

# B-3 Angular Correlation

## From Physics 191r

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first experiment: II

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## LEARNING GOALS

- Use Compton scattering to probe polarization of gamma rays
- Observe angular polarization correlation between gamma rays created in electron/positron annihilation
- Learn to use nuclear instrumentation modules such as sodium iodide detectors, amplifiers, single channel analyzers and coincidence detectors
- Perform nonlinear curve fits
- Work safely with radioactive material

## INTRODUCTION

In October 1946, John Wheeler published an article on the subject of “polyelectrons ,”<sup>[1]</sup> atoms consisting of

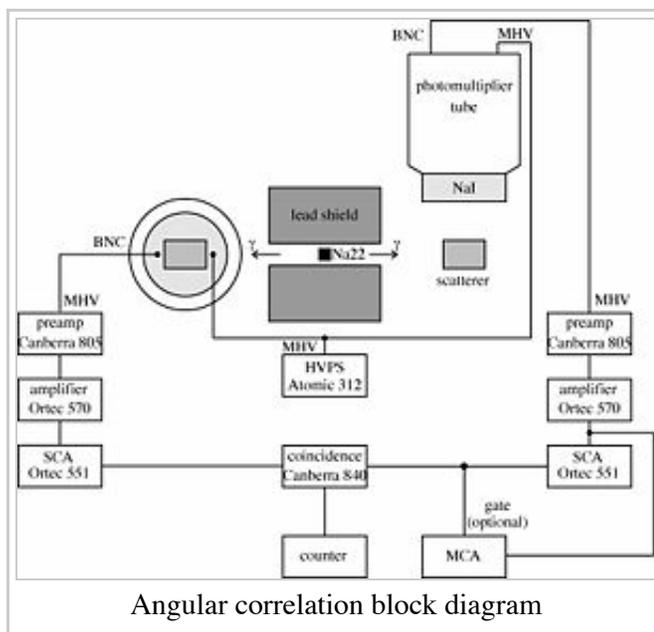
electrons and positrons. He postulated the lifetime of the bi-electron (known today as positronium) to be on the order of  $10^{-10}$  seconds or longer, and raised but left unanswered the question of whether larger such atoms or even crystals of polyelectrons might be stable.

Wheeler suggested two experiments to test his "pair theory:" 1) Collect a gas of polyelectrons and measure its emission spectrum. 2) Pair theory predicted that the two photons that emerge from an annihilation event would be polarized at right angles. Wheeler proposed the use of Compton scattering to detect this polarization correlation.

The second idea has been implemented in the current experiment. The experimental arrangement needed consists of two collimated antiparallel beams of annihilation radiation from a single source incident upon two scatterers. See the figure below. Two detectors are arranged to intercept the radiation scattered through approximately  $90^\circ$  at variable azimuth. An asymmetry should be observed in the number of photons arriving at the detectors in coincidence when the relative azimuth of the detectors is varied.

## APPARATUS

The present apparatus is similar to the one used by Wu and Shaknov<sup>[2]</sup>. A source of annihilation radiation is placed at the center of a lead cylinder. A fraction of the radiation is collimated by a 3/8-in. diameter hole drilled down the axis of the cylinder. At both ends of the hole, the gamma radiation scatters from cylindrical copper or aluminum plugs. Scintillation detectors are mounted at both ends of the cylinder so as to intercept radiation scattered through approximately  $90^\circ$ . Each detector may be positioned at any azimuth about the axis of the cylinder. The events of interest are those in which an annihilation event in the source creates two 511-keV gamma rays which each scatter into one of the detectors. The events of interest are extracted from the other detected events by coincidence analysis. A schematic diagram of the apparatus is shown below with the detectors at  $90^\circ$  relative azimuth (not to scale).



