PPCO: Polarizational-Polarizational Correlation from Oriented Nuclei

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In a modern "in-beam" γ-ray spectroscopy multidetector arrays are widely used. Usually, a large part of detectors in an array is, due to segmentation, sensitive to linear polarization of γ-quanta. This gives an opportunity to carry out correlation measurements between the γ-rays registered in polarimeters or in polarimeters and the remaining detectors. The correlation experiment, in which the linear polarization of at least one γ-quanta is measured, gives an important information concerning spins and parities of excited nuclear states.

In Ref. [1] the general formula for such correlation was given and the case of angular correlation between polarization of γ1 and direction of γ2 emitted from oriented nuclei (the PDCO method) was discussed in detail. This formula allows us to calculate also the correlation between polarization of γ1 and polarization of γ2 (for L=1,2 pure or mixed multipolarity) emitted in a cascade (at any direction) from oriented nuclei (PPCO). It is worth to mention that the polarizational-polarizational correlation was considered in an early work (Ref. [2]) but only for very particular case, namely when both γ-quanta either pure dipole or pure quadrupole are emitted in the opposite directions from an unoriented source. In our approach the unoriented source corresponds to the special case when the alignment parameter σ equals infinity (see Ref. [1]). The simple formulae given in Ref. [2] can be easily used to control the correctness of the PPCO computer program. For the same purpose the simple formulae (Ref. [3]) describing correlation between polarization of γ1 and direction of γ2 emitted from unoriented source can be used. In this case \( W_5 = W_5^* + W_5^3 \) (see text below).

In the present report the PPCO method is considered and preliminary results are presented. The discussion is limited to the case in which spin alignment is due to nuclear reaction.

A single polarimeter allows measuring the numbers \( N_5 \) or \( N_3 \) of photons scattered between its segments in the direction perpendicular or parallel to the emission plane (see Ref. [1] for the definition). Then the experimental asymmetry A is given by:

\[
A = \frac{N_+ - N_-}{N_+ + N_-}
\]

(1)
The polarization $P$ is defined as follows:

$$P = \frac{W_\parallel - W_\perp}{W_\parallel + W_\perp}.$$  \hspace{1cm} (2)

where $W_\parallel$ and $W_\perp$ are the probabilities that emitted $\gamma$-quantum is polarized in the plane parallel or perpendicular to the emission plane. The relation between quantities $A$ and $P$ is following:

$$A = Q*P$$  \hspace{1cm} (3)

In the case of two polarimeters working in coincidence one should consider four quantities, namely $W_\gamma$, $W_\delta$, $W_\alpha$, and $W_\beta$. Here, for example, $W_\gamma$ gives probability that $\gamma_1$ (registered in polarimeter $P_1$) is polarized in its emission plane while $\gamma_2$ (registered in $P_2$) is polarized perpendicularly to its emission plane. The meaning of the remaining $W$'s is analogues. These four quantities allow us to construct different observables, for example the following ones:

$$PP1 = \frac{W_\parallel - W_\perp}{W_\parallel + W_\perp},$$  \hspace{1cm} PP2 = \frac{W_\perp - W_\parallel}{W_\perp + W_\parallel},$$  \hspace{1cm} PP3 = \frac{(W_\parallel - W_\perp)(W_\parallel - W_\perp)}{(W_\parallel + W_\perp)(W_\parallel + W_\perp)}.$$  \hspace{1cm} (4)

All these observables can be measured for different polarimeter positions with respect to the ion beam.

Fig. 1. Symmetries in the PPCO method. (a) Polarimeter $P$ is placed at $\theta=90^\circ$ with respect to the ion beam axis. Eight positions of the polarimeters, working in coincidence with $P$, which give the same readings are shown (on the drawing-black spheres). (b) Polarimeter $P$ is placed at $\theta \neq 90^\circ$. There is only four positions of remaining polarimeters giving the same readings.
Fig. 2. Contours in the PP1 vs. DCO-ratio plane. Both polarimeters are placed at θ=90° while φ=90° (see Fig. 2 from Ref. [1]). The DCO-ratio is measured for the detectors at θ=0° and 90°. The parameter σ/I=0.3 is assumed. Squares and triangles on the contours correspond to pure quadrupole and pure dipole radiations, respectively. The arrows point the direction of increasing value of mixing ratio δ; the small crosses (+) are placed every Δ(artan δ) =5°.

The quantities PP1, PP2 and PP3 correspond to the quantities measured directly in experiments when the Compton polarimeters are used. For instance one has following relation for PP3, similar to eq.(3):

$$A A 3 = Q _{1} \cdot Q _{2} \cdot P P 3,$$

(5)

where

$$AA 3 = \frac{N _{\perp \perp} - N _{\perp \perp}}{N _{\perp \perp} + N _{\perp \perp}} - \frac{N _{\perp \perp} - N _{\parallel \parallel}}{N _{\perp \perp} + N _{\parallel \parallel}}$$

(6)

and N's are numbers of parallel and perpendicularly scattered photons in the Compton polarimeters (P1 and P2) being in coincidence. The quantities Q1 and Q2 are sensitivities of polarimeters.

Polarizational-polarizational correlation fulfills some symmetries (see appropriate formulae in Ref. [1] sect. 2) that are illustrated in Fig. 1. It is an important information for planning effective experiments.

The preliminary analysis of the PPCO method was made for the PP1. Contours in the PP1 vs. DCO-ratio (Ref. [4]) plane for different spin sequences and mixing ratios are
given in Fig.2 for the \( I^2 \rightarrow 4^+ \rightarrow 2^+ \) cascade, where \( I=2,3,4,5,6 \) and \( \pi=+1 \). This figure should be compared with Fig.7 of Ref.[1] which corresponds to the PDCO method. It seems, that for the studied case, the PPCO and PDCO methods have the similar limitations to determine spins and parities. For example, both methods encounter difficulties in distinguishing between the \( 5_{M1} \rightarrow 4_{E2} \rightarrow 2 \) and \( 3_{M1} \rightarrow 4_{E2} \rightarrow 2 \) transitions. It seems, that PPCO (with \( PP1 \) observable) allows us, in principle, to discriminate better between \( 6_{E2} \rightarrow 4_{E2} \rightarrow 2 \) and \( 4_{M1} \rightarrow 4_{E2} \rightarrow 2 \) transitions than the PDCO method. In practice, the ability of the PPCO method will depend on accuracy of measurement of observables \( PP \). One can expect, that the PPCO measurements should be less accurate than PDCO ones since:

a) number of events in PPCO is smaller than in PDCO
b) observables \( PP \) in PPCO depend on \( Q_1 \) as well as \( Q_2 \).

It follows from eq. (5) that the large values of \( Q_1 \) and \( Q_2 \) are desirable to get large and accurate value of \( AA \). Substantial improvement of \( Q \) can be expected when a new generation of highly segmented detectors with three dimensional position information [5] starts to operate.

The further analysis for other observables, spin sequences and geometry is in progress.

References