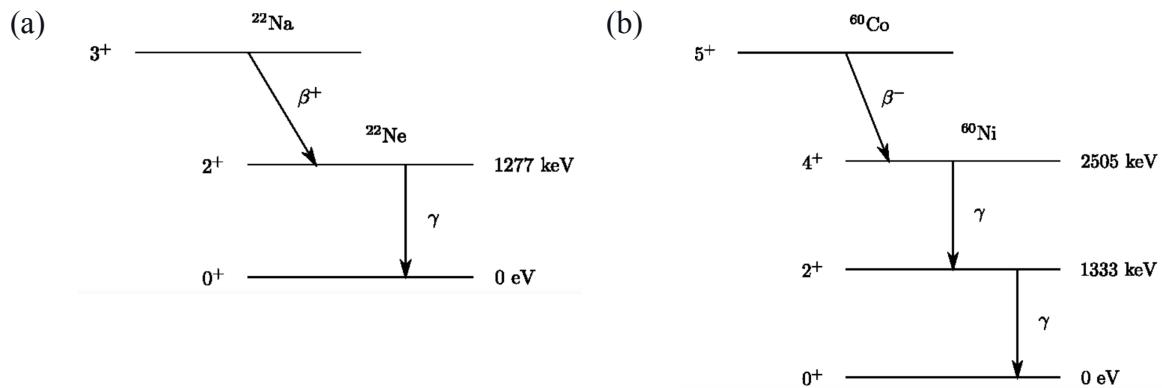


Fig. 1 Nuclear energy level diagrams. **(a)** ^{22}Na undergoes β^+ decay to an excited nuclear state of ^{22}Ne , which emits a gamma ray upon deexciting to its ground state. **(b)** ^{60}Co undergoes β^- decay to an excited nuclear state of ^{60}Ni . When ^{60}Ni deexcites to its ground state, it passes through an intermediate excited state, thus emitting two gamma rays [5].

In the decay of ^{22}Na , there are actually three gamma rays that are emitted. A 1277 keV gamma ray comes from nuclear the deexcitation of ^{22}Ne to its nuclear ground state as shown in Fig. 1(a). The other two are the result of β^+ decay, which emits an electron neutrino and a positron. When the positron annihilates with an electron in surrounding atoms, two 511 keV gamma rays are emitted in opposite directions to conserve momentum (Fig. 2). Thus, the angular correlation $W(\theta)$ of the two gamma rays is determined by

$$W(\theta) = \delta(\theta - \pi) [1]. \quad (1)$$

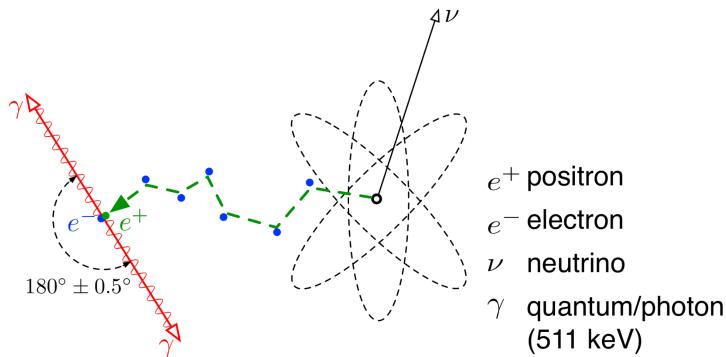


Image courtesy Jens Maus

Fig. 2 Gamma rays emitted from electron-positron annihilation. The positron from β^+ decay annihilates with an electron in surrounding atoms to create two 511 keV gamma rays (photons). The gamma rays are emitted in opposite directions because of conservation of linear momentum [1].

The two gamma rays emitted from electron-positron annihilation aren't from two successive nuclear transitions. Rather, the high anisotropy of these two gamma rays will be used to calibrate our measurement setup.

