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AN INTERNAL CONVERSION COEFFICIENT SPECTROMETER
UTILIZING SEMI-CONDUCTOR DETECTORS

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For
Nucl. Instr.
and
Methods

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Abstract

A description is given of a device that has been designed for the measurement of internal conversion coefficients by simultaneous observation of electron and gamma spectra with lithium-drifted silicon and germanium detectors, respectively. Calibration of the device was made by use of several well-known internal conversion coefficients (Hg^{203}, Au^{198}, Cs^{137}, Bi^{207}, Cd^{109} sources). Dependence of the efficiency of the germanium detector for full-energy absorption of gamma-rays has been determined.

Application of the method to the determination of conversion coefficients of the 191-keV transition from Pt^{197} decay and of the 346-keV transition from Pt^{197m} decay is described. The following results are obtained

Pt^{197}: 191 keV transition, $\epsilon_K = 0.69 \pm 0.07$, $K/L = 5.2 \pm 0.6$

Pt^{197m}: 346 keV transition, $\epsilon_K = 3.9 \pm 0.4$, $K/L = 1.8 \pm 0.2$.

[†] On leave from Oregon State University, Corvallis, Oregon.

1. Introduction

The measurement of absolute values of internal conversion coefficients has been a tool of wide use in nuclear spectroscopy. The internal conversion coefficient, defined as the ratio of electron emission probability to photon emission probability for a particular nuclear transition, is very sensitive to several nuclear parameters, e.g., atomic number, transition energy, and transition multipolarity. Thus it is in principle possible to deduce the multipole orders of gamma transitions of particular energy and Z by comparison of experimentally measured conversion coefficients with appropriate values from tables of theoretically calculated coefficients[1,2]).

A considerable effort has been expended in checking the accuracy of the theoretical tables[3]), and, as a result, several internal conversion coefficients have been rather precisely measured. These include the conversion of the 279-keV transition in Hg^{203} decay, the 412-keV transition of Au^{198}, and the 662- of Cs^{137}. However, the more general use of internal conversion coefficient determinations in nuclear spectroscopy has been hindered by experimental difficulties associated primarily with the poor energy resolution for gamma rays of scintillation crystals, so that only in cases of relatively uncomplicated decay schemes could measurements be made with confidence. It was however possible in some cases such as those mentioned above, where extremely strong sources could be prepared, to make use of precise but indirect methods, e.g., by "externally converting" the photon spectra to photoelectron spectra in a magnetic spectrometer with use of high-Z absorbers placed in front of the source, and making quantitative comparisons of the photo- and conversion-electron intensities[3]). Because of the small photoelectric cross sections and unfavorable geometric factors, the external-conversion method is inefficient and hence limited in application.

The recent availability of semi-conductor detectors sensitive to both electrons and photons with moderate efficiency and energy resolution provides

the possibility to measure internal conversion coefficients in a direct and convenient manner. This paper describes a simple "electron-gamma spectrometer" utilizing silicon and germanium detectors that has been constructed for this purpose. With it, conversion coefficients can be measured routinely with an accuracy in most situations of about 15%. The method is generally applicable, but, in particular, conversion coefficients of short-lived activities can be determined readily because the electron and gamma spectra are recorded simultaneously with the use of multichannel analyzers.

2. Description of the Apparatus

A picture of the conversion-coefficient spectrometer is shown in fig. 1 and a scale drawing is given in fig. 2. It is essentially a small vacuum chamber in which are mounted, at 180° fixed geometry, lithium-drifted silicon and germanium detectors, for recording the electron and gamma spectra, respectively. A 1/16-inch aluminum absorber placed in front of the Ge(Li) crystal prevents electron lines from being recorded in the gamma channel. No problem is encountered from gamma detection in the electron channel because the efficiency of Si(Li) for absorption of gamma rays above ~80 keV is very low and in any event gamma peaks fall at different energies from conversion electron peaks. Dimensions of the Si(Li) detector are 1 cm^2 by 3 mm deep. In order to minimize edge-effects in this crystal, a 5/16-inch diameter aluminum collimator was placed in front of it. Dimensions of the Ge(Li) detector are 4 cm^2 by 5 mm deep. Both detectors were produced at this Laboratory[4]).

The active sources are introduced into the vacuum chamber through an air lock of conventional design, evacuated by a separate roughing pump. The source holder is designed so as to assure reproducible positioning of the sources between the Si(Li) and Ge(Li) detectors. Sources are usually liquid-

deposited, on backings of Au-coated mylar, over an area of ~0.3 cm^2. The system is maintained at a pressure of 2×10^{-6} mm. with use of a standard oil diffusion pump, separated from the vacuum chamber by two cold-traps in series to minimize deposition of pump oil on the detectors.

In addition to the 4 cm^2 Ge(Li) detector in the e-γ spectrometer, a separate detector assembly with a Ge(Li) crystal (2 cm^2 × 7 mm deep) of superior energy resolution has been used for more detailed examination of the gamma spectra where resolution problems might be encountered.

The Ge(Li) detectors are maintained at "liquid-nitrogen temperature" (-196°C) with use of 10-liter gravity feed liquid nitrogen reservoirs of commercial manufacture[5]). The Si(Li) detector is maintained at -65°C, at which temperature it was found to have the best energy resolution, by the introduction of a heat leak at the Si-detector mount.

The associated electronics for each detector consists of a low-noise, low-capacity preamplifier and biased-amplifier system designed by Goulding and Landis[6,7]) and manufactured at this Laboratory. Pulse-height analysis of the spectra is made with 400-channel R.I.D.L. analyzers[8]).

3. Performance and Calibration of the System

The performance of the 2 cm^2 Ge(Li) detector system is illustrated in figs. 3 and 4, where portions of the gamma-ray spectra of Co^{57} and Co^{60} are shown. The achieved line widths are 2.3 keV at 122 keV photon energy ($\Delta E/E$ = 1.9%) and 4.2 keV at 1.33 MeV ($\Delta E/E$ = 0.32%). The observed increase in line width with energy can be explained partly by the statistics of charge production in the detector with the assumption of a "Fano factor"[9]) of about 0.3. This value has been observed in measurements on another detector by Goulding, Landis, and Hansen[10]).

