# GAMMA-GAMMA COINCIDENCE OVERLAP COINCIDENCE METHOD FOR MEASURING GAMMA-GAMMA COINCIDENCE OF $^{22}$NA

## RADIATION SAFETY

The radioactive sources used in this experiment are only a few microcuries in strength, and they are all sealed, so they actually pose no significant health hazard. However we will follow good safety procedure. Horseplay involving the sources is forbidden. While the sources are not dangerous, like any radioactive source they should be treated with respect and properly handled. Only the instructor is to handle the sources, and he/she will wash hands after handling the sources. When any source is not in use, it is to be stored behind lead shielding. In the event of any accident which results in spilled radioactivity, do not attempt to clean it up your self. The staff here at Building is specially trained for this and even they call someone else even more trained.

### PURPOSE

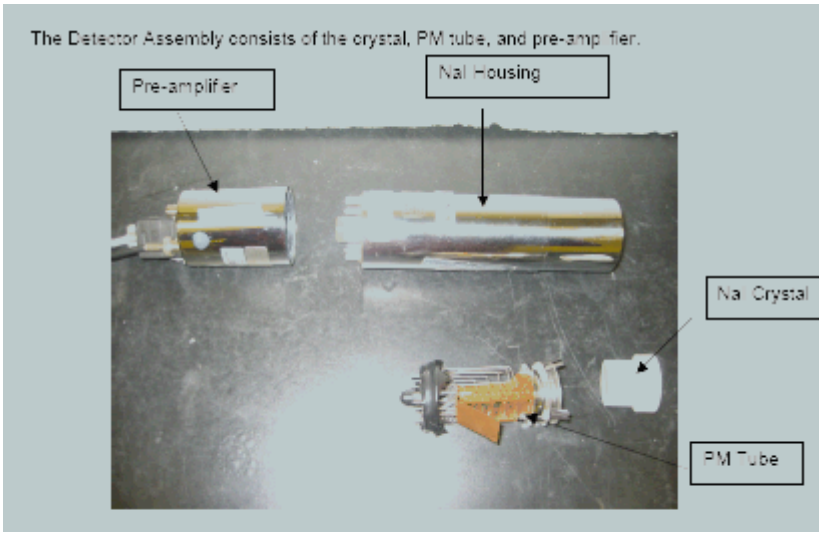
Two annihilation quanta are radiated from a $^{22}$Na source in coincidence with each other for each radiation event that will be measured in this experiment. The purpose of the experiment will be to verify that these quanta emanate from the source with an angular separation of 180°.

