Experiment 356: Angular Correlation of γ rays

Aim

To study the technique of making a $\gamma - \gamma$ correlation measurement and to verify that the angular correlation of rays emitted during nuclear transitions between states with spins $0, 2, 0$ agrees with the theory given in the additional pamphlet supplied with the apparatus.

References

After reading this pamphlet consult the following references. The first six describe the theory while the remaining are of experimental interest. Note that a sufficient theoretical understanding for this experiment can be obtained by reading Ref. 1 only. However, a deeper theoretical understanding will be obtained if the further references are consulted. Refs. 1, 7, 8 and 9 are available in the laboratory. A copy of Ref. 6 is supplied with the apparatus.

1. Evans, R.D. "The Atomic Nucleus" p.234, McGraw-Hill
2. Frauenfelder, H. & Steffen, R.M. "Angular Correlations" Chap. 19A of Alpha, Beta and Gamma Ray Spectroscopy, K.Siegbahn, Editor.
3. Brink, D.M. & Satchler, G.R. "Angular Momentum" Clarendon Press
4. Ferguson, A.J. "Angular Correlation Methods in Gamma Ray Spectroscopy" North-Holland
5. Rose, H.J. & Brink, D.M. "Angular Distributions of Gamma Rays in Terms of Phase-Defined Reduced Matrix Elements" Rev. Mod. Phys. 39, 306, (1967).
6. Avignone, F.T. & Pinkerton, J.E. Am. J. Phys. 40 (1972) 1542
7. Melissinos, A.C. "Experiments in Modern Physics" Chap. 9, Academic Press
8. ORTEC Application Note AN34 "Experiments in Nuclear Science"
9. ORTEC catalogue No. 1001 "Instrumentation for Research"
10. Methods of Experimental Physics 5, part B, page 129. Eds. Yuan and Wu, (539.7 Y94).

Introduction

Often, when two γ rays are emitted in rapid succession by the same nucleus, one finds that the directions of emission of the two rays are correlated. This means that upon assuming the direction of the first γ ray to be the z-axis, the probability of the second falling into the element of solid angle $\mathrm{d}\omega$ is not constant but depends on the angle θ between the two directions.

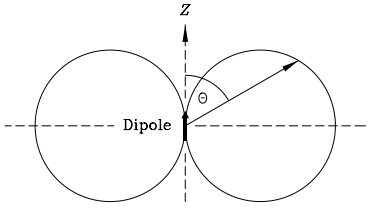

Figure 1: Radiation polar pattern of a dipole

Suppose that we have nuclei emitting quanta through electric dipole transitions. We place the nuclei in a magnetic field which orients them in such a way that the electric dipole is along the z-axis (see Fig. 1). We know that no quanta will be emitted in the direction of the z-axis and that the maximum probability of emission will be in the $x-y$ plane. Conversely, in the absence of an orienting field the fact that a γ quantum is emitted in a certain direction tells us that that direction is not the direction of the electric dipole and makes it *a priori* more probable that the electric dipole is perpendicular to the direction of the first quantum. A second quantum is thus less likely to be emitted in a direction perpendicular to the first quantum than in any other.

A quantum mechanical treatment of the correlation for more complicated cases shows that the probability $W(\theta)$ of successive emissions having an included angle θ is a polynomial of even degree in $\cos\theta$. This follows from the fact that $W(\theta)$ and $W(\pi-\theta)$ must be equal, if parity is conserved, i.e., if the correlation is not altered on reflection through the origin, as is the case for electromagnetic interactions. The degree of the polynomial in $\cos^2\theta$ and its coefficients depend on the spins of the three states involved and on the character (electric quadrupole, magnetic dipole, etc.) of the two radiations connecting them.

Experiment

To measure the ^{106}Ru $\gamma-\gamma$ correlation two scintillation detectors consisting of $1.5'' \times 1.5''$ NaI(Tl) crystals optically coupled to photomultipliers and contained in light-tight housings. These are mounted so as to rotate about the source. Each detector has associated with it a preamplifier and a main amplifier.

(1) Apply +1000 V to each photomultiplier tube and with the ^{22}Na source in the central holder adjust the amplifier gains in both channels so that the 1.3 MeV γ gives a pulse height of about 3 V at the 435 amplifier output. Check all pulse shapes to ensure that they are as indicated on the block diagrams. Bipolar pulses are required for accurate timing. Note that the 435 amplifier gives a bipolar output when the "clip" switch is at 2.

(2) In a coincidence experiment it is necessary that the time-coincident rays incident on each detector produce electrical pulses at the input to the fast coincidence unit which are also in time coincidence. A simple way of doing this is to use a ^{22}Na source. This is a positron emitter (see decay scheme in Fig. 2) and hence gives rise to coincident rays. (See Question 3.)

