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SPECTROMETER, USING NaI (Tl) - Ge (Li) DETECTORS IN COINCIDENCE AND ANTICOINCIDENCE FOR (n, GAMMA) INVESTIGATIONS

by

M. HESKE

1972

Joint Nuclear Research Centre
Geel Establishment - Belgium
Central Bureau for Nuclear Measurements - CBNM

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By using a pair-spectrometer, one can simplify such complex gamma-spectra. This leads, because of its low efficiency, to long measuring times. It will be advantageous in many cases to use the modifications of the pair-spectrometer with a higher efficiency.

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ABSTRACT

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KEYWORDS

PAIR SPECTROMETERS
SODIUM IODIDES
THALLIUM COMPOUNDS
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SCINTILLATION COUNTERS
GERMANIUM
LITHIUM DRIFTED SEMICONDUCTORS
SEMICONDUCTOR COUNTERS
ANTICOINCIDENCE
NUCLEAR REACTIONS
NEUTRON BEAMS
GAMMA RADIATION
EFFICIENCY
GAMMA SOURCES

Spectrometer, using NaI (Tl) - Ge(Li) detectors in coincidence and anticoincidence for (n,gamma) investigations. *)

1. Introduction

Gamma-ray spectra, resulting from resonance capture of neutrons, are used for determining resonance parameters. The spectra are measured with Ge(Li) detectors, but because these detectors respond to several physical processes (total absorption, single escape, double escape, compton events), the spectra are very complex. To allow a good interpretation it is necessary to simplify the spectra by using a pair-spectrometer, thus only the double escape events are allowed to be registered and the background is strongly suppressed. Several spectrometers of this type are described, see e.g. [1, 2, 3, 6, 7, 8, 10, 11]. All these spectrometers have an unavoidable low efficiency, this leads to long measuring times, especially with pulsed neutron sources (accelerators). In order to shorten inacceptable long measuring times it will be advantageous in many cases to use modifications of the pair-spectrometer. These modifications, as already proposed in [4] have higher efficiencies by reducing the good background suppression. Two versions, named "mode A" and "mode B" are investigated and described in this paper.
The pair-spectrometer as well as the two modes are effective at high gamma energies ($E > 2$ MeV). For low gamma energies an anticoincidence spectrometer is employed. Spectrometers of this type are described, see e.g. [5, 6, 7, 9, 10 .]

*) Manuscript received on March 27, 1972

2. Spectrometers

For the spectrometer (Fig. 1) we used a coaxial Ge(Li) detector with a useful volume of 25 cm^3 and two NaI(Tl) detectors (180 mm diam. x 114 mm).
Each of the two NaI(Tl) crystals has a semi-cylindrical hole of 77 mm diameter cut across the front face, thus forming the semi-annulus, and is coupled to a magnetically-shielded photomultiplier (Philips XP 1040).
In the common centre of the two NaI(Tl) detectors the Ge(Li) detector is located. The detectors are shielded by 10 cm of lead and an axial hole in the shield collimates the gamma-rays into the Ge(Li) detector. The lead shield attenuates direct gamma-rays to the NaI(Tl) detectors by a factor of about 100. The conditions for the pair-spectrometer are well known and described in several papers, noted above. The electronic bloc diagram of our pair-spectrometer is given in Fig. 3a.
A pair process produces a signal in the Ge(Li) detector and two annuhilation gamma-quanta, escaping from this detector. This pair production in the Ge(Li) detector is only allowed to be analysed in the analog-to-digital converter (ADC) if the following conditions are fullfilled : a) there is a fast coincidence (within 80 ns) between 3 signals coming from each NaI(Tl) dettector and from the Ge(Li) detector; b) the acceptance of the annihilation-gamma quanta within the windows of both single channel analysers (see Table 1).
The window settings of these analysers correspond to a pulse height of 511 $\pm$ 70 keV. As it is shown in [13], see Fig. 2, each NaI(Tl) detector has a specific photoefficiency or peak-to-total ratio P, for a certain gamma-energy. This peak-to-total ratio gives the fraction of

events, which fall into the full-energy peak, and thus within our window settings. For a 3" x 3" NaI(Tl) detector, comparable with ours, ref.13 gives P=0.64 at 511 keV gamma-energy. This means, that only 64 % of the annihilation gamma-quanta are falling within the energy windows, indicated above, and because of coincidence conditions between the two single channel analysers, the total efficiency is reduced by a factor of 0.41 . By reducing the lower threshold of the single channel analysers one could increase the percentage of accepted events. But instead of reducing the lower threshold we have chosen the following modifications :