Cases like ^{60}Co , however, are not so simple since the two emitted gamma rays are the result of two successive nuclear transitions. After ^{60}Co undergoes β^- decay to an excited nuclear state of ^{60}Ni , two gamma rays when ^{60}Ni deexcites to its ground state through an intermediate state. The angular correlation function $W(\theta)$ will depend on the angular momenta of the three states involved in the two transitions and on the multipole order of the emitted gamma rays in each transition [3]. In general, the angular correlation function is

$$W(\theta) = 1 + \sum_{i=1}^l a_i \cos^{2i}(\theta) \quad (2)$$

where $2l$ is the order of the lowest multipole and the coefficients a_i are determined by the angular momenta of the levels (given by [3] for all possible angular momenta). For the deexcitation of ^{60}Ni that follows the β^- decay of ^{60}Co , the two gamma rays are both of

quadrupole electric order and the angular momenta of the initial, intermediate, and ground states are $J_3, J_2, J_1 = 4, 2, 0$, which gives the angular correlation function

$$W(\theta) = 1 + \frac{1}{8}\cos^2(\theta) + \frac{1}{24}\cos^4(\theta) [4][5]. \quad (3)$$

Since we already know what the spins of the excited nuclear levels of ^{60}Ni and the multipole order of the transition from past experiences, we will be attempting to replicate these results by fitting data we obtain experimentally to eq. 3. Usually, the measurements of the angular correlation of successive gamma rays are used to study the structure of excited nuclear states. In particular, experimentally obtained angular correlations are compared to eq. 2 to determine the angular momenta of different nuclear levels as well as the multipole order of transitions like in [4]. Additionally, studying how angular correlations are perturbed in the presence of an external field can be used to measure the nuclear relaxation times and rotational correlation times of molecules bound to the radioactive nuclei. Because of this dependence, a radioactive nucleus can be used as a rotational tracer in biological applications [6].

Procedure

Our general setup relies on a radioactive sample in the center of our detectors. Both detector A and detector B are applied at a voltage of 1000 millivolts. In this setup we have both detectors hooked up in the setup below. We have the setup hooked up to the scintillator / electronics setup in figure 3 to count our gamma detections as when a gamma ray hits our detector it will go through our such system being detected by the scintillators. Our general procedure for acquiring data is that we first place the sample on the center platform, apply our voltage to our detectors and then we keep detector A stationary and then rotate detector B by 5 degrees. We then record our data for 2 minutes for Sodium and Cobalt for 15 minutes. This is due to the lifetimes of each sample being drastically different with sodium decaying much more rapidly than cobalt does.

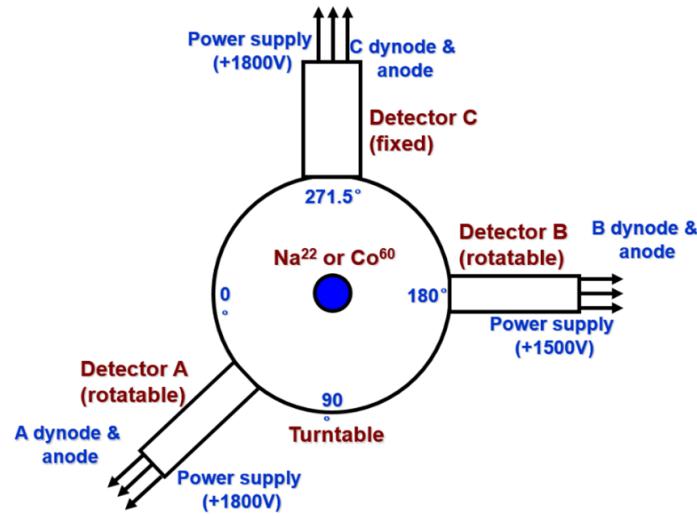


Fig 3: our general setup for collecting data for our sample. The detectors are on a 360 degree circle in which we can move both detectors around that 360 circle in which our radioactive sample is in [the center.

Electronics setup

Our electronics setup has us managing several independent variables to increase the number of gamma rays that enter our detectors for Cobalt 60 and Sodium 22. The main things that need to be optimized in this setup is our voltage threshold and managing our delay channels for our voltages in which they will both detect the gamma ray at the same time.

