Forecast:
Two new developments

The Relaxation Times

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TeachSpin will be showcasing, at the APS March Meeting 'Global Physics Summit', *two new products* aimed at upper-level undergraduate physics laboratories:

AntiMatter Matters & Liquid Crystal Physics

#1 'Antimatter Matters' is our name for a tabletop experiment in *positron physics*, with connections to quantum field theory, and applications to the medical physics of PET-scans, i.e. positron emission tomography.

We designed this experiment, in association with Dr. Adam Fritsch of Gonzaga University, with several goals in mind:

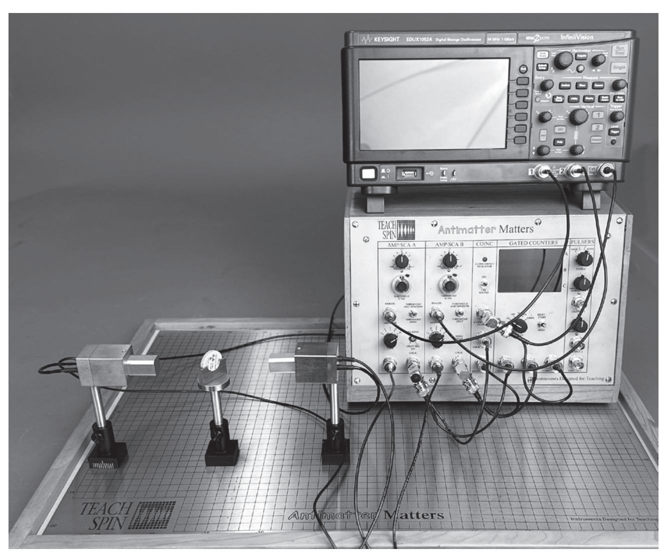
- Table-top operation with *license-exempt* radiation sources
- Full operational control of gamma-ray detection and event processing
- Convincing demonstration and application of time-coincidence techniques
- Gamma detection and energy measurement by CsI(Tl)/SiPM detectors
- Genuine source-localization, exploiting positron-annihilation gamma-ray pairs
- Full electronics, requiring only an oscilloscope – multi-channel analyzer ***not*** needed
- Experimental arena with all the tools needed for experimental layouts
- Extra projects including active-target Compton effect, γ-γ correlation, and photoproduction of positrons

All of these features together make for a complete system that directly addresses the question of how a PET-scan could possibly work. Together they make possible hands-on demonstrations of the predictions of quantum field theory for the properties of the antimatter counterpart of electrons, namely the positron. Collectively, these tools make possible an entire series of experiments in the production and propagation of gamma rays, and the exploration of a variety of nuclear properties.

We minimize the complications to users via an experimental design that allows all these experiments to be done with low-activity radioactive sources, for which NRC licenses are *not* required. Purchasers will be drop-shipped the sources required (10-μCi sources of Na-22 and Cs-137, and a 1-μCi source of Co-60).

Our AMM kit includes two of the new CsI(Tl)-based scintillation detectors for gamma rays, which are mated to 'silicon photomultipliers' (i.e. avalanche-photodiode arrays) for light detection, resulting in compact and robust detectors for gamma rays. These detectors are energy-sensitive, and illustrate the scintillation spectroscopy widely used in nuclear detection technologies.

Electrical pulses from these detectors are born already 'scope-detectable, and our AMM electronics box includes two channels of amplifier/single-channel-analyzer processing of these pulses. Each such channel allows selection-by-energy of the analog gamma events under consideration, and creates digital output pulses suited for counting and timing.



The 'baseplate' for AntiMatter Matters, bearing a small selection of the tabletop tools included.

The electronics include a ‘coincidence module’ that picks out those event pairs that are simultaneous to tolerance ±0.1 μs, and generates countable digital pulses for such events. Also included is a 3-channel counter for A-, B-, and C-for-coincidence events, plus a pulser system allowing end-to-end testing and investigation of the electronics.

So what do annihilation events look like? A raw view of the pulses coming from a gamma-detector shows a distribution of pulse heights, from which we can isolate those pulse heights corresponding to the deposition of a full 511 keV worth of energy in the detectors.

