Electron-Positron Annihilation

A positron is the anti-particle for the electron. It is the exact opposite of an electron: opposite charge, opposite spin, etc. (The mass is the same, though.) When a positron meets an electron, both disappear in a burst of energy, which comes in the form of γ radiation.

Energy conservation requires that the energy released during electron-positron annihilation be equal to the energy of the electron and positron immediately before the annihilation. Unless the particles are moving *very* fast, their energy is approximately equal to the rest energy, $E = mc^2$, where $m = 0.511$ MeV/c^2. The total energy of the γ radiation must then be 1.022 MeV/c^2.

Momentum conservation requires that the total momentum of the photons emitted from the electron-positron annihilation event must equal the total momentum of the incident electron and positron, which is (relatively) small. The momentum of a photon is $p = \frac{E}{c} = \frac{h\nu}{c}$, so if the mass energy of the electron and positron is converted to γ radiation then the only way to conserve both energy and momentum would be to emit *two or more* γ rays. The simplest decay would be two γ's emitted at 180° from each other, each with energy 511 keV. There could be other possibilities, though, such as three γ's at 120° from each other, each with energy 341 keV, and so on.

Angular momentum is also conserved. The electron and positron can have a total spin of either zero or one, since each of them has spin $\frac{1}{2}$. The resulting photons must also have a total spin of zero or one, since angular momentum is conserved. Since photons have spin 1, then a spin-zero electron-positron collision must result in an even number of photons, with opposite spin, giving a total spin of zero.[1]

So we have good theoretical reasons to expect electron-positron annihilation to result in a pair of photons, emitted at 180° from each other. In this experiment we will look for coincident photons at 180° and at other angles. If we find a relatively large coincidence rate at 180° this would support the idea that the electron and positron decay into two γ rays moving in opposite directions. On the other hand, if we find significant coincidences at other angles, this would lend credence to the idea that electron-positron decay results in more decay products than just two γ rays.

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[1] What happens if the initial combined electron-positron spin is one?

Equipment

A block diagram of the experimental apparatus, including rough sketches of the signal at various points, is shown in figure 1. One of the two Sodium Iodide (NaI) scintillators is held at a fixed position, the other is on a goniometer arm. A high-voltage power supply (not shown) is attached to each photomultiplier tube (PMT) pre-amp. The output of each PMT pre-amp is connected to the input of an Ortec 435 amplifier. The 435 outputs should be set to bipolar, since the zero crossing on the bipolar pulse allows more precise time triggering than can be obtained with a unipolar pulse.

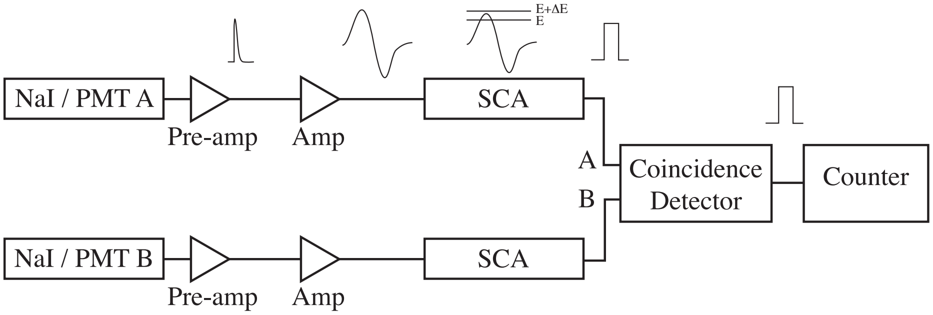

Figure 1: Coincidence measurement block diagram

The output of each 435 amplifier is then connected to the input of an Ortec 420 Single-Channel Amplifier (SCA). The SCA input should be set to bipolar also, so that the device knows what it's supposed to be looking for. The square-pulse outputs of the SCAs should then be connected to the A and B inputs of the 414A coincidence detector, which should be set so as to produce a pulse when it detects pulses on both A and B.

The output of the coincidence detector should then be connected to a counter which can be set to record the number of counts in a user-specified time interval.

Procedure

1. Put the two NaI detectors at 180° from each other. Set up the ^{22}Na source at the pivot of the goniometer arm. Adjust the height and position of the source so that it is directly on the centerline between the two detectors.

2. Make sure that the PMT pre-amplifiers are properly attached, then turn on the NIM box main power and finally the high voltage supplies

to the PMTs. (When you turn the equipment off, use the reverse order. You want to be sure that the high voltage is never on unless the preamps are powered.)

3. Use a BNC 'T' splitter to connect the A 435 amplifier output to an analog oscilloscope. Connect the A SCA logic-pulse output to the oscilloscope trigger input. Adjust the oscilloscope and amplifier so that you can clearly see the bipolar pulses coming from the amplifier. Adjust the gain on the amplifier so that the bulk of these pulses are not clipped at the top.

4. If you look closely at the pulse traces on the oscilloscope, you will note that there is a denser area at about half the maximum amplitude. This corresponds to the energy of the 511 keV γ rays, which are the primary constituent of the γ spectrum of ^{22}Na. Adjust the E setting on the A SCA upwards, until the scope traces below this area are removed. Then adjust the ΔE setting downwards until the traces *above* this area are removed. The A SCA is now set to give an output pulse only when it receives an input pulse corresponding to a γ ray in the desired energy region.

5. Remove the oscilloscope from the A side, and reconnect the SCA output to the coincidence detector.

6. Repeat steps 3–5 for the B side of the apparatus. At this point, the output of the coincidence detector should show a square pulse each time *both* NaI detectors see a γ ray with an energy of about 511 keV.

7. Send the output of the coincidence detector to the "clock" input on a counter, and arrange some way to count the pulses for a set time. The ELVIS II interfaces work well for this counting function: you can either write your own LabVIEW program to do what you need, or modify the program you wrote in the half-life lab in Phys 327.

8. Measure the count rate per time interval for a wide range of angles, and create a plot showing your results. What can you conclude?

9. Readjust one SCA so that the two are looking at different γ energies. How does this change your graph? What if both SCAs are looking at energies other than 511 keV? What do you conclude from these results, and why?