An example of the electron and photon spectra taken with the conversion-coefficient apparatus is shown in fig. 5. Here, the K, L, and M electron lines of the 279-keV transition in Hg^{203} decay are resolved, with line width 4.2 keV. The 279-keV photon line width is 4.6 keV.

The internal conversion coefficient may be expressed as:

$$\epsilon = \frac{A_e}{\eta_e(E_e)} \cdot \frac{\eta_\gamma(E_\gamma)}{A_\gamma} \qquad (1)$$

where A_e is the area under the conversion electron peak.

A_γ is the area under the corresponding gamma-ray peak.

$\eta_e(E_e)$ is the detection efficiency of the Si(Li) system for electrons in the full-energy peak (including solid-angle factor)

$\eta_\gamma(E_\gamma)$ is the detection efficiency of the Ge(Li) system for gamma-rays in the full-energy peak (including solid-angle factor).

Calibration of the instrument was done in the following way: First, a determination was made of the relative photopeak efficiency, $\eta_\gamma(E_\gamma)$, of the Ge(Li) detector as a function of gamma-ray energy E_γ, by use of a number of isotopes with well-measured photon relative intensities. The experimental gamma efficiency function is shown in fig. 6. A suitably normalized electron efficiency function $\eta_e(E_e)$ was then determined, with use of eq. (1), by measuring the areas under the electron and gamma-ray lines from transitions with known conversion coefficients. The "standard coefficients" are listed in table 1. All solid-angle factors are constant and need not be considered explicitly. The normalized electron efficiency function so obtained is shown in fig. 7.

As a check on the shape of the electron efficiency function, a source containing Bi^{205} and Bi^{206} was prepared, and an independent determination of the relative electron efficiencies was made, with use of the Bi^{205} and Bi^{206} electron intensity data of Stockendal and Hultberg[18]). Satisfactory agreement with the curve of fig. 7 was obtained.

4. Application of the Method - Pt^{197m} and Pt^{197} Decay

As an example of the application of this method, results of measurements of the internal conversion coefficients of the 191-keV transition from 18-hour Pt^{197} decay and of the 346-keV transition from 90-minute Pt^{197m} decay are summarized briefly:

Previous measurements of the conversion coefficient of the 191-keV transition from Pt^{197} have yielded values ranging from 0.65 ± 0.15[19]) to 2.5[20]). The relevant theoretical values are: M1, β_K 0.95, K/L 6.4; E2, α_K 0.185, K/L 1.05[1]). A value greater than 0.95 would indicate monopole (E0) admixture in the transition whereas values below 0.95 would indicate E2 admixture. It is of theoretical interest to decide between these alternatives[21]).

A source of Pt^{197m} and Pt^{197} was prepared by neutron irradiation of isotopically enriched Pt^{196} (*), and the electron and gamma spectra were recorded. Portions of these spectra are shown in fig. 8. From these and similar spectra the data of table 2 were obtained. Comparison of the experimental conversion coefficient, 0.69 ± 0.07, with the quoted theoretical values yields the result that the 191-keV transition is an M1-E2 mixture with 33 ± 9% E2 admixture. The K/L ratio, 5.2 ± 0.6, indicates a 22 ± 11% E2 admixture.

In table 3 are given the data for the 346-keV transition of Pt^{197m} decay. The experimental values, $\epsilon_K = 3.9 \pm 0.4$ and K/L = 1.8 ± 0.2, clearly establish the multipolarity of this transition as M4 since the theoretical M4 values[1]) are: $\beta_K(M4) = 4.2$, K/L = 1.75.

A more complete account of the studies of the mass-197 isobars will be published elsewhere.

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*Obtained from the Stable Isotopes Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Acknowledgments

It is a pleasure to acknowledge the essential contribution of F. S. Goulding and his colleagues in the development of the semi-conductor counting system. In particular, thanks are due C. A. Crayne, W. L. Hansen, B. Jarret, G. W. Kilian, D. A. Landis, and C E. Miner.

We are grateful also to C. J. Butler for help in constructing the spectrometer, and to J. A. Harris for the preparation of sources. Conversations with Dr. T. Novakov have been most helpful.

Table 1. "Standard" internal conversion coefficients used for calibration of e-γ spectrometer.

Isotope	Transition Energy (keV)	Electron Energy (keV)	ϵ_K	Reference
Hg^{203}	279	193	0.162 ± 0.003	11
Au^{198}	412	329	0.0303 ± 0.0005	12
Cs^{137}	662	625	0.095 ± 0.004	13
Bi^{207}	1771	1683	0.0025 ± 0.0005	14
Cd^{109}	88	62	9.9 ± 0.5	15

Table 2. K-conversion coefficient and K/L conversion ratio of 191-keV transition in Au^{197}

Run	A_K/A_γ	$\epsilon = \frac{A_K}{A_\gamma} \cdot \frac{\eta_\gamma}{\eta_e}$ [a]	A_K/A_L	$K/L = \frac{A_K}{A_L} \cdot \frac{\eta_L}{\eta_K}$ [a]
1	1.141	0.705	5.87	4.95
2	1.025	0.633	6.72	5.67
3	1.200	0.742	4.78	4.04
4	1.149	0.710	6.23	5.26
5	1.088	0.672	6.54	5.52
6	1.051	0.649	6.68	5.64
7	1.104	0.682	----	----
		$\epsilon = 0.69 \pm 0.07$		$K/L = 5.2 \pm 0.6$

[a] The following efficiency values were used:

191-keV γ, $\eta_\gamma = 21.0$

108-keV K electron, $\eta_e = 34.0$

177-keV L electron, $\eta_e = 28.7$

Table 3. K-conversion coefficient and K/L conversion ratio of 346-keV transition in Pt^{197m}

Run	A_K/A_γ	$\epsilon = \frac{A_K}{A_\gamma} \cdot \frac{\eta_\gamma}{\eta_K}$ [a]	A_K/A_L	$K/L = \frac{A_K}{A_L} \cdot \frac{\eta_L}{\eta_K}$ [a]
1	16.03	3.62	2.31	2.16
2	16.42	3.71	1.75	1.64
3	19.00	4.29	1.80	1.68
		3.9±0.4		1.8±0.2

[a] $\eta_\gamma = 5.6$, $\eta_K = 24.8$, $\eta_L = 23.2$.