"mode A" : The energy condition for one totally absorbed annihilation gamma-quantum (511 $\pm$ 70 keV) has to be fulfilled in only one of the two single channel analysers. We expect an increase in efficiency by a factor of about 1.6 (-1.0/0.64).

"mode B" : In this mode, only fast triple coincidence is required without any pulse height condition. The expected increase in efficiency is about 1.6 in comparison to the "mode A".

Finally we investigated a Ge(Li)-NaI(Tl) spectrometer in the compton suppression mode. In this mode, Fig. 3b, all Ge(Li) events are rejected in which any radiation escaped the Ge(Li) detector and interacted with either NaI(Tl) halves.

The modes are summarized in Table 1.

	detector	pair-spectrometer	"mode A	"mode B	anti-coincidence
fast coincidence	Ge(Li) NaI(Tl)Nr.1 NaI(Tl)Nr.2	R and R and R	R and R and R	R and R and R	R not (R or R)
slow coincidence	NaI(Tl)Nr.1 NaI(Tl)Nr.2	R and R	R or R		

R = response

Table 1

3. Measurements

3.1. Gamma spectra of ^{56}Co and $^{10}B(\alpha,p\gamma)^{13}$ sources

The sources were placed at a distance of 25 cm from the surface of the Ge(Li) detector. The results of these measurements are shown in Fig.6 for the $^{10}B(\alpha,p\gamma)^{13}C$ source and in Fig. 5 for the ^{56}Co source. In order to obtain the efficiencies in the different modes of operation the areas of several double escape (D), single escape (S) and full-energy (F) peaks were compared with their corresponding intensities in the ungated Ge(Li) spectrum (single). For this the gamma-rays at 3854 and 3685 keV (only the mono-energetic component) in the $^{10}B(\alpha,p\gamma)^{13}C$- and the gamma-rays at 3253 and 2598 keV in the ^{56}Co-spectrum were used. The results of these comparisons (normalized) are listed in Table 2. It turns out, that the pair-spectrometer has an efficiency for the double escape gamma-rays of about 13 % compared to their intensities in the single spectrum. With the spectrometer "mode A" this efficiency is raised to an averaged value of 20.5 %, but the peak-to-background ratio (P/B) becomes reduced by a factor of about 3. The increase of efficiency from 13 % to 20.5 % gives a factor of about 1.6 and shows a good agreement with the theorietically expected value. Even the high efficiency of 31 % was obtained in "mode B" at the expense of a further reduced P/B-ratio, but the P/B-ratio is still 4 - 7 times larger than in the single spectrum. This increase in efficiency from 20.5 to 31 % gives the factor of 1.5 and confirms the expected value.

In the anticoincidence mode the suppression factor for the Compton background is about 2 - 2.5. There is also a significant suppression of the single and double escape peaks relative to the full energy peaks. The full energy peaks are not attenuated, whereas the escape peaks are attenuated by a factor of 2 - 3, respectively to their intensities in the single spectrum.

3.2. Gamma spectra of ^{22}Na source.

To study the influence of the geometrical arrangement of the Ge(Li) detector relative to the NaI(Tl) annulus, the central detector has been replaced by a ^{22}Na source.

