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Background subtraction of digital coincidence Doppler broadening spectra

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Abstract
A new method of subtracting the chance coincidence background is presented. The two-dimensional (2D) background spectrum is discussed in detail. We found that the Compton scattering boundary is not parallel to the axis in the 2D spectrum. The conclusion has been demonstrated by some experiments.

Keywords: positron annihilation, digital, chance coincidence, background

1. Introduction

Positron annihilation spectroscopy (PAS) is a very sensitive method in materials research, and has been widely used in recent decades. One of the most important PAS methods is Doppler-broadened annihilation radiation (DBAR), which gives information on the momentum distribution of electrons at the annihilation site.

DBAR is always distorted by background events, which come from Compton scattering, incomplete charge collection, pulse pile-up and environmental radiation. The ratio of peak to background (PB) is poor in these experiments, and is about 10^3. In 1977, Lynn *et al* developed a coincident set-up to detect both of the annihilation photons simultaneously [1], which increased the PB ratio to the order of 10^5 and improved the relative energy resolution by a factor of $\sqrt{2}$. This method has been used in many fields recently [2, 3]. The core electron of the atom can be observed, which carries information about different elements.

Several groups have developed this method [4, 5]. The most important improvement is the use of digital technology. One of the advantages of digital technology is that much information in the experiments can be stored and analysed off-line. In the present study, we have found a new method of subtracting the chance coincident events. This method is based on the delayed coincidence method and realized with the help of digital technology. The background of Compton scattering is discussed in detail for the 2D spectrum.

2. Experimental set-up

Recently, we have developed a digital system of two-detector DBAR [5]. As shown in figure 1, a data acquisition (DAQ) card with software is used to replace the conventional multichannel analyser (MCA) and some coincidence units. The analogue signal from the main amplifier is sent to the DAQ card directly, and will be processed by the computer online. The information on the amplitude and the time of the signal will be stored in the computer. This set-up is much simpler than the traditional system but more information in the experiment is stored and analysed flexibly.

3. Results

In our system, every coincidence event is recorded in a data file, including the energies of the two photons and the time difference between them. The data will be processed using an off-line program.

3.1. Chance coincidence

In the traditional system, the chance coincidence is usually measured using a delayed coincidence method. For a digital system of coincidence Doppler broadening (CDB), we found a universal solution to this problem. The distribution of the time difference is shown in figure 2. The time zero is not in agreement with the peak position of the time difference distribution. This is because of the different types of the two

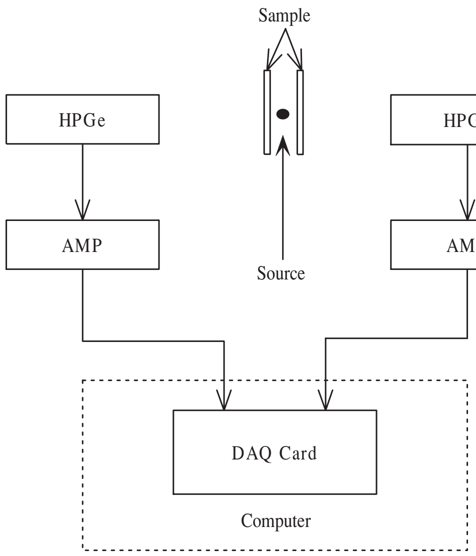

Figure 1. Block diagram of the system.

HPGe detectors and the two main amplifiers in our experiment. It can be seen from figure 2 that the distribution tends towards a constant far from the peak. This constant value is the chance coincidence rate. So the procession of chance coincidence events would be as simple as a common one-dimensional background problem. First, a time window is selected far enough away from the peak. The width of the window is about several δ, where δ is the FWHM of the peak in figure 2. Then the events in the time windows are selected from the data list and distributed into a 2D spectrum, which is the chance coincidence spectrum. Finally, this chance coincidence spectrum is subtracted from the initial spectrum.