Coincidence circuit to establish individual counts for each detector & coincidence counts

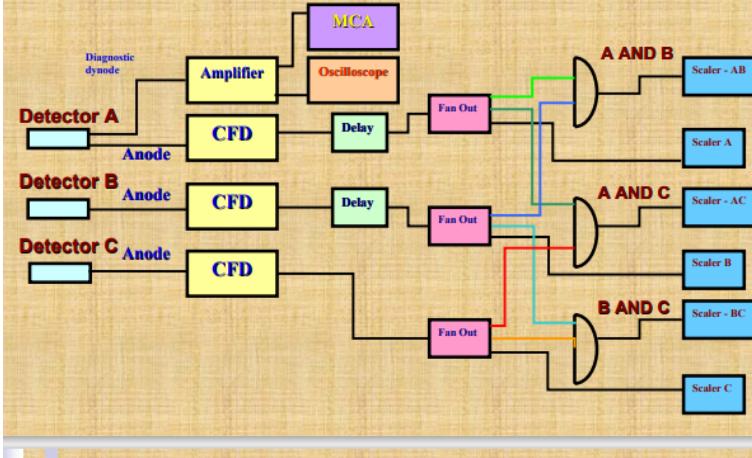


Fig 4 : electronics setup of how the gamma rays are detected in which detector a and b are hooked up to scintillators that manage our detection and can be hooked up to an oscilloscope to measure the voltage delay and a multi channel analyzer to input to measure and control the gamma gamma particle energy thresholds.

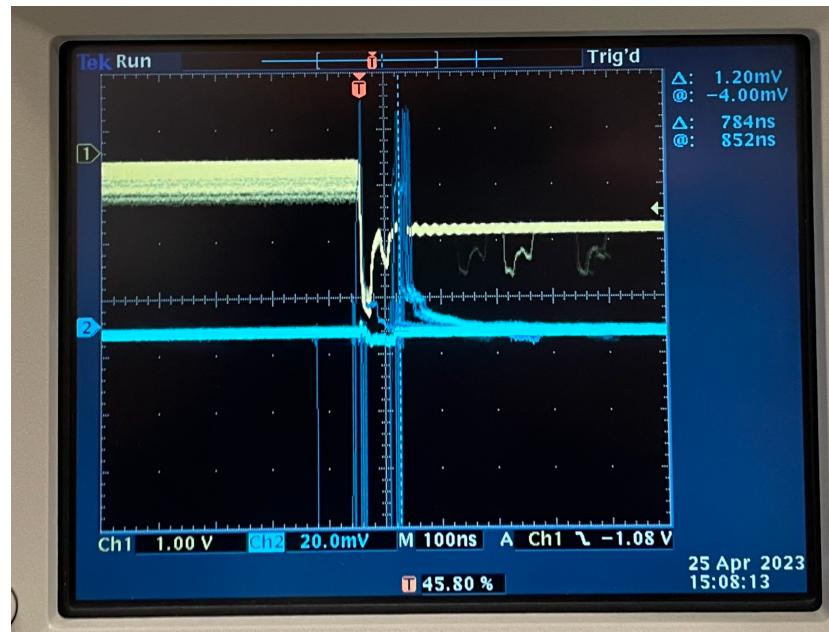


Fig 5 : our oscilloscope setup to measure our voltage delays to make sure both detectors are receiving and sending signal to maximize our coincidence counts

Our energy threshold optimization was done in order to maximize our given samples gamma ray distribution. We did this by using our multi count analyzer and hook it up to one of the detectors in which we then control our highest range and lowest range for our gamma count. These counts are supposed to be maximized around 1277 keV for Sodium and 2506keV for Cobalt as these values are the optimum range for gamma detection on our given setup.