### INTRODUCTION

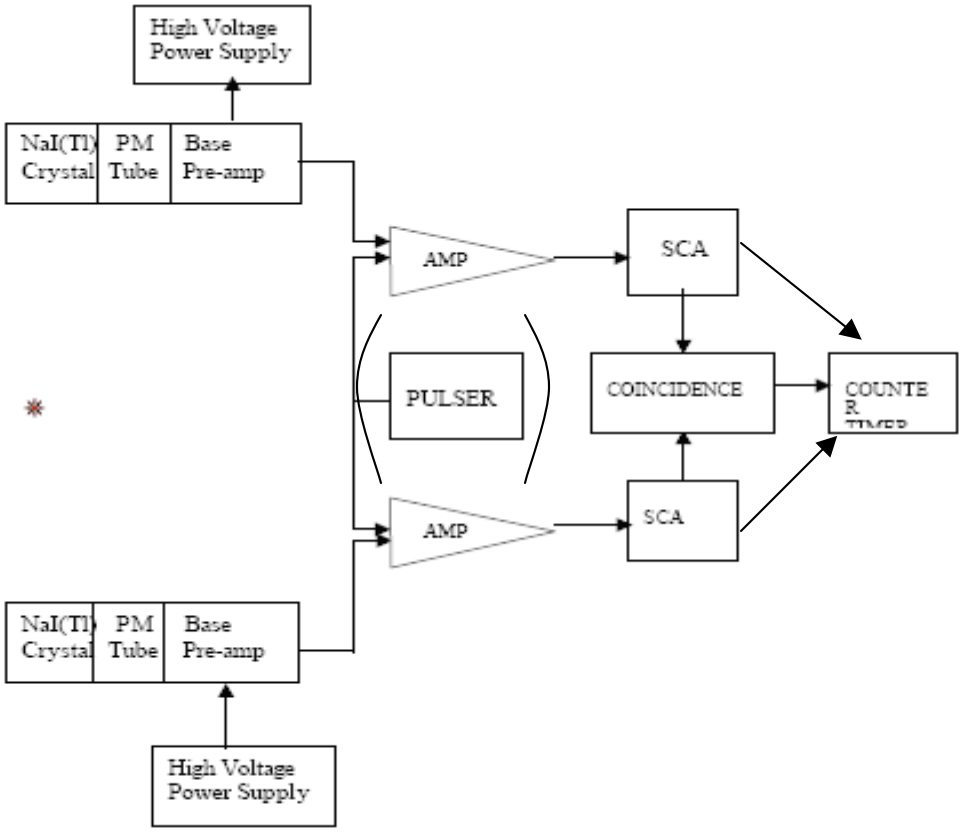
Sodium-22 is an excellent source for a simple gamma-gamma coincidence experiment. The decay scheme for this isotope is shown in Fig. 13.1. From the decay scheme it can be seen that 99.95% of the time the $^{22}$Na decay occurs by positron emission and electron capture through the 1.274 MeV state of $^{22}$Ne. Ninety percent of these decay events occur with positron emission, which then annihilate and produce a pair of 0.511- MeV gamma rays that can be seen in the gamma spectrum. Figure 13.2 shows a typical gamma spectrum for $^{22}$Na that was obtained with a NaI(Tl) detector. The 0.511-MeV peak will usually be quite a bit more intense than the 1.274- MeV peak, primarily because of the detector efficiency differences at the two energy levels and the annihilation process. The $^{22}$Na source is usually covered with a thin absorber such as a thin (-1/16-in.) piece of metal or plastic. Positrons from the source will lose energy in the absorber and will be annihilated in the absorber. The NaI(Tl) detectors will see an approximate point source of radiation. When the positrons are annihilated, two 0.511-MeV gammas will leave the source with an angular separation of 180°. Experimentally the pair of gamma rays are detected and measured with one detector that is fixed and another detector that can rotate about the source.

## EQUIPMENT NEEDED

- Two Canberra NaI(TI) Crystal, Phototube Assembly
- Photomultiplier Tube Base (Preamplifier Model 2007P)
- High Voltage Power Supply
- Two Amplifier
- Two Timing Single-Channel Analyzer (SCA)
- Universal Coincidence Counter (or Scaler)
- NIM Bin and Power Supply
- Oscilloscope
- Na source




A typical electronics diagram for measuring a gamma-gamma coincidence is shown below in Fig 2. The pulser and detector are alternately connected to the AMP inputs and are not connected simultaneously.



**PROCEDURE**

1.) Unfortunately, since you do not have the safety training required to operate all of the equipment in Building 88, Julien will be handling the NaI detectors and the sealed $^{22}Na$ source. However, it will be very important for you to make careful observations of the experiment and write down both the singles count and the coincidence counts for each angle.

**2.)** We will first measure singles counts from both meters. This means how many gamma rays are hitting the counter both from background and from the source. Record this in Table 1.

**3.)** The instructor will now change the setting so that the detectors will only count gamma rays that pass through both detectors at the same time. This is very similar to what you experienced with the cosmic ray detectors. Record the coincidence counts at each angle in the table.