## Annihilation Radiation Source

The source is an  $1890\text{-}\mu\text{Ci}^{[3]}$   $^{22}\text{Na}$  radionuclide sealed in a stainless steel capsule. There should be no need to remove the source from the apparatus. Its position is adjustable vertically via a micrometer screw. Know your safety precautions for handling radioactive materials. You must have attended the "Radiation Safety Lecture" given at the beginning of the semester before you can carry out this experiment. Check the gamma radiation near the source as well as the areas in which you work. Record the dose rates in the radiation log book at the beginning and end of each laboratory session; notify the staff of any significant changes. Plan out what precautions and safety measures you must make during the course of your experiment. Wear the personal dosimeters and record your dose at the end of every laboratory in the logbook.

## Scatterers

Cylindrical aluminum and copper scatterers are available in various lengths. There are a number of holders for the scatterers; choose from these based on the proximity to the source which you require for your measurement.

## Scintillation detectors

The detectors<sup>[4]</sup> consist of 1.25-inch diameter by 1-inch long cylindrical thallium doped sodium iodide scintillation crystals coupled to photomultiplier tubes (PMTs). When annihilation gamma rays enter the scintillation crystals, they lose energy in the crystals via Compton scattering and the photoelectric process. The resulting energetic electrons cause ionization or excitation of the phosphor. The excitations decay by emitting visible light which is detected by the PMT.<sup>[5]</sup> The PMTs require positive high voltage; one thousand volts is sufficient (1250 V maximum). The voltage divider in each tube has a resistance of approximately 6 MΩ.

## Instrumentation for coincidence analysis

The output of the photomultiplier tubes is a negative current pulse, the magnitude of which is proportional to the energy of the detected gamma ray. The negative current pulses are converted to positive voltage pulses by preamplifiers (Canberra Model 805) and further amplified by spectroscopy amplifiers (Ortec Model 570). The amplifiers are capable of making pulses up to ten volts in height. The spectrum of pulse heights is analyzed by single channel analyzers (Ortec Model 551), which output logic pulses only when the input pulses fall within a voltage window set via the front panel controls. In “normal” mode, the window width is set by the lower level discriminator (LLD) and upper level discriminator (ULD). Each SCA has a variable delay; the relative delay between the two SCAs must be set correctly for the coincidence measurement to be successful. The positive output pulses from the SCAs are sent to a coincidence module (Canberra Model 840) which gives an output pulse when its engaged inputs are all switched high within a time interval called the resolving time. The resolving time is set via a front panel potentiometer. Consult the manual for dial calibration. The output pulses from the coincidence unit may be counted with a digital counter. Note that the counter requires negative input pulses.

## Multichannel Analyzer

The multichannel analyzer (MCA) performs a function similar to that of the single channel analyzer, with an added level of sophistication. Rather than creating an output pulse for certain input pulses, the MCA sorts the input pulses which fall in a voltage window (also set by an LLD and ULD) into many voltage bins; it stores the number of counts in each bin and plots a histogram of counts vs. bin number. Since the height of the scintillator pulses is proportional to the energy of the detected gamma ray, the MCA is plotting number of events vs. energy.

The MCA is an Ortec TRUMP-PCI-2K card installed in a Dell Optiplex GX280. Software called Maestro talks to the PCI card. Two of the inputs are of interest – the signal "IN" and the "GATE" input. For basic operation, open Maestro and turn the ADC Gate Off<sup>[6]</sup>. Connect the amplifier output to the TRUMP-PCI-2K signal "IN" and click the GO button. To save data, select File:Save, and Save as type: ASCII SPE. This produces a file containing the counts in each channel. It can be opened with Notepad.

In order to check the SCA window, use the Gate:Coincidence mode. The SCA output will gate the analyzer on when active. Unfortunately, the timing requirements are quite specific, and the direct SCA output is not

adequate to gate the analyzer. Quoting the manual, "[The Gate] signal must occur prior to and extend 0.5  $\mu$ sec beyond the peak of the pulse." To achieve this, use the Canberra 1457 Delay Amp to delay the amplifier output, and the Canberra 2055 Logic Shaper to extend the duration of the SCA output.