3.2. *Two-dimensional background*

The main background in the 2D distribution of CDB is caused by Compton scattering of the 1.28 MeV and 0.511 MeV photons. A 2D step function has been used to describe the background [4], but no details have been discussed. As we know, only a narrow range in the 2D spectrum is concerned with the constraint $|E_1 + E_2 - 2m_0c^2 - E_b| < \sigma$, where E_b is the binding energy of the positron and electron. σ is the width of the window according to the resolution of the sum spectrum [6]. The Compton scattering events far from the region of 511 keV will not affect the difference spectrum. But useful information of the details of the 2D step function can be deduced from the boundary of the Compton scattering.

The energy distribution of a scattered photon can be described by the Compton scattering equation, which can be found in any textbook on the interaction of matter and light. Compton scattering of the photon with $E_\gamma = 1.28$ MeV, energy will lead to a constant background in the peak area of the 2D spectrum, while the background of the annihilation photon will be a 2D step function. Since the energy distribution of the annihilation photon is broadened because the total momentum of the annihilation positron and electron is not zero, the edges of the 2D step function would not be parallel to the axis but actually along the slope of the sum spectrum. This can be confirmed by another situation: the photon was scattered inside the detector. In this situation, the detector only records the deposition energy of the Compton scattering. The boundary is near the energy of 340.7 keV. We try to describe the energy distribution using the following equation:

$$y = a\,\mathrm{e}^{b(x-c)} + d, \tag{1}$$

where a, b, c, d are undetermined coefficients. The Compton boundary is determined by the value of c. In fact, there is a little shift between c and the Compton boundary because of the limitation of the detector. Since this shift is in the same direction, it will not affect the final result.

An experiment has been designed to demonstrate this work. The sample is a high quality zinc slice. The total number of counts is about 2×10^7, with a count rate of about 100 s^{-1}. In the 2D spectrum, we choose seven energy points along an axis from 508 keV to 515 keV. Figure 3 shows the fitting constant c using the least squares method.

Figure 4 shows the final result of background subtraction from the 2D spectrum of pure Zn. From the figure, we can see that there is little difference between the corrected and uncorrected difference spectra. This is partly because of the constraint of energy selection. But the difference between the corrected and uncorrected sum spectra is large, and the former is more symmetrical and physically meaningful.

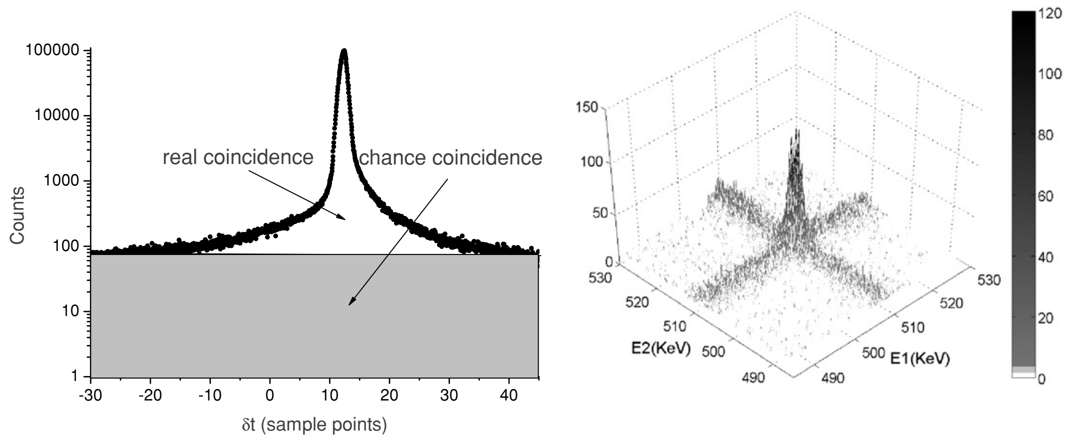

Figure 2. The chance coincidence background of 2D DBAR. Left: how to sort out the chance coincidence events. Right: the distribution of chance coincidence in 3D space.