**DATA**

**Table 1- Singles Count**

| **_ Degrees (positive)** | **Fixed Detector Counts** | **Rotating Detector Counts** | **_ Degrees (positive)** | **Fixed Detector Counts** | **Rotating Detector Counts** |
|---|---|---|---|---|---|
| **0** | | | **185** | | |
| **5** | | | **190** | | |
| **10** | | | **195** | | |
| **15** | | | **200** | | |
| **20** | | | **225** | | |
| **45** | | | **270** | | |
| **90** | | | **340** | | |
| **160** | | | **345** | | |
| **165** | | | **350** | | |
| **170** | | | **355** | | |
| **175** | | | **360** | | |
| **180** | | | | | |

**Table 2- Coincidence Counts**

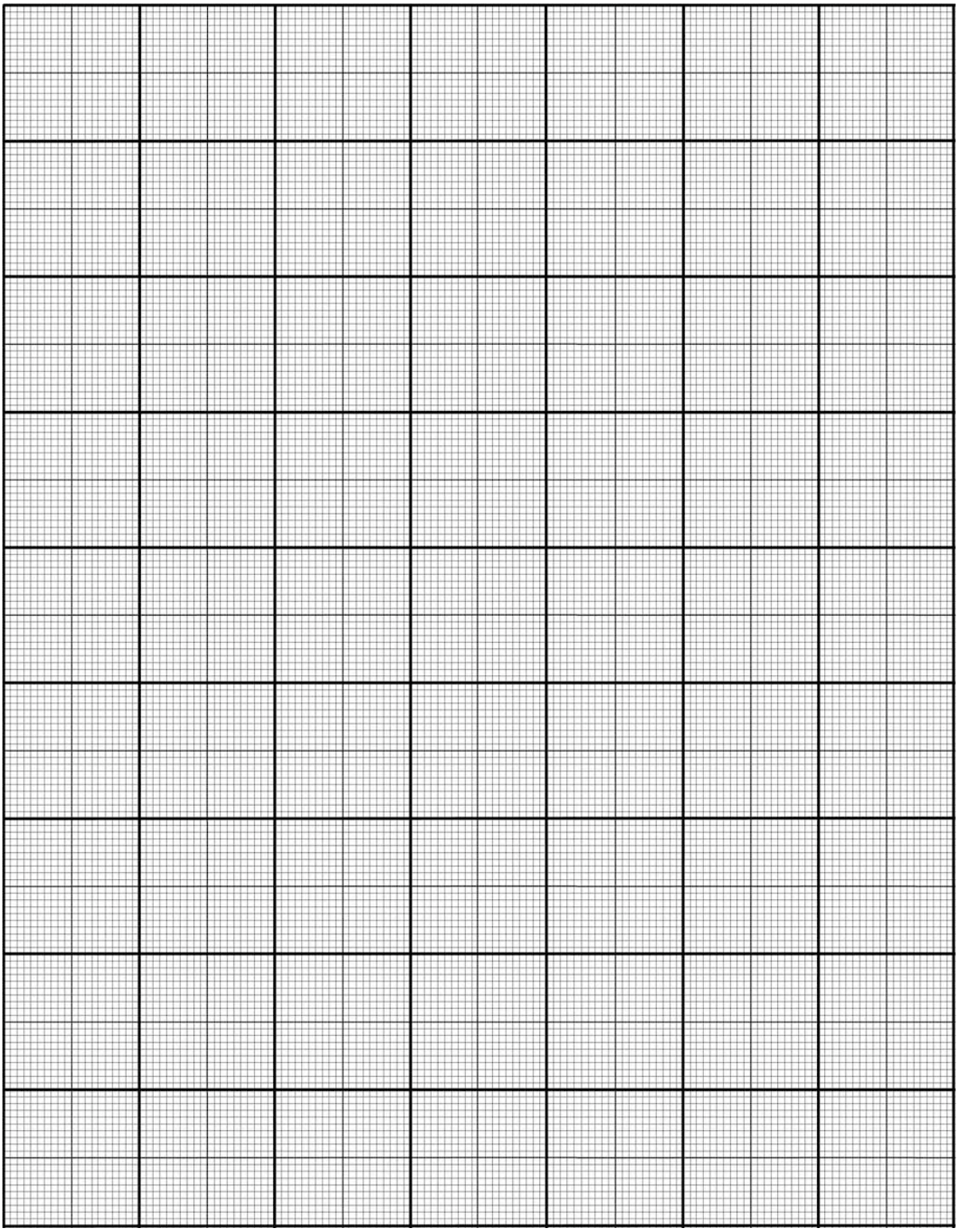
| **_ Degrees (positive)** | **Counts (N)** | **Statistical Variation** $\pm\sqrt{N}$ | **_ Degrees (positive)** | **Counts (N)** | **Statistical Variation** $\pm\sqrt{N}$ |
|---|---|---|---|---|---|
| **0** | | | **185** | | |
| **5** | | | **190** | | |
| **10** | | | **195** | | |
| **15** | | | **200** | | |
| **20** | | | **225** | | |
| **45** | | | **270** | | |
| **90** | | | **340** | | |
| **160** | | | **345** | | |
| **165** | | | **350** | | |
| **170** | | | **355** | | |
| **175** | | | **360** | | |
| **180** | | | | | |