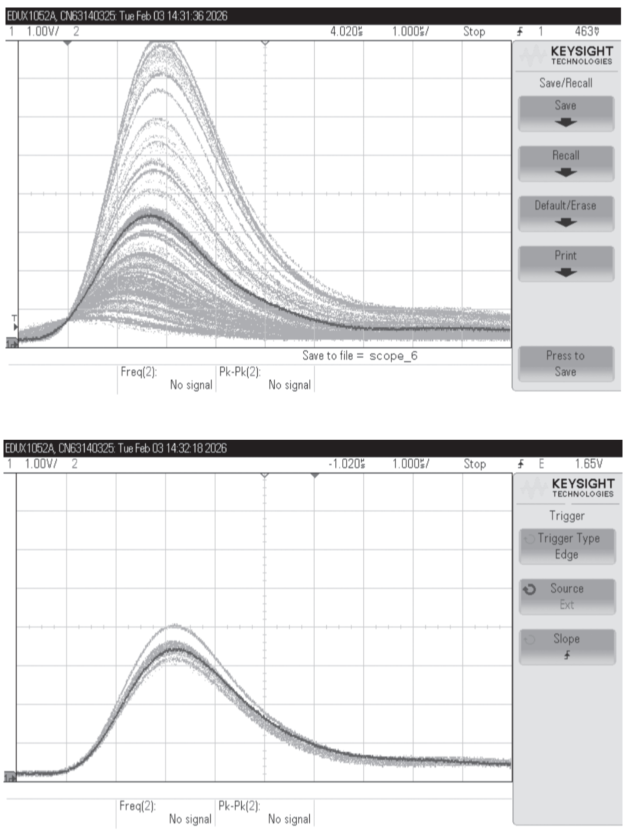


Fig. 1. Analog pulses from a CsI(Tl) detector exposed to gamma rays from Na-22. Top: all pulses; Bottom: energy-selected pulses corresponding to 511 keV of energy deposition in the detector.

With *two* detectors viewing a common Na-22 source (as in the photo on p. 1), one can look for the time-coincident detection of two such energy-selected events. Below we plot the rate of detection of such events, as a function of the position of the radioactive source relative to the line connecting the two detectors. Clearly, one can localize the source by exploiting the fact that positron annihilation inside the source-holder produces a pair of simultaneous, and *back-to-back*, gamma rays.

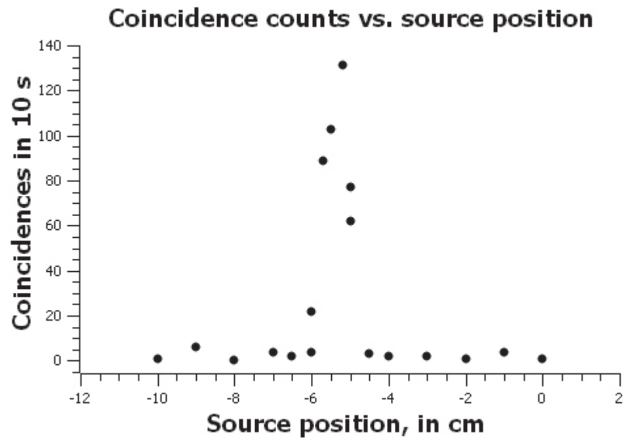


Fig. 2. 511 + 511 keV coincidences detected in 10 s, as a function of source position relative to the line connecting two fixed gamma-ray detectors.

By contrast, the count rates at the two individual detectors show only slow variations with source position:

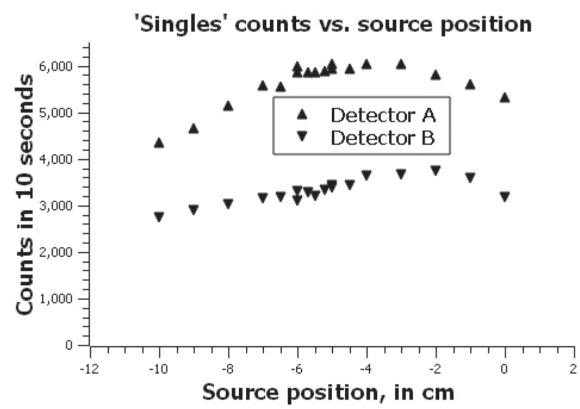


Fig. 3. The two detectors’ 511 keV rate-of-counts detected in 10 s, as a function of source position relative to the line connecting two fixed gamma-ray detectors.

Users may hide the source(s) included under an opaque dome that’s part of the AMM kit, so that by doing two orthogonal 1-d scans of this character, students can localize in 2-d space a point-source of positron annihilations.

The highly flexible experimental arena, together with the modular nature of the electronics, makes possible a whole array of gamma-based experiments, ranging from familiarization with detectors and electronics to some quite sophisticated projects beyond positron physics.

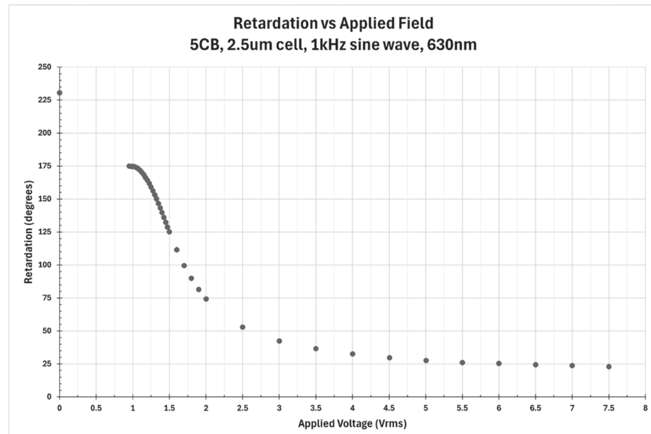
You’re invited to play with this apparatus in real time – come see it on display outside the TeachSpin exhibition trailer at the APS March meeting in Denver.