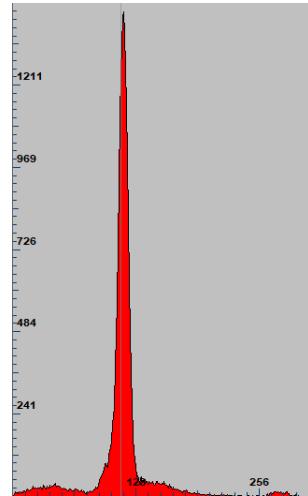


Fig 6: Sodium 22 energy distribution after optimization

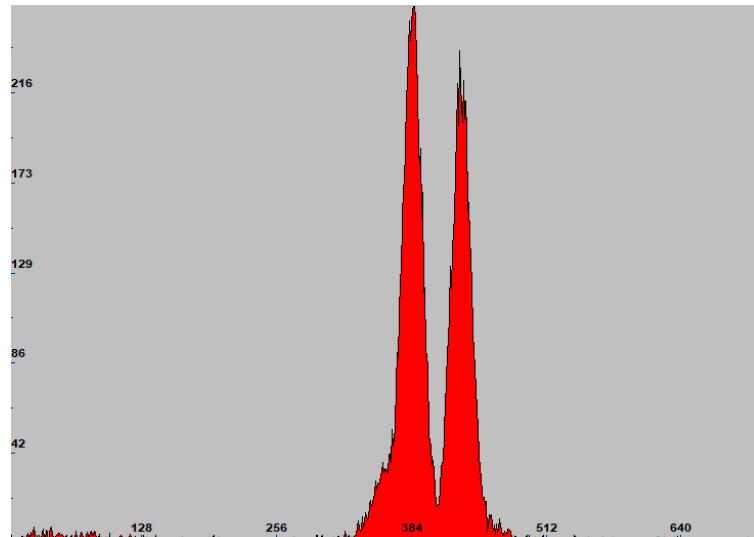


Fig 7: Cobalt 60 energy distribution after optimization

Results & Analysis

Our Sodium 22 result fits follow the given distribution for sodium that we require. That being that our gamma rays will follow a max peak around 180 degrees and suddenly drop off from their following a given gaussian distribution. When analyzing the graph we notice we get a 10 degree error on our data . This is due to the detector being of a width of 10 degrees on our

setup meaning that the gamma rays won't hit perfectly on 180 for our angle distribution thus shifting it over to 182 degrees. This follows our given delta distribution as by theory our gamma rays from our sodium sample is shooting gamma rays at 180 degree relative to our sample.

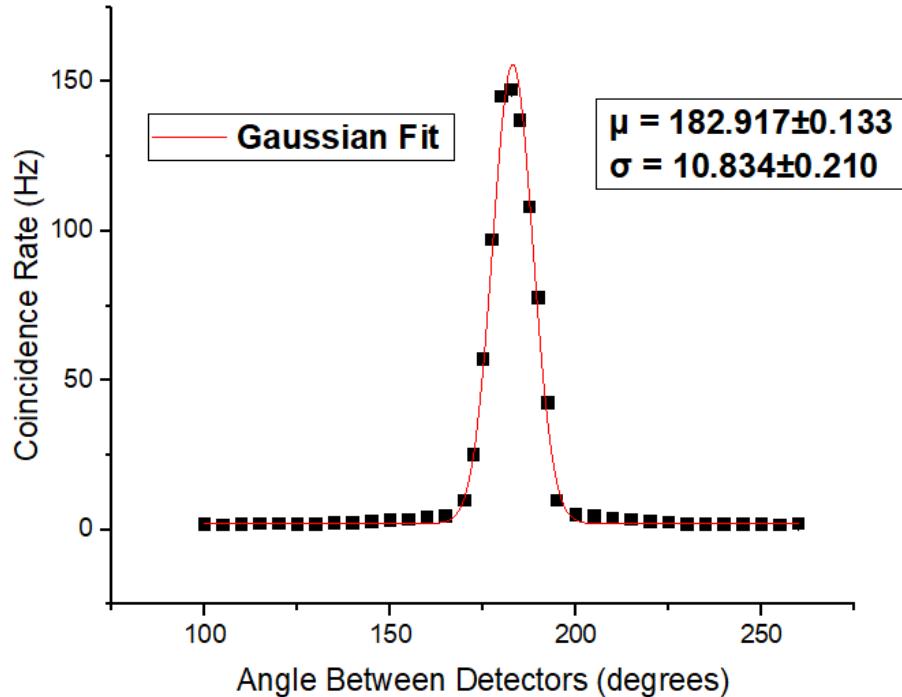


Fig 8 : Sodium 22 gamma ray Coincidence rate vs angle following a gaussian distribution

For our Cobalt results we used the same process as for Sodium in which we do an angle scan of 5 degrees . We find that we have to normalize our results due to the nature of Cobalt 60. So first in that normalization we have to measure the background count of the gamma rays thus we have to measure the system with no sample and with max voltage delay to get the background count. The resulting background count that we observe over a 15 minute time frame 50 for AB coincidence count is such that the rate given is 0.064. Thus after obtaining our background counts we normalize our Coincidence count using equation 4.

