Coincidence method for semiconductor detector calibration

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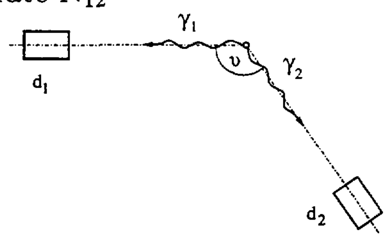
The coincidence method has been used successfully for decades in nuclear spectroscopy and various applications. It is considered to be the only feasible method to study complex decay and level schemes of atomic nuclei. Furthermore, a widely accepted application of the coincidence method is the determination of the absolute activity of standards for detector calibration. However, the coincidence method can be applied more generally and allows the determination of the absolute detector efficiency .

At present the absolute calibration of photon detectors proceeds in two steps. In the first step determination of the absolute source intensity is performed using $\beta - \gamma$ coincidence method. This results in an absolutely calibrated standard, which is used in the second step to determine the absolute efficiency of the photon detector.

Use of the coincidence method can potentially reduce the number of steps in detector calibration procedure to a single step, thus reducing the error of the calibration. This approach may be especially useful for several high energy photon sources (e.g. ^{11}B + p $\rightarrow^{12} C^{*}$), which are difficult to calibrate absolutely.

The coincidence method is rather simple and can be used if the source nucleus decays by two cascading photons γ_1 and γ_2. The calibration setup consist of two detectors and is shown schematically below. Detectors d_1 and d_2 are used for measurement of gamma ray γ_1 and γ_2, respectively. The following relations hold for detection rates N_1 in detector d_1, N_2 in detector d_2 and the coincidence rate N_{12}



$$N_1 = \Omega_1 A$$

$$N_2 = \Omega_2 A$$

$$N_{12} = \Omega_1 \Omega_2 A W(\theta),$$

where A is the unknown decay rate of the calibration source, Ω_i is the efficiency of detector i for gamma ray γ_i and $W(\theta)$ is the angular correlation function, i.e. angular distribution of γ_2 with respect to the gamma ray γ_1 detected in d_1. The angle θ is defined by the position of both detectors. These three equations can be solved for three unknown variables Ω_1, Ω_2 and A

$$\Omega_1 = \frac{N_{12}}{N_2} \frac{1}{W(\theta)}$$

$$\Omega_2 = \frac{N_{12}}{N_1}\frac{1}{W(\theta)}$$

$$A = \frac{N_1 N_2}{N_{12}} W(\theta).$$

From these relations the efficiency of detector d_1 for gamma ray γ_1 can be determined form the ratio of coincidence to single counts of gamma ray γ_2 in detector d_2. The same holds for gamma ray γ_2 detected in d_1 and γ_1 detected in d_2. Thus we do not need to know efficiency of detector d_2 to determine the efficiency of detector d_1.

These simple relations can be further refined to describe the realistic experimental situation with respect to the full energy peak efficiency of the calibrated detector, calibration sources with more complicated decay schemes and finite detector volumes. A two-parametric data acquisition system is necessary in order to perform precise efficiency measurement. Further reduction in measurement errors can be achieved by measuring the time distribution between coincident γ rays.

For precise detector calibration using coincidence method slightly different needs in decay data of calibration sources arise. A crucial parameter is the number of gamma rays γ_2 per single photon γ_1, thus population of individual levels, branching ratios of electromagnetic transitions as well as the internal conversion coefficients need to be known. However, there is no need to know absolutely the number of nuclei that decay during the efficiency measurement; thus the half-life of the source is irrelevant and does not need to be known precisely.

On the other hand, spatial and time correlations of both photons are important. However, since the half-lives of the majority of nuclear levels in nuclei used for calibration are much shorter than the time resolution of commonly used photon detectors, we can assume that both photons are emitted at the same time.

The spatial correlations between two successive γ transitions are at present well understood. Correlation depends on the spins and parities of all three nuclear levels involved as well as on the multi-polarities of both γ transitions. General theory of correlations is rather complex, but in principle the correlation function can always be reduced to the sum of Legendre polynomials

$$W(\theta) = \sum_{k_{even}} A_{kk} P_k(\cos\theta).$$

Since the spins of the nuclear levels of most nuclei used for detector calibration are rather low, directional correlations are weak and the first two or three members of the above sum describe satisfactorily the observed correlations. The influence of the correlations can be further reduced by measurement at an angle of 125°, where the second Legendre polynomial equals to zero. Nevertheless, the influence of angular correlations should be taken into account in the coincidence method.