**ANALYSIS**

**a.** Look at the data from table 1, what observations can be made about the activity as we move around the source? What would a graph of this data look like?

**b.** Plot the data in Table 2 on linear graph paper. For each counting rate (N) the statistical variation $\pm\sqrt{N}$ should be included as an error bar on the graph. Using the detector geometry, your graph and activity rate of $^{22}$Na, estimate the expected coincidences and compare with data. Where do you see the most activity? Does it make sense?

c. What causes the few counts or background on the far sides of the peak at very large angles? Why don't these counts go to 0 even when you can no longer connect a straight line between them? Explain (and if you don't know, ask Julien).



INSTRUCTOR NOTES

**REFERENCES**

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**BACKGROUND**

## Positron Sources

Positrons can be obtained from the $\beta_+$-decay of radioactive isotopes, e.g. from $^{22}$Na according to the decay reaction $^{22}Na \rightarrow {}^{22}Ne + \beta_+ + \nu_e + \gamma$. The $^{22}$Na isotope gives a relatively high positron yield of 90.4 % (Fig. 1) and has several other advantages. First of all, the appearance of a 1.27-MeV γ-quantum almost simultaneously with the positron enables positron lifetime measurement by a start–stop coincidence γ-spectrometer. Moreover, the manufacture of laboratory sources is simple, due to the easy handling of different sodium salts in aqueous solution, such as sodium chloride or sodium acetate. The half-life of 2.6 years and a reasonable price make this isotope the most used source material in positron research. The accidental contamination of laboratory personnel is less harmful, since the biological half-life is only a few days. In addition to $^{22}$Na, other isotopes ($^{64}$Cu, $^{58}$Co, etc.) can be used, but are less common. The generation of electron–positron pairs from high-energy photons is an alternative way to obtain positrons for use in beam systems. No broad application has been reported so far for applications in semiconductor research due to the need for appropriate accelerators.

The positrons generated in the $\beta_+$-decay reaction mentioned above exhibit a broad energy distribution up to an energy of 540 keV and can penetrate deep into a sample. In electron-irradiation experiments, a particle energy of 0.5 MeV may be sufficient to generate irradiation defects such as Frenkel pairs in many materials. This should be similar for positrons. However, the dose amounts only to ~ $1\times10^{11}$ cm$^{-2}$ for a rather long positron experiment of several days. Supposing a defect introduction rate of 1 cm$^{-1}$, the density of introduced defects is ~ $1\times10^{11}$ cm$^{-3}$ and thus several orders of magnitude lower than the sensitivity limit of positron annihilation.

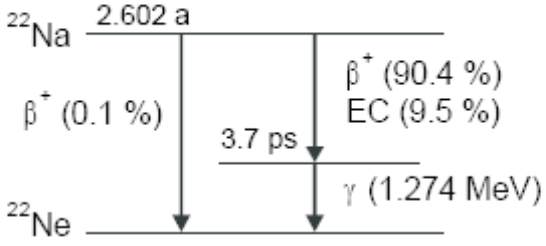


**Fig. 1.** Decay scheme of the radioactive isotope $^{22}$Na. 90.4 % decays by emission of a positron and an electron neutrino to the excited state of $^{22}$Ne. The ground state is reached after 3.7 ps by emission of a γ-quantum of 1.274 MeV. Competitive processes with lower probabilities are electron capture (EC) and direct transition to the Ne ground state.