This source was positioned in the center of the annulus and moved along the axis of the hole in steps of 2 cm to the side. ^{22}Na desintegrates by emitting a gamma-ray of 1.27 MeV and in 90 % of these events annihilation-quanta are emitted after a β^+- decay. The annihilation-quanta are detected with the NaI(Tl) detectors and the results are shown in Fig. 4. The diminuation of the countrate as a function of the displacement of the source relative to the center is different in the serval modes. In Table 3 the diminuation is expressed numerically for a displacement of 1.7 and 3.4 cm.

The distance of 3.4 and 1.7 were chosen, because it is equal to the length of the Ge(Li) detector, and the half length, respectively.

	Displacement	1.7 cm	3.4 cm
mode	one NaI(Tl) detector	1 %	5 %
	pair spectrometer	7 %	20 %
	"mode A"	4 %	14 %
	"mode B"	1 %	3 %

Table 3

4. Conclusions

As the results of the measurements (3.1.) show, the pair-spectrometer is a good instrument to simplify complex gamma-spectra, but as a consequence of the low efficiency one has to pronlong measuring time. In many cases, especially measurements with pulsed neutron sources, it will be advantageous to interprete complex gamma-spectra by using the spectrometer in "mode A" or "mode B". The advantages are higher efficiencies in the double escape peaks and therefore reduction in measuring time. In the low energy region, the spectrometer when used in the anticoincidence mode, gives an appreciable suppression of the Compton background.
The results of the measurements with the ^{22}Na source (3.2.) demonstrate, that it is necessary for a good efficiency, especially in the pair-spectrometer, to place the Ge(Li) detector exactly in the center of the annulus.

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		$^{10}B(\alpha,p\gamma)^{13}C$						^{56}Co					
		3854 keV			3685 keV			3253 keV			2598 keV		
		F	S	D	F	S	D	F	S	D	F	S	D
Single	efficiency	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
	P/B		0.3	0.7					0.8	0.9		0.7	0.8
pair - spectrometer	efficiency			12.4%			13.3%			12.2%			14 %
	P/B			10.2						22.3			23.3
"mode A"	efficiency			19.6%			23.5%			18.5%			21 %
	P/B			3.8						8.9			8.5
"mode B"	efficiency			27 %			30 %			34 %			33.5%
	P/B			3.0						5.5			5.6
anticoinc. mode	efficiency	100 %	70 %	30 %	100 %	57 %	33 %	100 %	51 %	22 %	100 %	52 %	31 %

