JAERI-M
90-213

NEUTRON TRANSMISSION MEASUREMENTS ON GALLIUM IN THE RESONANCE REGION

December 1990

Makio OHKUBO

日本原子力研究所
Japan Atomic Energy Research Institute

JAERI-Mレポートは，日本原子力研究所が不定期に公刊している研究報告書です。
入手の問合わせは，日本原子力研究所技術情報部情報資料課（〒319-11茨城県那珂郡東海村）あて，お申しこしください。なお，このほかに財団法人原子力弘済会資料センター（〒319-11 茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

JAERI-M reports are issued irregularly.
Inquiries about availability of the reports should be addressed to Information Division Department of Technical Information, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan.

編集兼発行　日本原子力研究所
印　　　刷　いばらき印刷㈱

Neutron Transmission Measurements on Gallium in the Resonance Region

Makio OHKUBO

Linac Laboratory,
Department of Physics,
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

(Received November 5, 1990)

Neutron transmission measurements were made on natural gallium using a TOF spectrometer of the Japan Atomic Energy Research Institute linear accelerator. Neutron resonance parameters are obtained for 54 levels in the energy region extended up to 10.4 keV. The average level spacing D and the s-wave strength function S_0 are deduced to be:

$D = 185 \pm 12$ eV,

$S_0 = (1.2 \pm 0.2) \times 10^{-4}$ below 10.4 keV.

Keywords: Neutron Cross Sections, TOF Measurements, Resonance Region, Natural Gallium, $E_n < 10.4$ keV, 54 Levels, Resonance Analyses, $D = 185$ eV, $S_0 = 1.2 \times 10^{-4}$

ガリウムの共鳴領域における中性子透過率の測定

日本原子力研究所東海研究所物理部
大久保牧夫

（1990年11月5日受理）

原研リニアックの飛行時間スペクトロメータを用いて，天然ガリウムの中性子透過率を測定した。共鳴解析を行い，10.4KeV以下の54本の中性子共鳴につき，共鳴パラメータを得た。これより平均準位間隔 $D=185\pm12$eV，及びS波強度関数 $So=(1.2\pm0.2)\times10^{-4}$ を得た。この測定により，共鳴解析を行った領域を，従来の5.9KeVから10.4KeVに拡張した。オーバラップしている領域では，従来の測定値とよく一致した。

東海研究所：〒319－11 茨城県那珂郡東海村白方字白根2－4

Contents

目　　次

1. Introduction

Slow neutron interaction with medium and heavy nuclei is characterized by fine structure resonances. Many experimental data in resonance region have been compiled under the international cooperation with a strong demand from nuclear reactor design. However, the neutron cross sections of some elements have not enough been measured, if these elements are neither fissile, nor fission product, nor structural, nor biological elements. Gallium is one of these elements, which is used as semiconductor materials. Nowadays, such semiconductors are widely used even in radiation fields; reactor sites or in space. Thus it is important to measure resonances of all nuclei as the basic nuclear data.

The resonance parameters of gallium are compiled in reference 1. The latest data are of Maletsky et al.[2] of Dubna in 1968. They have measured on separated isotopes using a time-of-flight(TOF) spectrometer of IBR pulsed reactor in the energy region below 5.9 keV. We have made a series of transmission measurements on many elements with a TOF facility of the JAERI linac from 1982 to 1986. Total cross sections deduced were sent to NEA DATA BANK in a magnetic tape, and are compiled in a book, "Neutron Cross Section", Vol-2 Curves [3].

In this report, transmission measurements on natural gallium and the results of resonance analyses are described.

2. Measurements and Analyses

The measurements were made at a 47-m TOF station of the JAERI electron linac[4,5]. The condition of the measurements is shown in Table 1. The pulsed neutrons were produced at a water cooled tantalum target bombarded by the electron beam ; energy was 120 MeV, peak current 3 A, pulse width 25 ns, and repetition rate 300 pps. The neutrons were moderated by a moderator surrounding the target[6], and traversed to the detector station through an evacuated flight tube. In the 47-m station, a ^{6}Li-glass transmission-type neutron-flux monitor was placed. At 1 m downstream from the monitor, transmission samples were placed, where the neutron beam was collimated to 35mm in diameter. At 1.5 m downstream from the sample, a main neutron detector of ^{6}Li-glass scintillator(38mmϕ x12.7mmt NE912) was placed in a boron-paraffine shielding, an inner wall of which was

1. Introduction

Slow neutron interaction with medium and heavy nuclei is characterized by fine structure resonances. Many experimental data in resonance region have been compiled under the international cooperation with a strong demand from nuclear reactor design. However, the neutron cross sections of some elements have not enough been measured, if these elements are neither fissile, nor fission product, nor structural, nor biological elements. Gallium is one of these elements, which is used as semiconductor materials. Nowadays, such semiconductors are widely used even in radiation fields; reactor sites or in space. Thus it is important to measure resonances of all nuclei as the basic nuclear data.