(from http://www.positronannihilation.net/techniques/Positron%20Sources.pdf

## GAMMA RAYS AND ANNIHILATION

> "Gamma rays are also produced in the important process of pair annihilation, in which an electron and its antiparticle, a **positron**, vanish and two photons are created. The photons are emitted in opposite directions and must each carry 511 keV of energy—the rest mass energy (*see* **relativistic mass**) of the electron and positron.

## DETECTION OF GAMMA RAYS (OVERVIEW OF TECHNOLOGY)

In this experiment, gamma rays are detected by a scintillation crystal made of thallium-activated sodium iodide, abbreviated NaI(TI). The energy deposited in the crystal is converted to a flash of light, whose intensity is proportional to the energy of the gamma ray. This is converted to a voltage pulse by a *photomultiplier tube (PMT,* for short) and associated electronics.

The detection process is as follows (Fig. 3):

1. The γ -ray interacts with the NaI(TI) crystal and produces radiation which is predominantly in the ultraviolet region. The light output resulting from one photon's hitting the crystal lasts about $10^{-6}$ sec.
2. The radiation strikes the cathode of the PMT and produces low energy electrons by means of the photoelectric effect.
3. High voltage applied to the PMT accelerates the photoelectrons down a series of electrodes ("dynodes"), where more electrons are produced by secondary emission.
4. The electron current at the final electrode (anode) is integrated, and an output voltage pulse is formed.

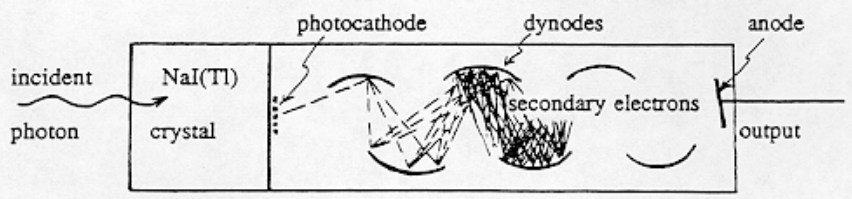

Figure 3. The NaI(Tl) crystal and photomultiplier tube

The amplitude of the output voltage pulse is proportional to the energy lost by the γ -ray in the crystal. However, the pulse is only a fraction of a volt high. For analysis, it must be *amplified* while retaining the linear relationship between γ ray energy and output voltage. The amplified voltage pulses are sorted by a multichannel analyzer, a "voltmeter with a memory" which records how many pulses in each voltage "channel" (hence γ ray energy) were produced. This is the gamma ray *spectrum*.

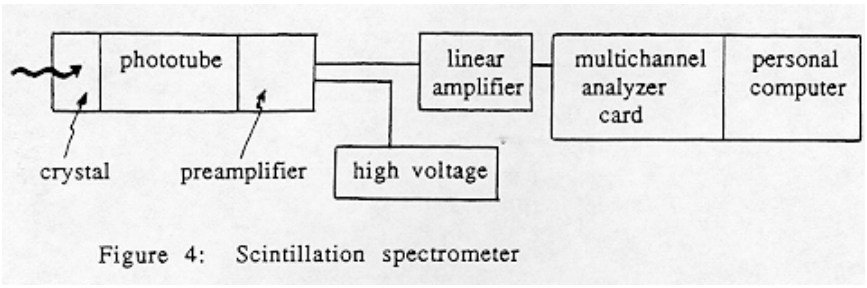


Figure 4: Scintillation spectrometer

http://www.cas.muohio.edu/~marcumsd/p293/lab9/lab9.htm

APPLICATIONS

Positron Emission Tomography (PET) Scans of the Brain
http://science.education.nih.gov/supplements/nih2/addiction/guide/lesson1-2.htm