#2 Unless you're reading this Newsletter via genuine ink-on-paper, it's more than likely you're viewing a collection of digital pixels forming an image on some screen. Nowadays almost all such screens depend wholly on the properties of *liquid crystals* to create the colored pixels that collectively form the image. But how does one such pixel work? and what physics can be learned about, and beyond, the pixel that you see? All of these investigations in 'soft matter' are goals we've addressed in our new offering called **'Liquid Crystal Physics'.** We designed this new apparatus in association with Dr. Peter Collings of Swarthmore College.

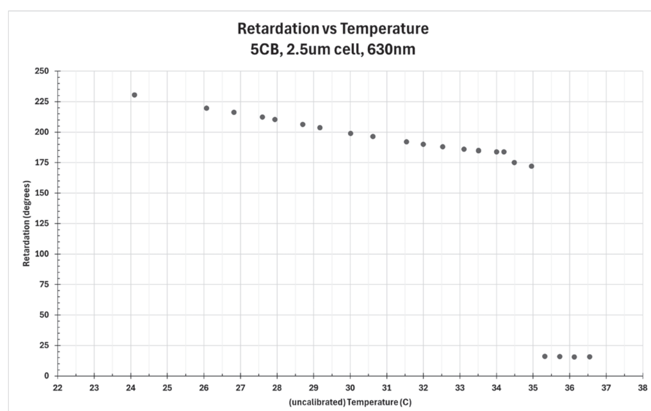
Liquid crystals are a phase of condensed matter with molecules exhibiting an absence of positional ordering, while still preserving orientational ordering. As such, they offer easy detection via the pronounced optical birefringence that follows from orientational ordering. Because the molecules are polar, it is also possible for imposed electric fields to control that birefringence. So a layer of liquid crystal material just a few microns thick in a suitable cell can have the effect of being an electrically-controlled element in the transmission of visible polarized light. The deeper physics of the process is represented by the thermodynamic competition between ordering effects (of the container boundaries, and the electric field) and the disordering effects (that vary with temperature). So in our LCP apparatus, we've added temperature control of the sample, so that by monitoring the ordering consequences by optical methods, students can also study with remarkable sensitivity the *phase transition* between ordered and disordered states.

In TeachSpin's realization of this phenomena, students have easy access to the optical diagnostics of a one-element liquid-crystal sample. A bright red-LED light source, an optical polarizer and analyzer, and a quantitative photodiode detector form the optical train that allows polarization diagnostics. There's an (interchangeable) optical cell that students can fill with a liquid-crystal material. That cell mounts into a metal block that is temperature-controllable, via a thermoelectric module and temperature servo. The cell for the liquid crystal also provides the transparent electrodes that allow the material to be electrically polarized. And our kit includes, in one compact box, the controller for all these elements; users need only supply a generic DMM to measure the voltage levels that can be controlled into, and read out of, the apparatus.

The polarization diagnostics enable the user to measure the optical retardation of the sample, and the first independent variable is the electric field that is applied to the sample. As is done with most liquid crystal displays, we use an a.c. waveform to orient the molecules; the data below shows that a few Volts of potential difference will saturate the orientation.



The optical retardation also displays the thermodynamic phase transition of interest, so (with orienting voltage held constant) here's the retardation as a function of temperature:



For our sample of '5CB' liquid crystal, the phase transition is of first order, and occurs near 35 ˚C.

We hope you visit the interior of TeachSpin's 'Food Truck for the Physics Mind' on the exhibition floor of the March meeting, where our new 'Liquid Crystal Physics' will be on working display along with TeachSpin's collection of existing experiments.

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Inside:

Announcing the *two new experiments*
that you'll be able to see at the TeachSpin trailer
at the APS March meeting in Denver

A note to users of our 'Muon Physics' apparatus

Cosmic rays continue to rain down uninterruptedly, the resulting muons cause a scintillator to flash, a PMT reliably detects these light pulses, a box of electronics does the required timing – in short, everything in Muon Physics works fine...*until* there are unilateral changes in the Windows operating system running the Muon software package that records the results.

We have followed Windows changes as far as Windows 10, and do not intend to go any farther. Instead, we have devised an alternative to the former p.c.-based way to host the software, and now offer a

Raspberry-Pi based alternative software engine, with a Linux operating system

It takes the place of the former personal computer; it runs its pre-installed Muon software; it comes with a case and power supply. You need only supply the usual keyboard, mouse, and display to run this system, thereby achieving permanent independence from Windows, from the web, and from any resulting IT complications.

All future sales of Muon Physics will include this new engine for running the software. We also have the pre-programmed RP systems in stock at TeachSpin, and we offer them at $350 to any existing Muon Physics users who wish to free themselves from undesired future OS updates and problems.