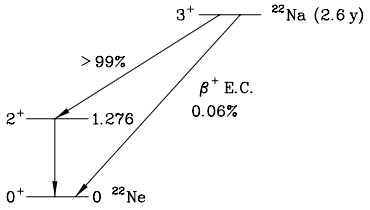

Figure 2: Decay scheme of ^{22}Na

Identify the coincident γ's by observation of the pulse height spectrum on the oscilloscope or the multichannel pulse height analyser and adjust each single channel analyser to pick out these γ's only. This may be done by either of the following methods:

(a) With the arrangement shown in Fig. 3, adjust the delay amplifier until the timing of the Y deflection is correct. The two γ peaks will be readily identifiable and the SCA can be adjusted so that only the required γ pulses trigger the oscilloscope.

(b) The signal from the linear gate in Fig. 4 is connected to the input of the multichannel analyser. It is convenient to set the conversion gain to 512 (channels = 8 volts) and also expanded display to 512 so that you display all of the pulses from the amplifier.

Only that part of the spectrum passed by the SCA will appear in the MCA. Do not place the SCA limits too close to the steep sides of the peak otherwise small amplitude drifts will give large count rate changes.

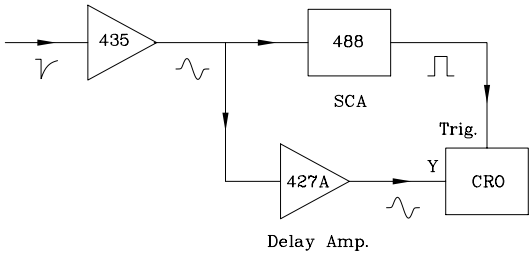

Figure 3: Experimental setup

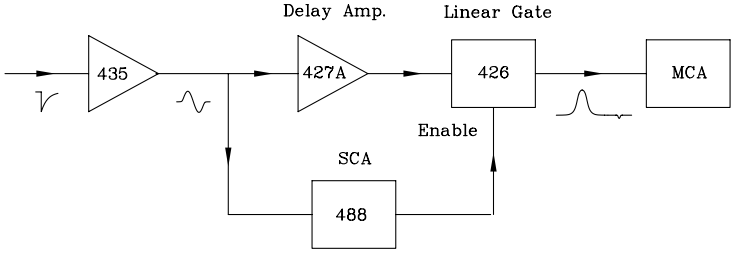

Figure 4: Experimental setup

(3) Having set both single channel analysers to the desired peak it is now necessary to adjust the timing. It is best to set the delay of the 488 SCA near the middle of its range and leave it fixed. The other has a dial calibrated in μs.

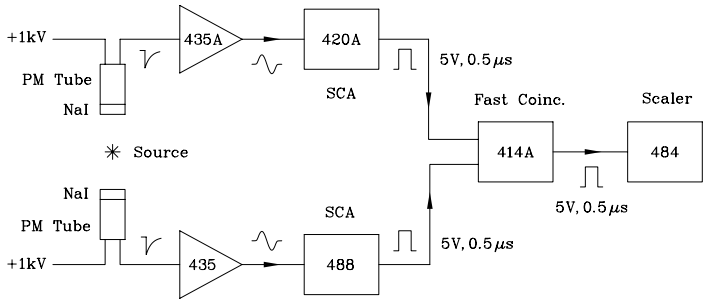

Figure 5: Experimental setup

Set up the apparatus as shown in Fig. 5. Place the detectors 5 cm from the ^{22}Na source and in the correct orientation. ^{22}Na has a half-life of 2.6 years. If your source is new, place the detcetors further away from the source. Set the 414A resolving time to about 70 ns. Turn the scaler on and watch the coincidence rate as the 420A delay is slowly varied. This will give the approximate delay setting. Now make this quantitative by plotting total coincidence counts, for a suitable counting time, against delay. An almost rectangular graph should result with a flat top which must be at least 30 ns wide. At this point, some thought should be given to the statistical accuracy of your results and the possibility of random coincidences. Excellent discussions of these points are given in Evans (Ref.1).

(4) Before making an angular correlation measurement, it is essential that the source be accurately on the axis of rotation and that the singles count rate in the moveable detector be independent of position. Check this.

(5) The angular correlation for ^{22}Na γ's may now be determined. The true correlation will be considerably distorted by the poor geometry. Roughly estimate the experimental correlation before making your measurement and compare with the experimental results.

(6) Replace the ^{22}Na source with the ^{106}Ru source and set up the SCAs as in procedure (2) so as to pick

out the two γ lines in one detector. For the other detector, set the lower limit at around 0.1 MeV and the upper limit at, say 1 MeV.