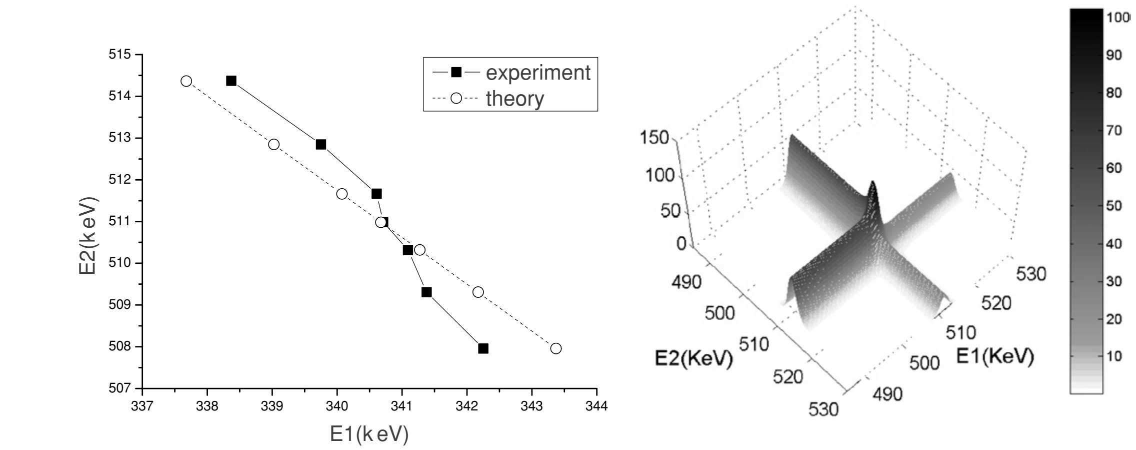

Figure 3. The Compton scattering background of CDB. The left figure shows the Compton edge. The solid squares are the fitting value of c, and the open circles are the calculated result from equation (1). The experiment curve has been shifted by a few keV for comparison. Right: the distribution of Compton scattering background in 3D space.

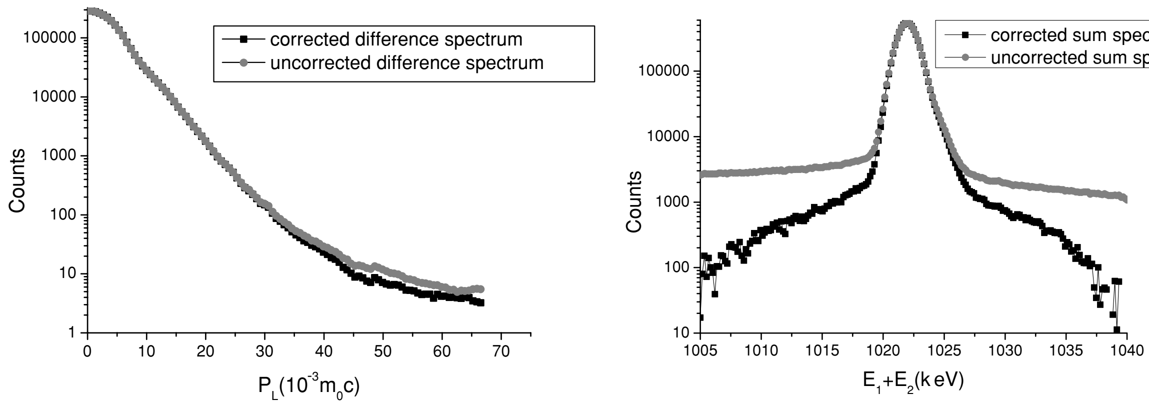

Figure 4. Left: the corrected and uncorrected difference spectra. Right: the sum spectra of pure zinc.

4. Conclusions

In this article, a new method of subtracting the chance coincidence background is presented. This method is feasible because of the use of digital technology. The 2D step function is discussed in detail. The final result is not obviously improved because there are few background events in CDB experiments. The ratio of chance coincidence events to total events is about 1% in our experiment. And the rate of Compton scattering events is about 1–2%. In fact, there are quite a few incomplete charge collection events in the 2D step function, which are in the low energy tail of the annihilation peak and are very difficult to separate from the Compton scattering events. Since the decreasing edge of the 2D step function will not be affected by these events, we think the 2D step function is a suitable model for describing these two types of background events.

Acknowledgments

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