The resonance parameters of gallium are compiled in reference 1. The latest data are of Maletsky et al.[2] of Dubna in 1968. They have measured on separated isotopes using a time-of-flight(TOF) spectrometer of IBR pulsed reactor in the energy region below 5.9 keV. We have made a series of transmission measurements on many elements with a TOF facility of the JAERI linac from 1982 to 1986. Total cross sections deduced were sent to NEA DATA BANK in a magnetic tape, and are compiled in a book, "Neutron Cross Section", Vol-2 Curves [3].

In this report, transmission measurements on natural gallium and the results of resonance analyses are described.

2. Measurements and Analyses

The measurements were made at a 47-m TOF station of the JAERI electron linac[4,5]. The condition of the measurements is shown in Table 1. The pulsed neutrons were produced at a water cooled tantalum target bombarded by the electron beam ; energy was 120 MeV, peak current 3 A, pulse width 25 ns, and repetition rate 300 pps. The neutrons were moderated by a moderator surrounding the target[6], and traversed to the detector station through an evacuated flight tube. In the 47-m station, a ^{6}Li-glass transmission-type neutron-flux monitor was placed. At 1 m downstream from the monitor, transmission samples were placed, where the neutron beam was collimated to 35mm in diameter. At 1.5 m downstream from the sample, a main neutron detector of ^{6}Li-glass scintillator(38mmϕ x12.7mmt NE912) was placed in a boron-paraffine shielding, an inner wall of which was lined with B_4C layer of 1cm in thickness. A B_4C filter was inserted in the beam to eliminate slow neutrons which overlapped to the subsequent neutron bursts. Neutron detection signals from these detectors were amplified, sorted and sent to a computer room through double shielded coaxial cables.

The neutron detection events of the main detector were stored in a 4096 channel time analyzer with the minimum channel width of 31.25ns. The neutron pulses from the flux monitor were gated to count in the time region corresponding to 1.1- 0.3 keV in neutron energy. The accumulated data in the time analyzer were transfered to a FACOM U-200 mini-computer, and were finally stored on a disk memory of a large computer FACOM M380 at the JAERI computing center. The data processings and analyses were made through a remote terminal at the linac laboratory.

The sample of natural gallium (^{69}Ga 60.2%, ^{71}Ga 39.8%) was gallium oxide (Ga_2O_3) powder which was heated to 400 C in air to eliminate moisture and was packed in two aluminum cases of different thicknesses. The sizes and the thicknesses of the samples are shown in Table 2.

Neutron time spectra for open beam(without sample) and for thin and thick samples in the beam are shown in Fig.1 and 2, which were normalized by the monitor counts. Neutron transmissions of these samples were deduced from the ratio of the sample-in spectrum to the open-beam spectrum. The background in these spectra were estimated from the counts at saturated resonances of cobalt(132 eV), manganese(337 eV), aluminum(35 and 88 keV), and some of saturated resonances of gallium. To deduce the total cross section of gallium, oxygen cross section

$$\sigma_o = (3.85 - 0.002\ E)\ \text{barn}$$

was subtracted[7], where E is neutron energy in keV.
Energy scale of the TOF system was calibrated by the aluminum resonances at 5.9035 and 119.75 keV by adjusting the initial delay time of the analyzer.

The total cross sections of gallium from 50 to 715 eV are shown in Fig.3a and 3b, these from 1 to 5 keV region in Fig.4, and 5 to 10 keV in Fig.5, respectively. The transmission data were analyzed to deduce $fg\Gamma_n^0$ of each resonance by fitting the Breit-Wigner formula with a modifeid single level Atta-Harvey area analysis code, where f is isotopic aboundance, g spin statistical factor and Γ_n^0 the neutron reduced width. For large s-wave resonances the spin values(J=1 or 2) were determined by evaluating the fitting curves for each spin state.

3. Results

The resonance parameters are listed in Table 3 for 54 levels of natural gallium up to 10.4 keV. Resonance energies and $g\Gamma_n^0$ values for large resonaces are found to be in good agreement with that of Maletsky et al.[2] in the region below 5 keV; the comparison between the two sets of resonance parameters are shown in Fig.6. Cumulative numbers of resonances vs. neutron energy is shown in Fig.7, and the average level spacing D for probable s-wave levels was deduced to be:

$$D = 185 \pm 12 \text{ eV} \qquad \text{below } 10.4 \text{ keV}.$$

Cumulative values of $fg\Gamma_n^0$ vs. neutron energy are shown in Fig.8. The value of s-wave strength function for natural gallium is deduced to be:

$$S_0 = (1.2 \pm 0.2) \times 10^{-4} \qquad \text{below } 10.4 \text{ keV}.$$

These values are in good agreement with the values in reference 2. In the mass region from 65 to 100, the observed S_0 values are systematically smaller than the deformed optical model calculations[8].

In the present measurements, the resonance parameters and the neutron total cross sections are deduced in extended energy region, and are summarized in Table 4.

Acknowledgements

The author would like to thank Dr.Mizumoto and Dr.Nakajima for valuable cooperation, and the operator crew for the production of intense neutron beam.