$$AB_{Coinc} = AB_{coinc} - AB_{Background} \quad (4)$$

Thus after doing that we need to normalize our AB results to detector A and B. This is to average out our counts from both detectors since Cobalt by nature has a more sinusoidal distribution thus we use a normalizing function to both detectors A and B

$$AB_{C\text{oinc}-N\text{orm}} = \frac{\overline{AB}_{C\text{oinc}}}{\frac{\overline{A}}{\overline{A}_{\text{Average}}} * \frac{\overline{B}}{\overline{B}_{\text{Average}}}} \quad (5)$$

After normalization we can see that our results follow the sinusoidal trend that it is supposed to follow for Cobalt 60. This results mostly follow the curve given in equations 3 and with a standard error distribution of

$$\sqrt{AB_{C\text{oinc}-norm}} \quad (5)$$

we see that our results will align with our theory. When fitting, we fix the second coefficient $A_{44} = 1/24$ and find that the first coefficient generally agrees with the theoretical value of $A_{22} = 0.125$. Though, the error bar on our value is rather high.

To improve the error, we can also factor in our 10 degree angle error from our previous Na sample in accounting for that with our Cobalt sample since we are using the same detectors and we find that our results are pretty accurate. We can also improve the error bars on individual data points by getting more counts, either by increasing the time of each data run (from an already long 15 minutes) or by using more active samples.

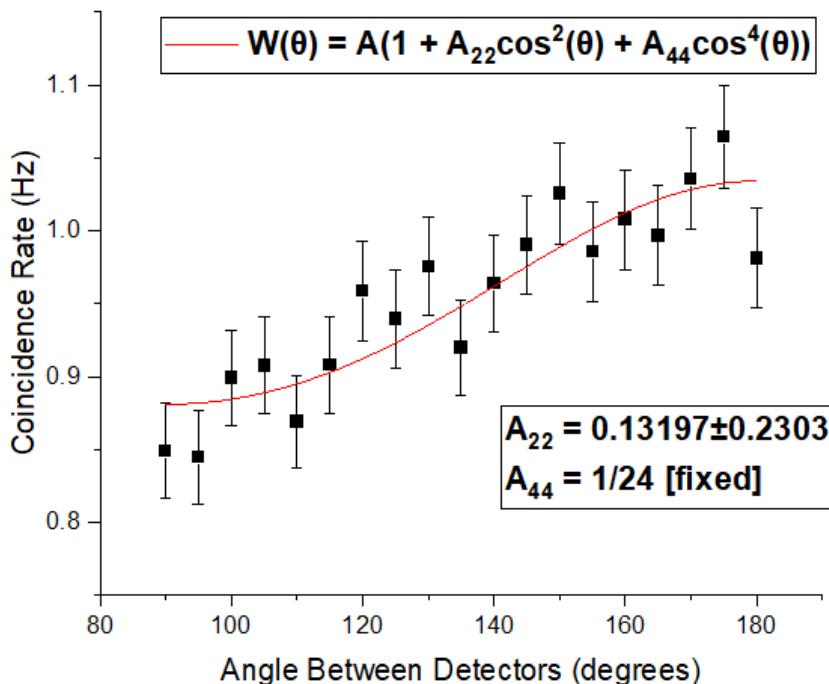


Fig 9 : Cobalt 60 gamma ray Coincidence rate vs angle following a sinusoidal distribution
Conclusions

We measure angular correlations of ^{22}Na and ^{60}Co that are generally in agreement with theoretical results. Our ^{22}Na measurements follow a gaussian distribution centered a

$\theta \approx 180^\circ$. Our ^{60}Co measurements are consistent with spin states of $J_3, J_2, J_1 = 4, 2, 0$ and quadrupole-quadrupole transitions. With longer data acquisition periods and more active samples of ^{60}Co , we suspect that the high error in our coefficient values would decrease.

Appendix

References

1. A. C. Melissinos and J. Napolitano. Experiments in Modern Physics. *San Diego, Academic Press* (2003).
2. G. Goertzel. Angular Correlation of Gamma-Rays. *Physical Review* **70**, 897 (1946). doi:10.1103/PhysRev.70.897
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