Table 2

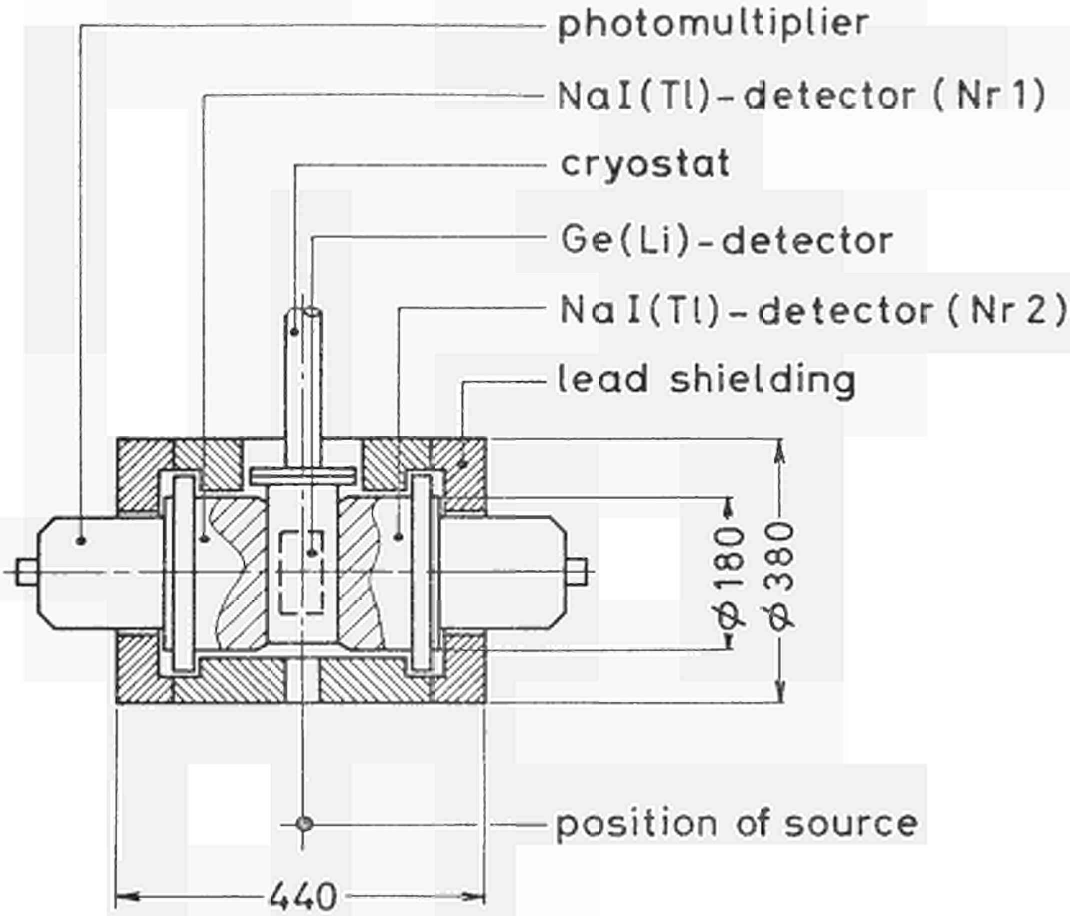

Fig.1 Schematic drawing showing the orientation of Ge(Li) detector relative to the NaI(Tl) annulis.

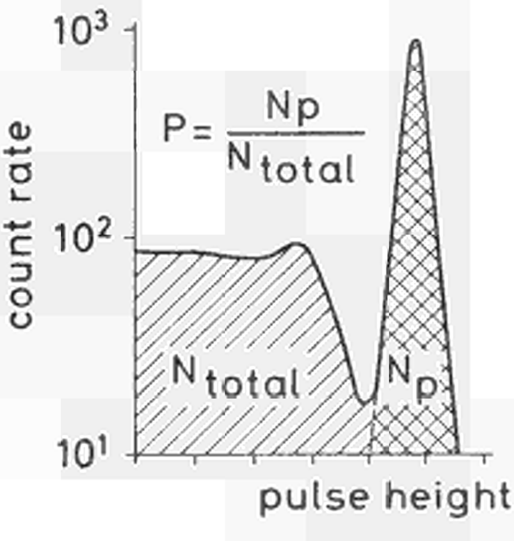

Fig.2 Illustration of peak-to-total ratio P.