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Fig. 1. Photograph of conversion-coefficient spectrometer utilizing Si(Li) and Ge(Li) detectors.

Fig. 2. Drawing of conversion-coefficient spectrometer.

Fig. 3. Co^{57} gamma-ray spectrum taken with 2 cm^2 × 7 mm deep Ge(Li) detector system.

Fig. 4. Co^{60} gamma-ray spectrum taken with 2 cm^2 × 7 mm deep Ge(Li) detector system.

Fig. 5. Portions of Hg^{203} electron and gamma-ray spectra taken with conversion-coefficient spectrometer.

Fig. 6. Efficiency function for photoelectric absorption of gamma-rays in the 4 cm^2 × 5 mm Ge(Li) detector of the electron-gamma spectrometer. Values of the gamma-ray intensities used in constructing this curve, with the exception of Lu^{177m} were taken from reference 16. The Lu^{177m} values were those of Alexander et al. (ref. 17). The following symbols denote isotopes used for the calibration: O - Ta^{182}; ● - Lu^{177m}; □ - Bi^{207}; ▽ - Hg^{203}; △ - I^{131}.

Fig. 7. Efficiency function for "full energy" electron absorption in Si(Li) detector of conversion-coefficient spectrometer, normalized to the gamma-ray efficiency function for use in determining internal conversion coefficients. Points obtained from the "standard" conversion coefficients, shown with error bars, were used to obtain this normalized function.

Fig. 8. Portions of the Pt^{197} and Pt^{197m} electron and gamma-ray spectra taken with conversion-coefficient spectrometer.