## EXPERIMENTAL PROCEDURE

Read the pertinent sections of the manuals in the bench notes and know the limitations of the equipment regarding pulse amplitudes and polarities and the voltage requirements of the PM tubes. Bench Notes and manuals must remain in the laboratory.

The first step in alignment of the apparatus is to optimize the source position. This is done by minimizing the asymmetry of the counts in a single detector as a function of angle. You may also wish to check the effect of the earth's magnetic field on the detectors. Mu-metal shielding can be wrapped around the PMTs if desired.

Next use the MCA to measure the direct spectrum from the  $^{22}\text{Na}$  source. There should be a high-energy gamma ray in addition to the annihilation radiation. Do an energy calibration and take note of how the detector resolution changes with energy. Set the detector azimuths and distance from the scatterers to the detectors. Measure the energy spectrum of the scattered gamma rays and use this information to set the SCA windows.

Before attempting to make a coincidence measurement, check the resolving time by monitoring the coincidence unit's input and output pulses. This is most easily done by either splitting the output from one preamplifier into both channels or by using the reference pulser (Canberra Model 1407). Set the relative delay between the two SCA output pulses and decide on a scheme for measuring the accidental coincidence rate. Then set up the coincidence measurement for an appropriate length of time.<sup>[7]</sup> Measure the number of coincidences as a function of angle between the detectors.

## NOTES

1. ↑ Annals of the New York Academy of Sciences 48, 219 (1946).
2. ↑ Physical Review 77, 242 (1950).
3. ↑ Source strength as of 1 May 2005. Half life equals 2.605 years.
4. ↑ Harshaw NaI(Tl) Integral Line Scintillation Detector Type 5S4/2I.
5. ↑ See Birks (1964) or Curran (1953) for details of scintillation detection. Early scintillation detectors used human eyes to detect the fluorescence. Fortunately in our apparatus, photomultipliers are substituted for the student's eye and counting electronics for a pencil and paper.
6. ↑ Under the "Acquire: MCB Properties" menu. This dialog box also allows you to choose Conversion Gain, LLD, ULD and zero adjust as well as preset run time parameters.
7. ↑ Calculate the expected coincidence count rate to order of magnitude and estimate the time required to accumulate enough counts for good statistics. Do this starting with the source strength, experiment geometry, the Klein-Nishina formula and the efficiency of the counters. Include this calculation in your report.

## REFERENCES

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## BENCH NOTES

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- Sodium 22 Holder Specifications  
([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/Na22\\_holder.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/Na22_holder.pdf))
- Scintillation Detector Specifications  
([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/NaIdetector.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/NaIdetector.pdf))
- How to Plug in the Preamps ([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/mhvpurgatory.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/mhvpurgatory.pdf))
- Atomic 312 High Voltage Power Supply  
([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/atomic312HV.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/atomic312HV.pdf))
- Canberra 805 Preamplifier ([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/canberra805.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/canberra805.pdf))
- Ortec 570 Amplifier ([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B2/ortec570.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B2/ortec570.pdf))
- Ortec 551 Single Channel Analyzer  
([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B2/ortec551.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B2/ortec551.pdf))
- Canberra 840 Coincidence Analyzer  
([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/canberra840.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/canberra840.pdf))
- BNC PB-3 Pulse Generator ([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/bncpb3.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/bncpb3.pdf))
- Canberra 1457 Delay Amplifier  
([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/canberra1457.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/canberra1457.pdf))
- Canberra 2055 Logic Shaper ([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/canberra2055.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/canberra2055.pdf))
- Attenuation Coefficients (Siegbahn)  
([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/B3/Attenuationcoefs.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/B3/Attenuationcoefs.pdf))
- Canary II Dosimeter ([http://www.fas.harvard.edu/~phys191r/Bench\\_Notes/canary.pdf](http://www.fas.harvard.edu/~phys191r/Bench_Notes/canary.pdf))

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