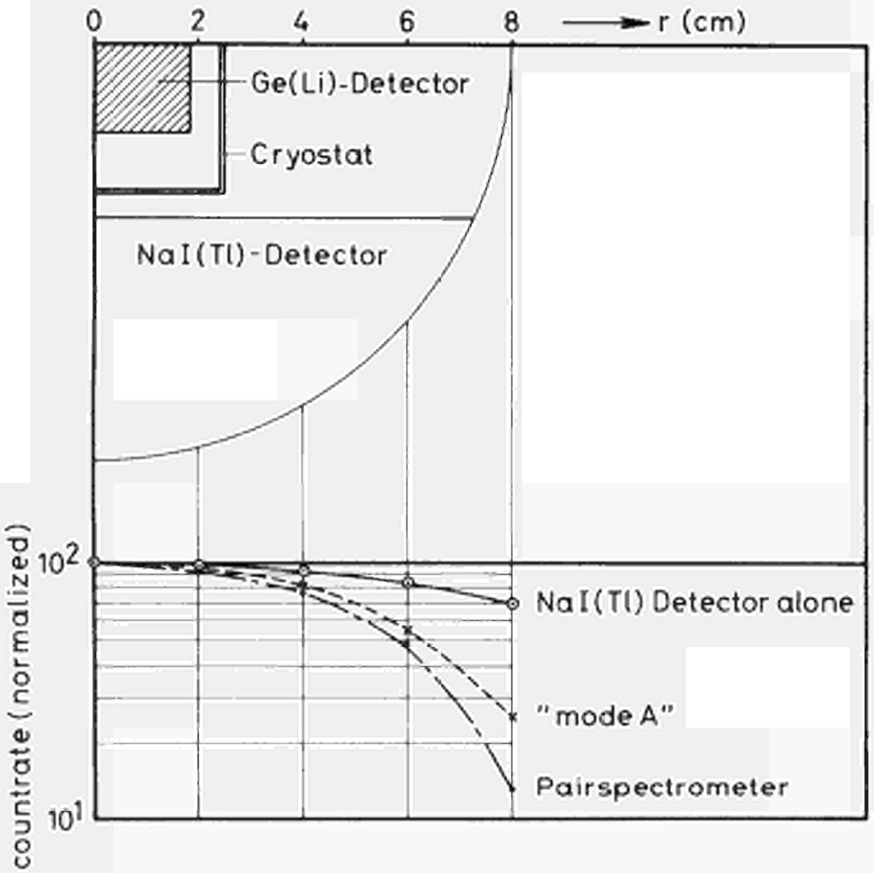

Fig.4 Countrate as a function of displacement.

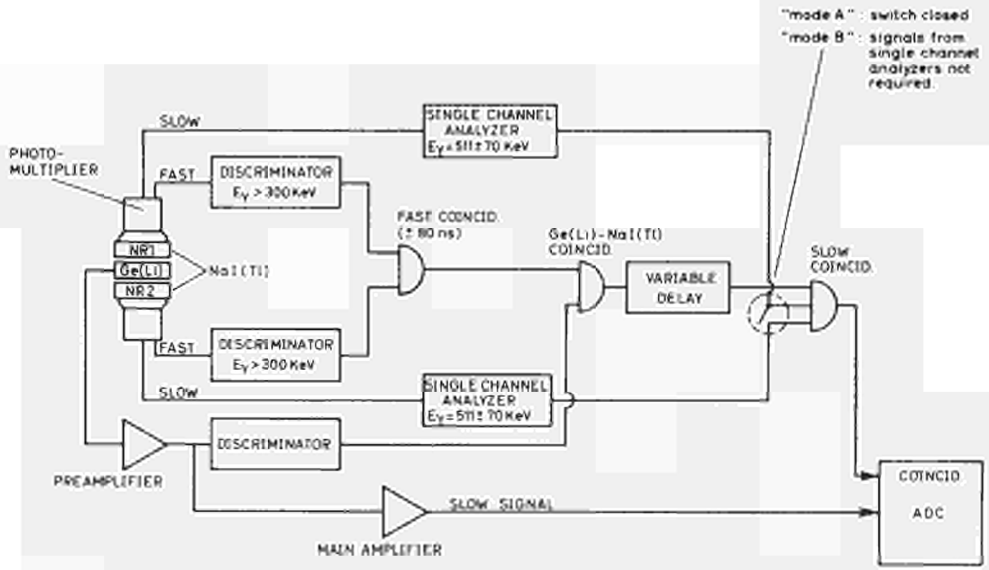

Fig.3a Electronic block diagram for operation as : a) pairspectrometer
b) "mode A"
c) "mode B"