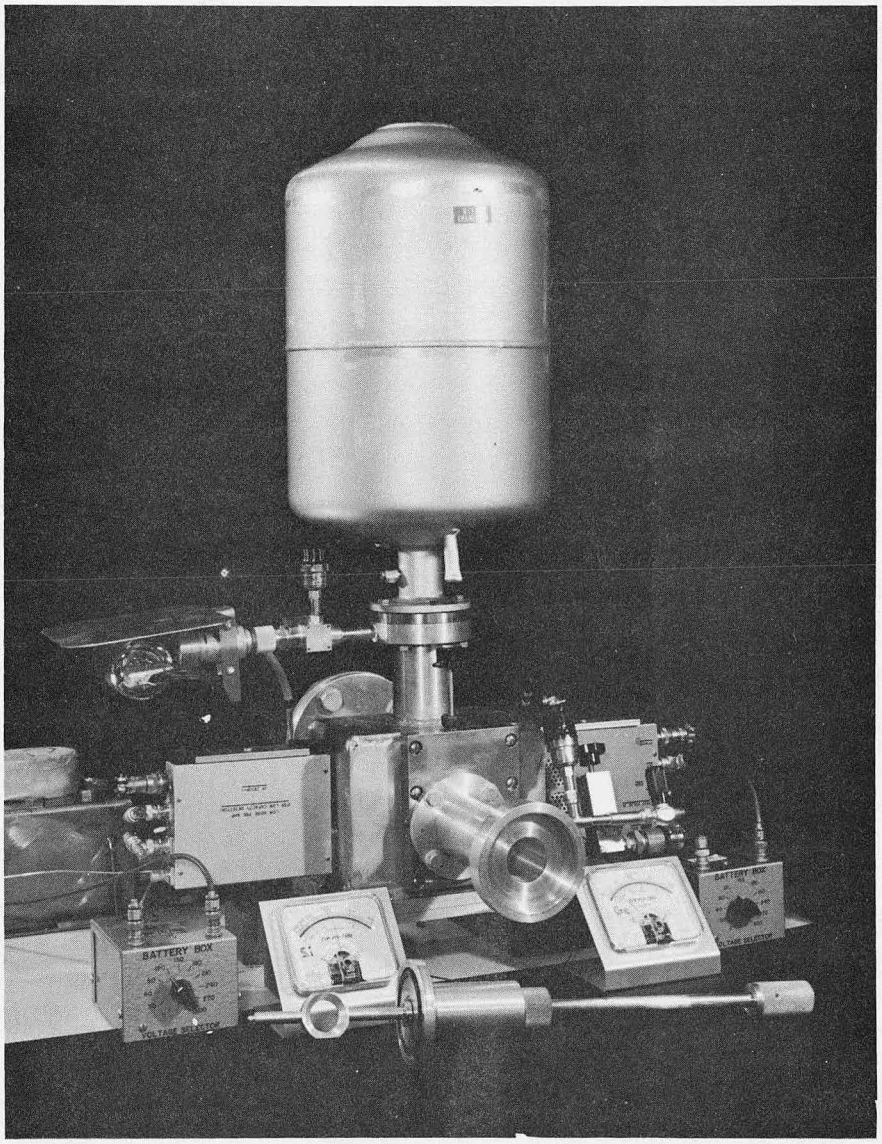

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Fig. 1

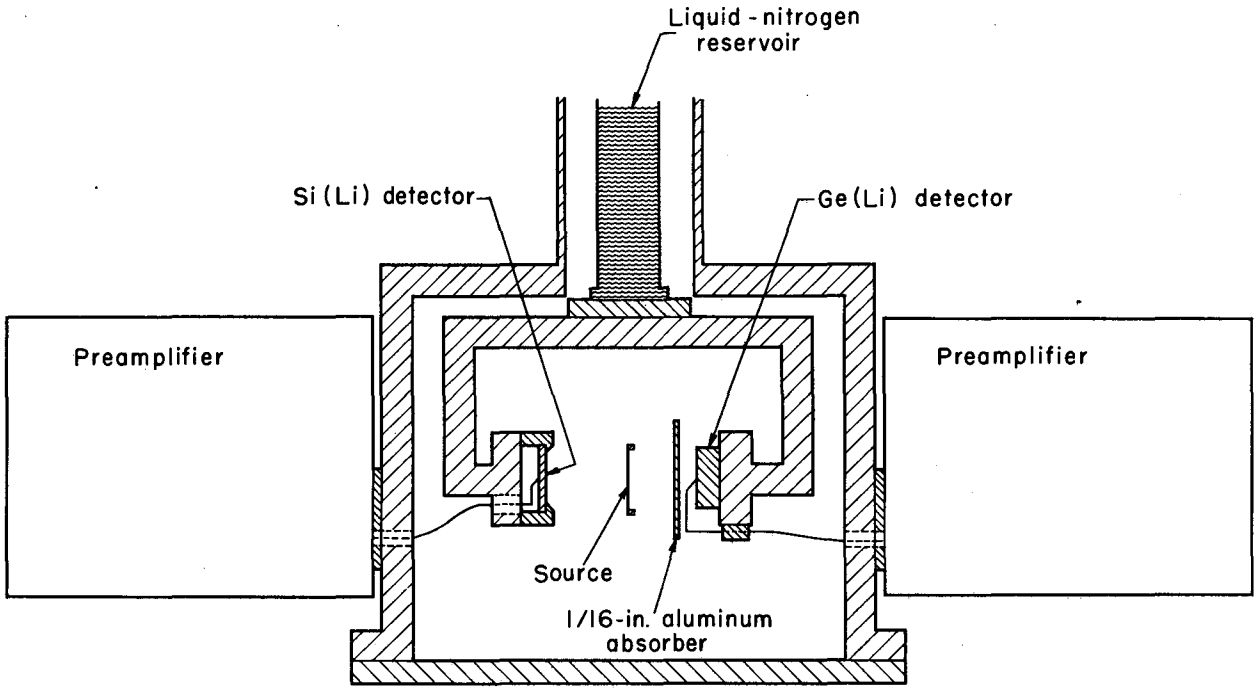

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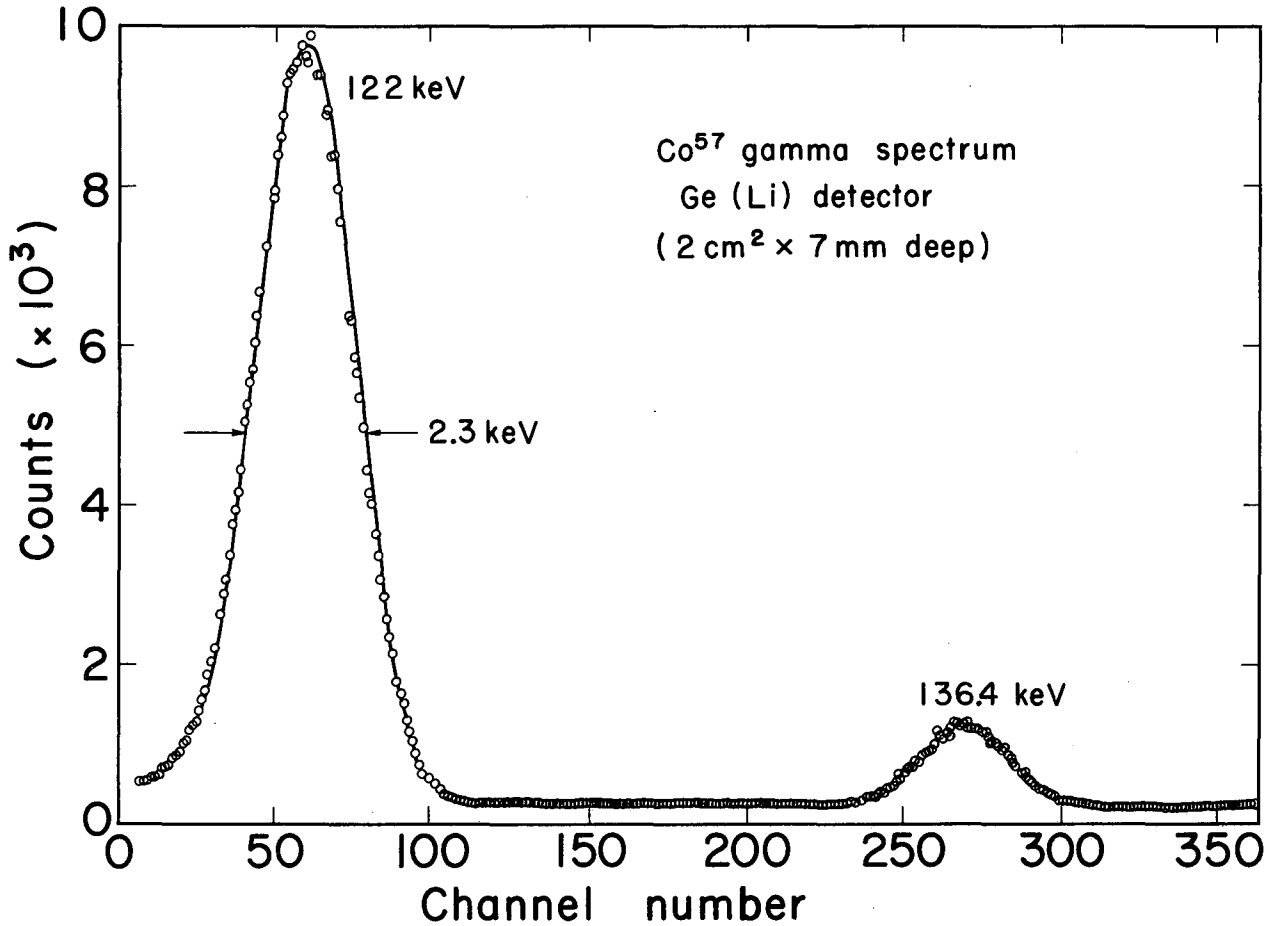
Fig. 2



