Experiments in Modern Physics
Two Photon Angular Correlation Measurements
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Goal
In this experiment you will learn time coincidence techniques and measure the correlation in angle between two photons ("gamma rays") that are emitted simultaneously from the same source.

Introduction
Frequently, in the decay of a nucleus, two (or more) photons will be emitted simultaneously (or, at least, very close). This can be due (as with $^{60}$Co) to the creation of a highly unstable nucleus which decays immediately in a "cascade" emitted several photons. Or (as with $^{22}$Na) two photons may be produced when a decay product, $\beta^+$ (a positron), annihilates inside the source. In this experiment, you will investigate the angular correlation of these "pairs" of photons that are produced in $^{22}$Na and $^{60}$Co. You will learn time-coinicidence techniques that are commonly employed in nuclear and particle physics. You will also analyze the data and to determine the experimental and theoretical aspects of these phenomena.

The ideas for this experiment were taken from References [1-3] - many details should be found there.

Equipment
- 2 NaI scintillation counters mounted on an adjustable angular spectrometer apparatus.
- High Voltage Supplies.
- Amplifiers, discriminators, coincidence units.
- Counter/Timer
- Gate and delay generator, delay amplifier.
- Oscilloscope, multichannel analyzer.
- 10$\mu$Ci $^{22}$Na source, 100 $\mu$Ci $^{60}$Co source.

Preparation
- Read about the decays of $^{22}$Na and $^{60}$Co in Refs [1,2,4].
- Read about scintillation counters and associated electronics in Refs. [4,5].
- Read about time coincidence techniques in Ref [3].

Precautions
These sources are quite active and should be handled with care. A 10$\mu$Ci $^{22}$Na source delivers 0.1 R/hr at 1cm, a 100 $\mu$Ci $^{60}$Co 1 R/hr at 1cm. Use ALARA principles when doing the experiment. Your instructor will install the $^{60}$Co source into the apparatus.
Setup
- Adjust the NaI detectors so that they are arranged at 180° and located about 30cm apart. Verify that they are aligned. Connect them to the HV supplies - make sure that the polarity is correct! Turn the HV to ~1800V. Look at the signals on the scope while doing this to be sure there are no light leaks.
- Obtain the $^{22}$Na source and install it in holder.
- Verify that there are simultaneous pulses in the detectors. The signals from the detectors should have a maximum amplitude of ~100mV.
- Hook up the electronics as shown in Figure 1.
- Adjust the gain of the amplifiers so that the output at this stage is the approximately the same for both detectors (gain setting ~16).
- Verify the signals at each stage in the chain above and verify that there is a substantial coincidence rate on the counter/timer.

What does each module do? How does this circuit measure the coincidence rate? Do the cable lengths matter? How does the rate change with distance from the source? What is the coincidence rate with no source in place? What are the count rates of the detectors individually (the "singles" rate)?
**Experiment**
- Plot the singles rate of the counters as a function of discriminator setting (on the SCA). Determine the optimum setting. When set correctly the singles rate for each counter will be approximately equal.
- Check the time widths of the logic pulses into the coincidence circuit. Make a "delay curve": a plot of coincidence rate as the delay on the SCAs is changed. Determine the optimum delay settings and the resolving time [1,2]. Note that with our setup the resolving time is much larger than in [1,2].
- With the $^{22}$Na source in place, obtain an energy spectrum with the MCA when both with and without the coincidence requirement.
- Measure the coincidence rate from $^{22}$Na as a function of angular separation. Record the singles rate for each detector. Do this for 2 different source-detector distances. One of these should have the distance between counters as large as possible while maintaining a large counting rate. You want the statistical errors on your measurements to be as small as reasonable. Do this in $2^\circ$ steps around $180^\circ$ - bigger steps where the rate is lower.
- Measure the accidental background by removing the source.
- Have your instructor install the $^{60}$Co source.
- Repeat the measurement as above, however, since the angular correlation is different for this source, determine and optimum angular steps and detector separation. Remember to measure the accidental background.

**Analysis**
- Summarize all data in tables.
- Plot the "delay-curve". Is it consistent with the widths (in time) of the logic pulses.
- What is the accidental rate and signal-noise ratio?
- Plot the angular correlation data for $^{22}$Na. Indicate the background contribution. What is the angular width of the distribution? Is it consistent with the experimental setup?
- Plot the $^{60}$Co angular correlation data. Plot the quantity $\alpha(\theta) = C(\theta)/C(90^\circ)$ as a function of $\theta$. Fit to a function of the form [1,2]:

$$\alpha(\theta) = 1 + a_1 \cos^2 \theta + a_2 \cos^4 \theta .$$

Compare your results to that expected from the theory.

**References**
http://www.ortec-online.com/application-notes/an34/an34-front.htm