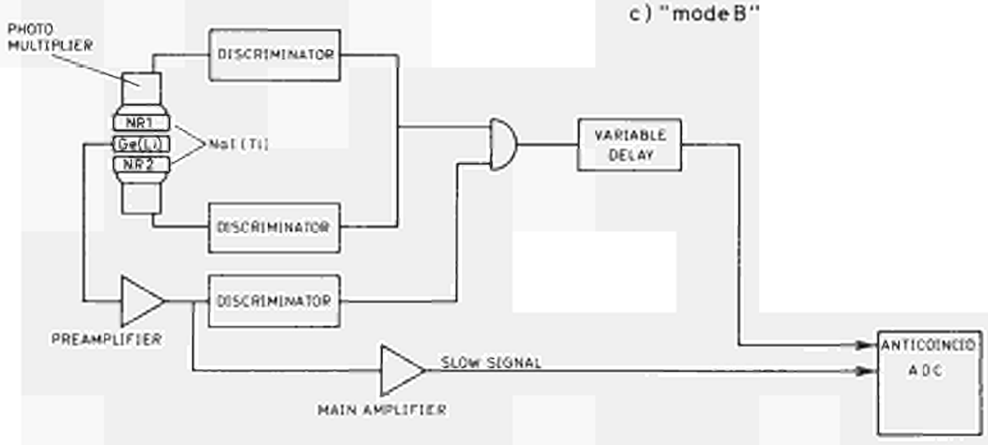

Fig.3b Electronic block diagram for operation as anticoincidence spectrometer.