MUB-3715

Fig. 3

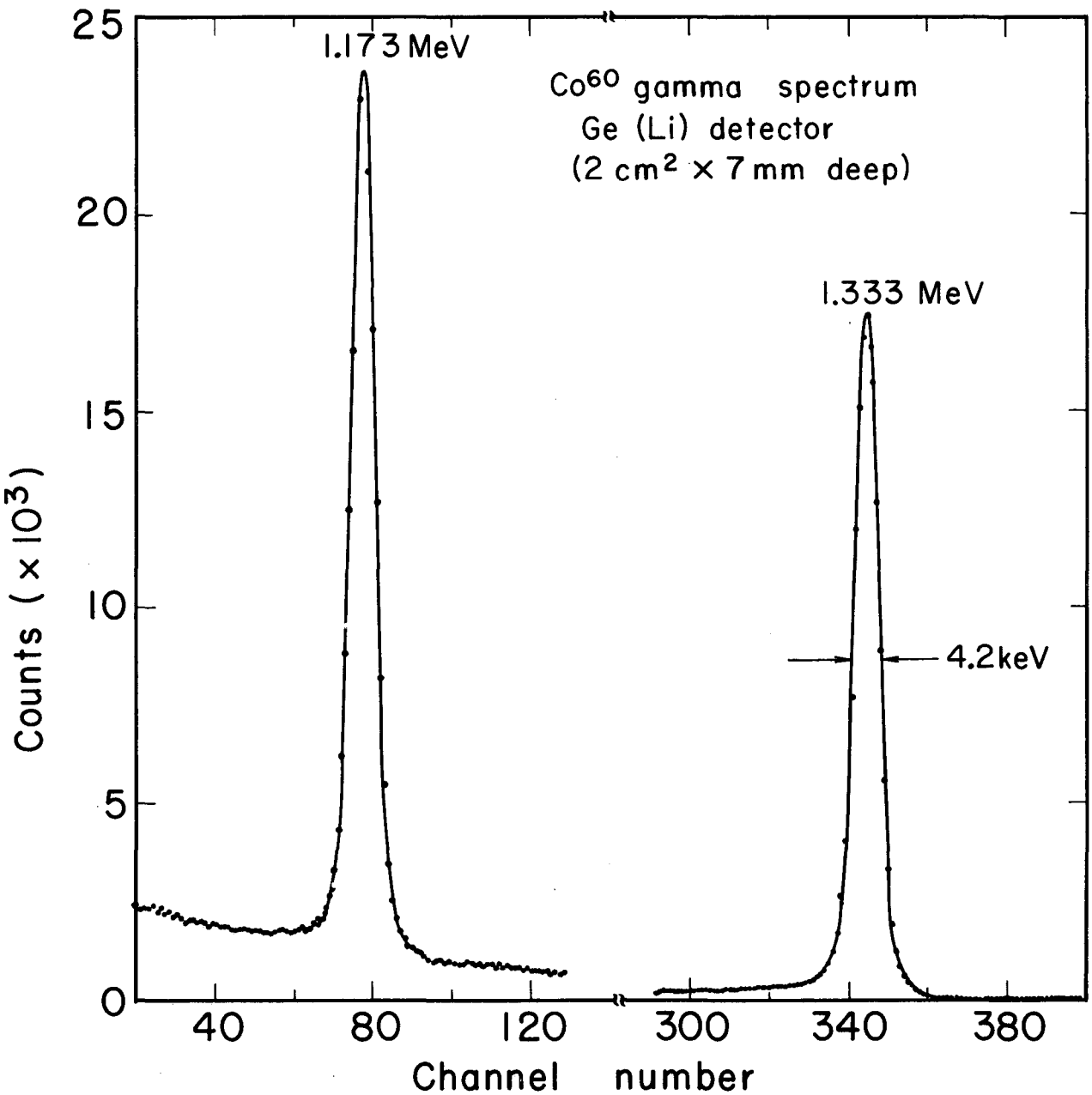


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Fig. 4

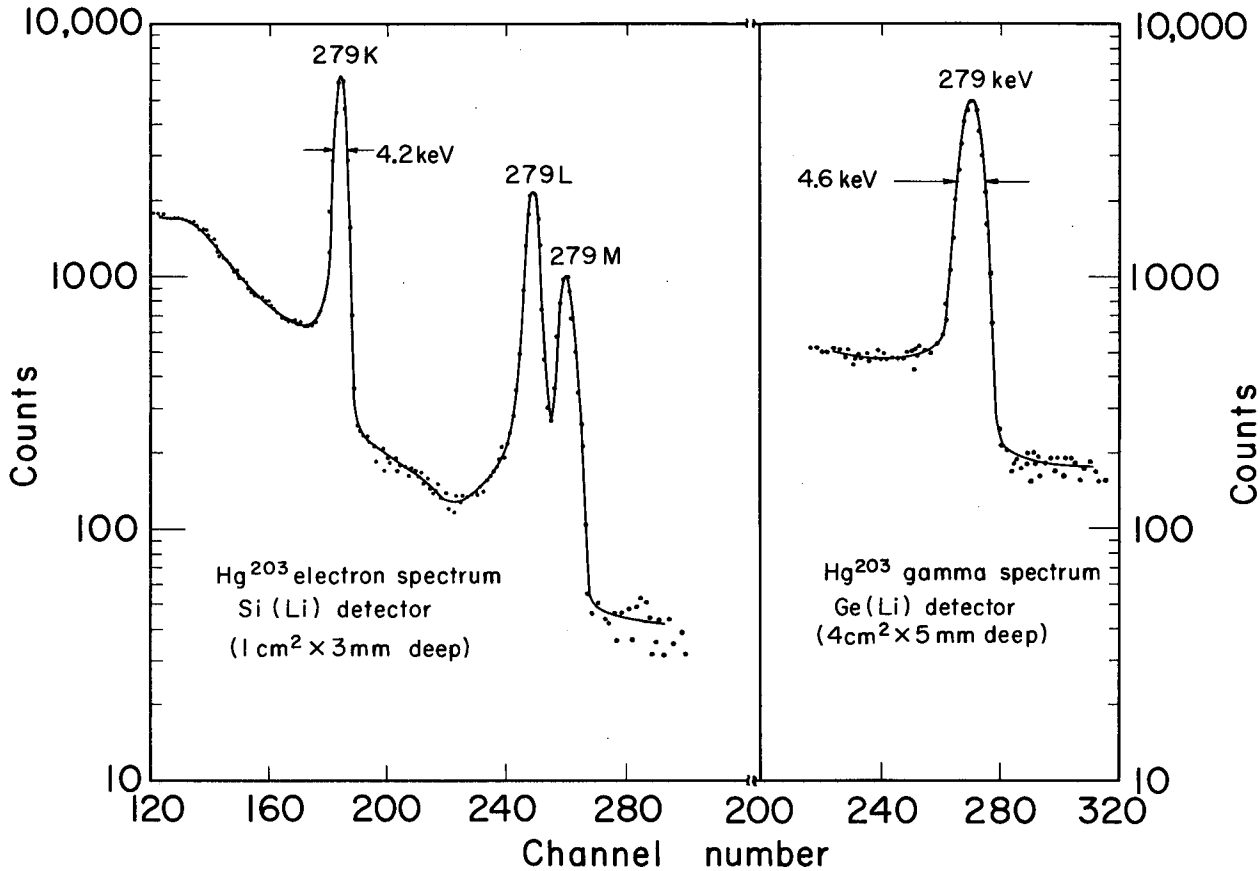

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Fig. 5

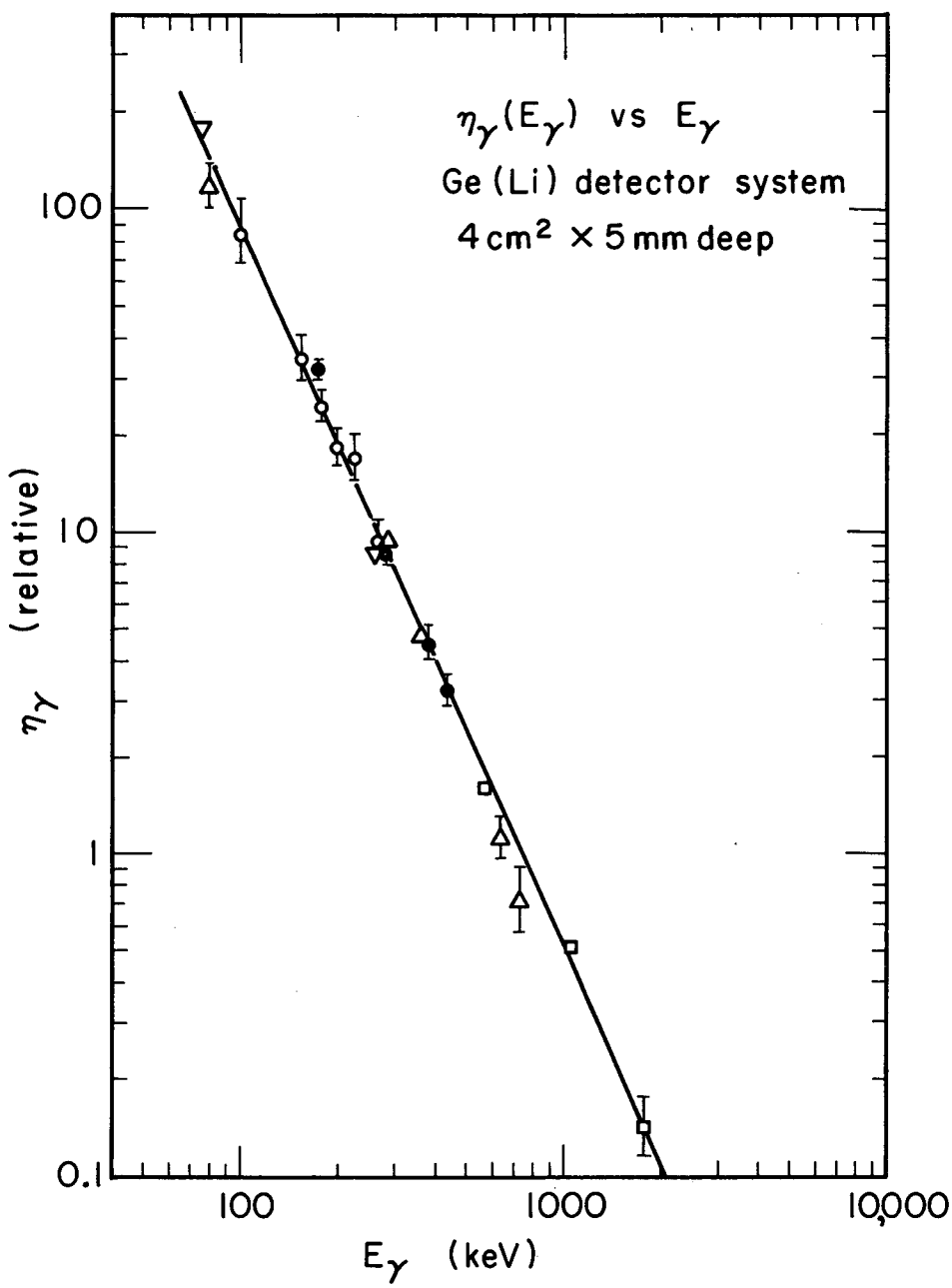