Feed the output from this detector through the linear gate (now enabled by the output of the fast coincidence as in Fig. 6) to the MCA. The following points should be noted:

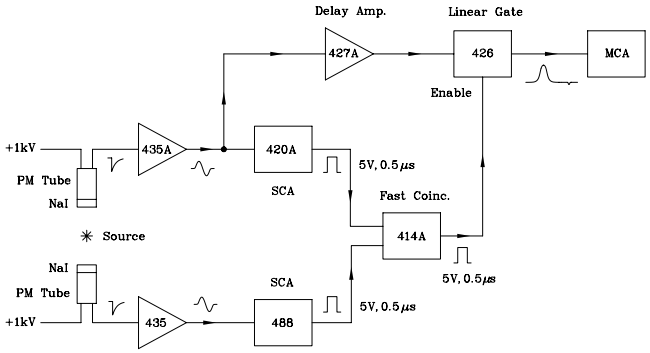

Figure 6: Experimental setup

(a) The source has a very complicated decay scheme. ^{106}Ru decays first to ^{106}Rh which then decays via many beta channels to various excited states of $^{106}\mathrm{Pd}_{56}$. The two γ's detected result from transitions between two of the palladium excited states and the ground state (see the decay scheme in Fig. 7).

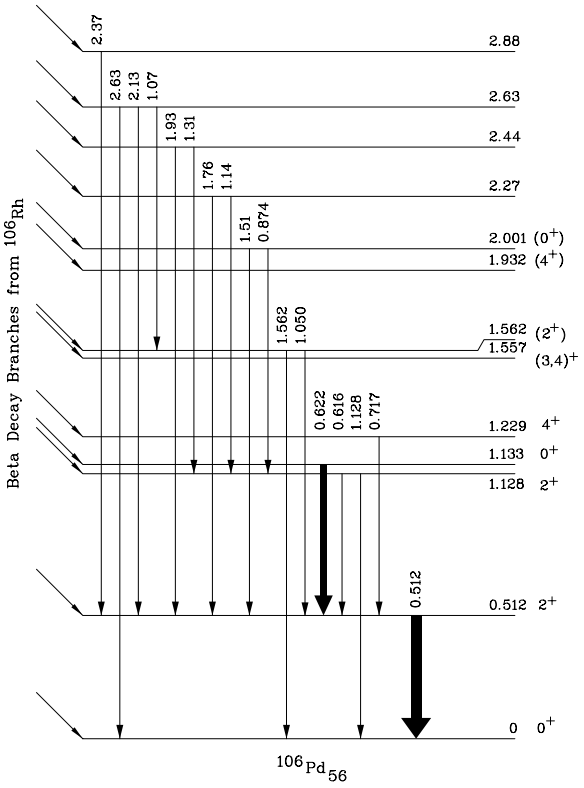

Figure 7: Decay scheme of source

(b) The source has been mounted in a stainless steel container which absorbs most of the unwanted beta rays leaving the γ's almost unaffected.

(c) The two rays of interest have energies of 512 and 622 keV. They could be identified by comparison with the ^{22}Na annihilation radiation, however they are the only two well-defined peaks in the energy spectrum and identification presents no problem

(d) The pamphlet with the apparatus contains a paper from the University of South Carolina describing the use of this source and a simplified derivation of the correlation function.

(7) Again ensure that the SCA limits on the first detector are on the flat portions of the spectrum well away from the peaks so as to minimise the effects of amplitude drift. (See Questions 5 and 6.)

(8) Measure the random rate by setting the delay several microseconds away from the correct value. Measure the correlation at 10° intervals with a counting time such that the desired statistical accuracy is obtained.

The major barriers to good results are time and amplitude drifts in the apparatus. Hence the importance of correct setting up of SCAs and timing resolution. Various modes of recording results may be devised to minimise these effects and you should give this careful thought before beginning.

(9) Plot the results in the form $W(\theta)/W(90°)$ vs θ. Use MATLAB to fit the data to a function of the form $1 + ax + bx^2$ where $x = \cos^2\theta$ (see references). A MATLAB fitting routine which you could use is `[param,error]=regress(x,y,err,n)` where `err` is the error in the `y` values and `n` is the order of the polynomial. Alternatively, write your own or use `fmins`.

Questions

These must be answered in the write-up.

1. Why is there a steel cylinder surrounding the moveable detector?
2. Why is it necessary to use bipolar pulses?
3. What is the form of the angular correlation of the 0.511 MeV γ's from ^{22}Na?
4. Why is it necessary for the delay curve to have a flat top?
5. Why is it permissible, and in fact desirable, to allow both detectors to look at both γ's?
6. Why is it not desirable to include the Compton continuum within the SCA window, although that would increase detection efficiency?
7. Discuss effects which would distort the angular distribution from the theoretical shape.

List of Equipment

1. 2 x NaI scintillation detector optically coupled to photomultiplier
2. 2 x Preamplifier
3. ORTEC Model 435 amplifier
4. ORTEC Model 435A amplifier
5. ORTEC Model 426 linear gate
6. ORTEC Model 414A fast coincidence unit
7. ORTEC Model 427 delay amplifier
8. ORTEC Model 488 timing single channel analyser
9. ORTEC Model 420 timing single channel analyser

10. ORTEC Model 484 scaler
11. MCA (PC with Nucleus PCAII-1000 card)
12. Brandenburg Model 472R high voltage power supply
13. ^{22}Na source
14. ^{106}Ru source
15. An oscilloscope and multichannel analyser are also available but may have to be shared with nearby experiments.

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