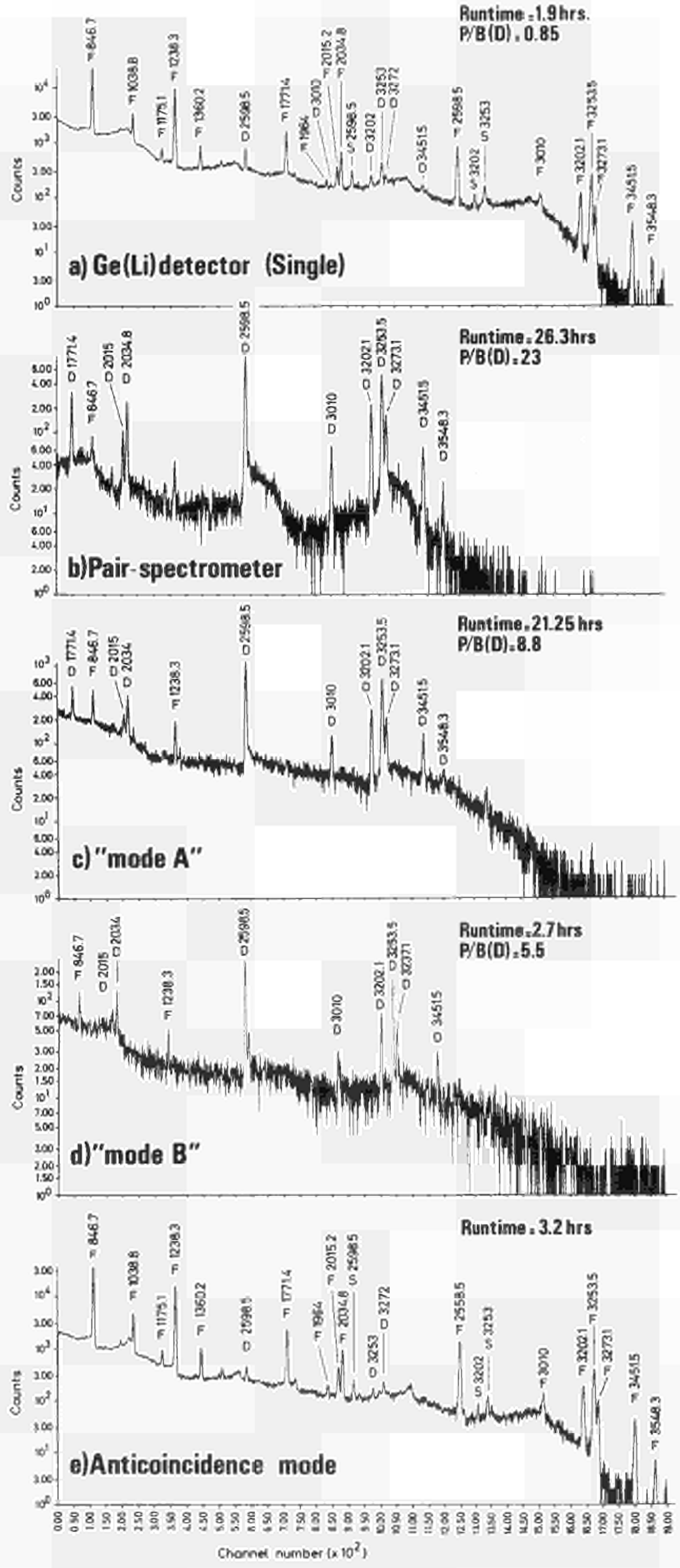

Fig.5 Gamma-ray spectra of ^{56}Co

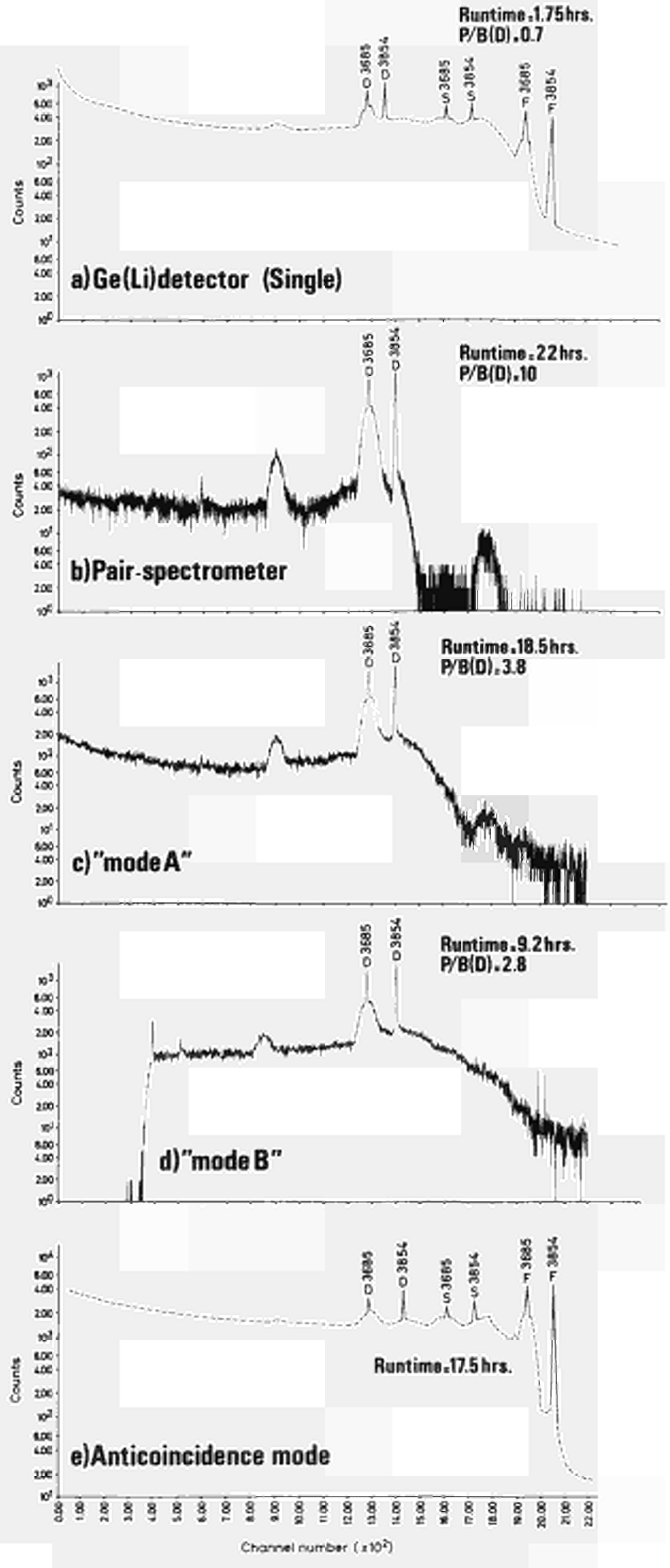

Fig.6 Gamma-ray spectra of $^{10}B(a,p\gamma)^{13}C$

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Alfred Nobel

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