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Fig. 6

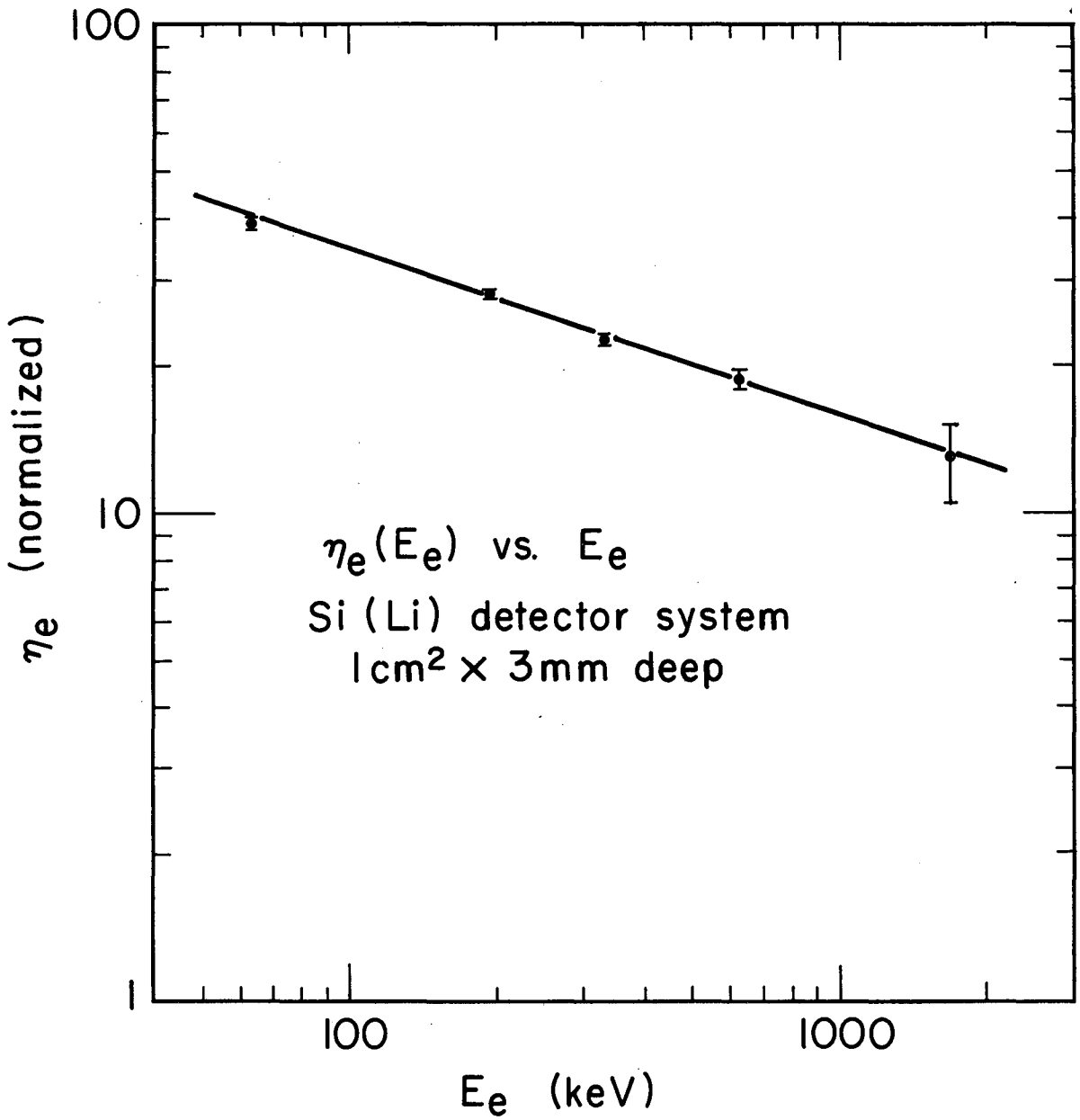

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Fig. 7

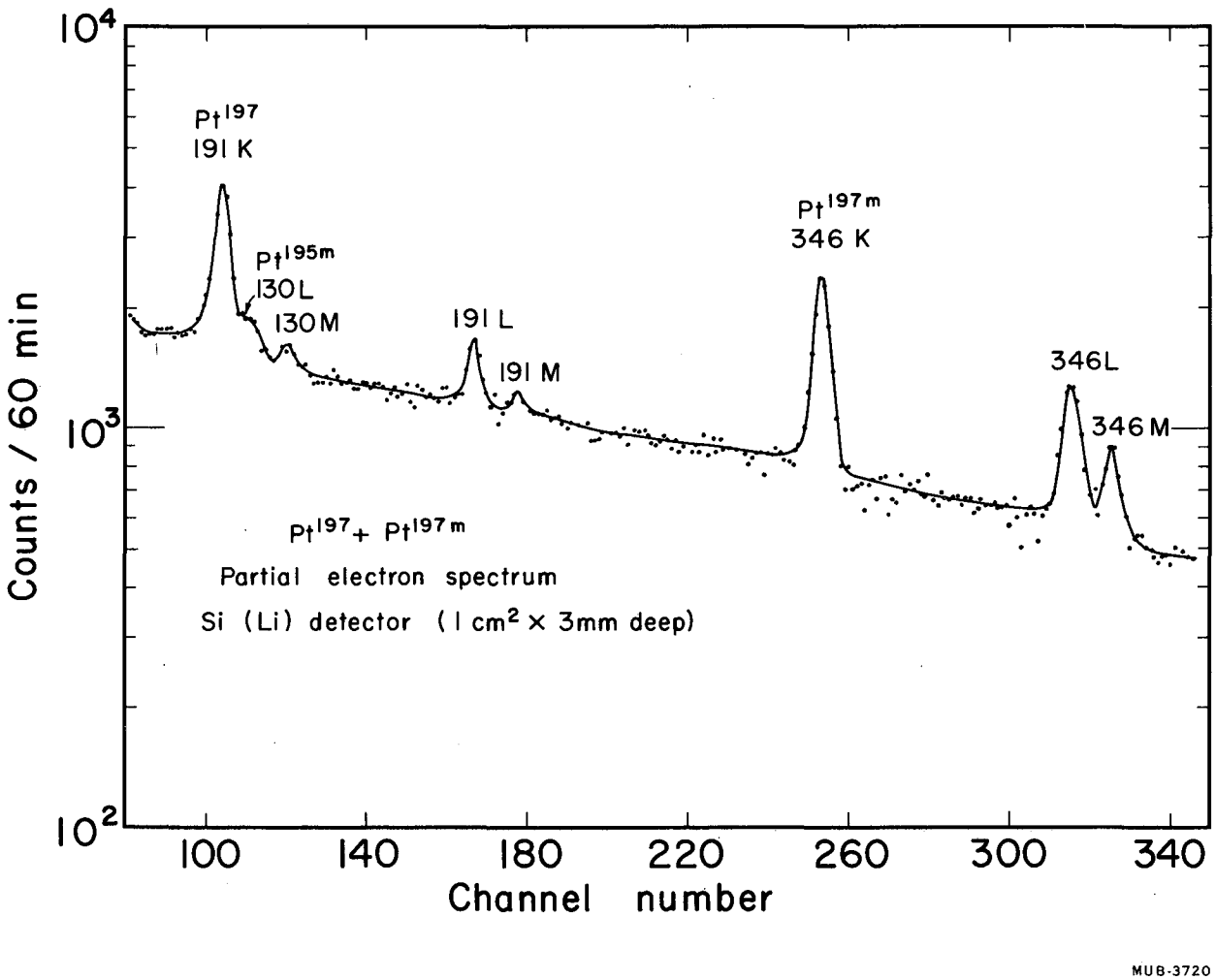
10^4
10^3
10^2
Counts / 60 min
Pt^{197}
191 K
Pt^{195m}
130L
130M
191 L
191 M
Pt^{197m}
346 K
346L
346M
Pt^{197}+ Pt^{197m}
Partial electron spectrum
Si (Li) detector (1 cm^2 × 3mm deep)
100
140
180
220
260
300
340
Channel number
MUB-3720

Fig. 8a

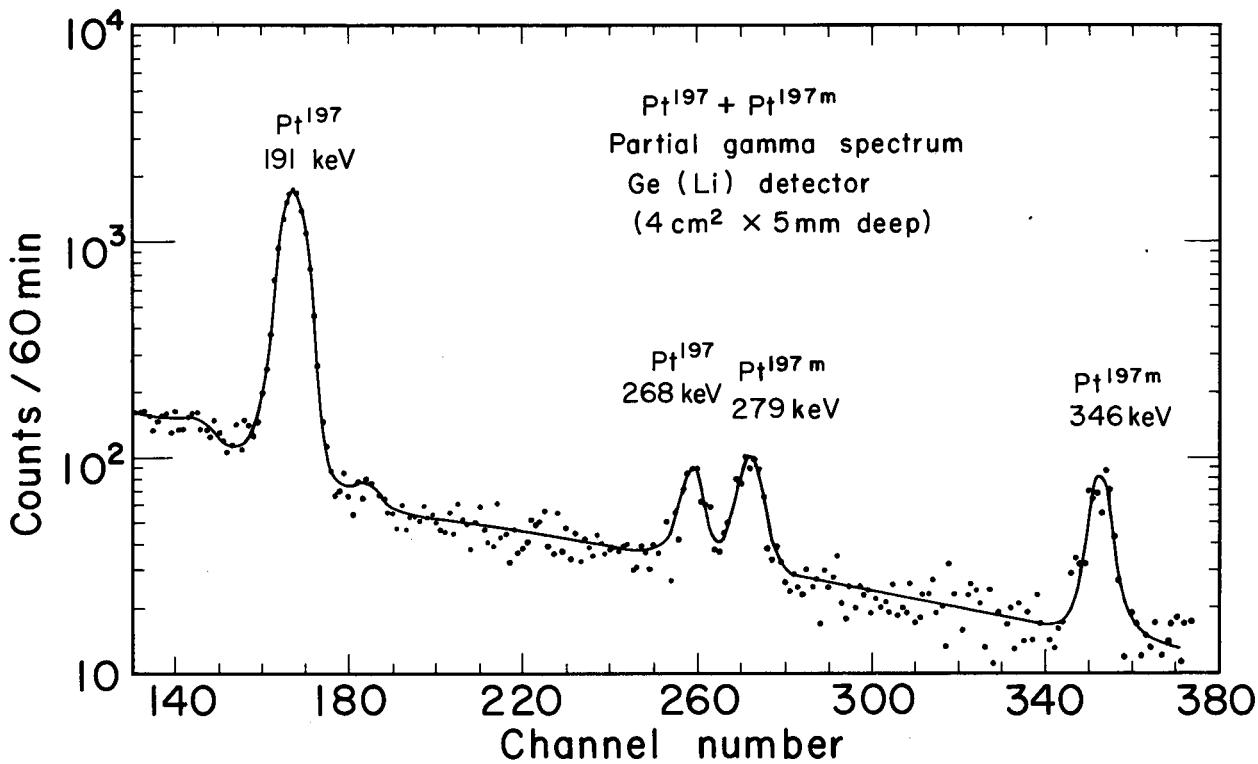
Pt197 + Pt197m
Partial gamma spectrum
Ge (Li) detector
(4 cm2 × 5 mm deep)
Pt197
191 keV
Pt197
268 keV
Pt197m
279 keV
Pt197m
346 keV
Counts / 60 min
Channel number
10
10²
10³
10⁴
140
180
220
260
300
340
380
MUB-3721

Fig. 8b

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