3. Results

The resonance parameters are listed in Table 3 for 54 levels of natural gallium up to 10.4 keV. Resonance energies and $g\Gamma_n^0$ values for large resonaces are found to be in good agreement with that of Maletsky et al.[2] in the region below 5 keV; the comparison between the two sets of resonance parameters are shown in Fig.6. Cumulative numbers of resonances vs. neutron energy is shown in Fig.7, and the average level spacing D for probable s-wave levels was deduced to be:

$$D = 185 \pm 12 \text{ eV} \qquad \text{below } 10.4 \text{ keV}.$$

Cumulative values of $fg\Gamma_n^0$ vs. neutron energy are shown in Fig.8. The value of s-wave strength function for natural gallium is deduced to be:

$$S_0 = (1.2 \pm 0.2) \times 10^{-4} \qquad \text{below } 10.4 \text{ keV}.$$

These values are in good agreement with the values in reference 2. In the mass region from 65 to 100, the observed S_0 values are systematically smaller than the deformed optical model calculations[8].

In the present measurements, the resonance parameters and the neutron total cross sections are deduced in extended energy region, and are summarized in Table 4.

Acknowledgements

The author would like to thank Dr.Mizumoto and Dr.Nakajima for valuable cooperation, and the operator crew for the production of intense neutron beam.

References

[1] S.F.Mughabghab, M.Divedeenam and N.E.Holden; "Neutron Cross Section" Vol 1, Resonance Parameters Part A, Z=1-60, Academic Press (1981)

[2] H.Maletsky, L.G.Pikelner,I.M.Caramatin and E.I.Sharapov: JINR-P3-4151(1968)

[3] V.McLane, C.L.Dunford and P.F.Rose ed.:"Neutron Cross Sections" Vol 2, Neutron Cross Section Curves, Academic Press (1988)

[4] H.Takekoshi ed. JAERI-Report 1238(1975)

[5] M.Ohkubo, M.Mizumoto and Y.Kawarasaki; J.Nucl.Sci.Technol. 21,254(1984)

[6] M.Ohkubo: Nucl. Instr.Methods A253(1986) 43

[7] M.Ohkubo: JAERI-M 86-193 (1986)

[8] S.F.Mughabghab, Neutron Cross Sections and Technology, J.A.Harvey and R.L.Macklin ed. p 386, Knoxville, Tennessee, 1971.

Table 1 Condition of Measurements

Linac Electron Beam	120 MeV, ~3A, 20 ns, 300 pps
Neutron Flight path	47.38 m
Neutron Beam Diameter	35 mmφ
Neutron Detector	6Li-glass (38mmφ x12.7mmt NE912)
Flux Monitor	6Li-glass transmission type
Time Analyzer	4096 channels , 31.25ns
Computer	FACOM-M380

Table 2 Transmission Samples

Sample Size	Thickness
120 mm x 80 mm x 2 mmt	0.00215 atoms/barn
40 mmφ x 20 mmt	0.0258
40 mmφ x (20 + 20) mmt	0.0510

Table 3 Resonance Parameters of Natural Gallium

iso- * tope	Energy (eV)	DE (eV)	$2fg\Gamma_n$ (meV)	$D(2fg\Gamma_n)$ (meV)	$fg\Gamma_n^0$ (meV)	$D(fg\Gamma_n^0)$ (meV)	J
B	95.7	0.0	53.	5.9	2.7	0.3	
A	110.8	0.0	51.	4.2	2.4	0.2	
B	286.7	0.1	3010.	140.	89.	4.0	2
A	333.8	0.1	110.	15.	3.	0.4	
B	375.7	0.2	1090.	78.	28.	2.	1
A	472.7	0.2	74.	8.7	1.7	0.2	
A	691.	0.4	950.	53.	18.	1.	1
B	704.8	0.4	218.	21.	4.1	0.4	
A	1353.8	0.9	81.	7.4	1.1	0.1	
	1366.6	1.0	67.	7.4	0.9	0.1	
B	1525.3	1.1	1800.	160.	23.	2.	2
A	1582.3	1.2	1470.	160.	18.5	2.	2
A	1636.5	1.3	2220.	160.	27.5	2.	1
A	1868.	1.5	1900.	170.	22.	2.	2
B	1930.7	1.6	114.	9.	1.3	0.1	
B	2400.5	2.2	2060.	200.	21.	2.	2
A	2456.5	2.3	5300.	400.	53.	4.	2
B	2787.7	2.7	630.	63.	6.	0.6	
B	2870.	2.9	129.	11.	1.2	0.1	
A	3078.	3.2	550.	55.	5.	0.5	
B	3319.1	3.6	2070.	230.	18.	2.	1
B	3415.4	3.7	187.	12.	1.6	0.1	
A	3502.6	3.9	14800.	2400.	125.	20.	
	3854.2	4.4	199.	12.	1.6	0.1	
A	4208.7	5.1	1170.	130.	9.	1.	
	4341.3	5.3	316.	26.	2.4	0.2	
	4388.7	5.4	760.	66.	5.7	0.5	
	4584.	5.7	340.	41.	2.5	0.3	
	4792.	6.1	1730.	280.	12.5	2.	
A	4846.	6.2	23700.	1400.	170.	10.	
B	5057.	6.6	7400.	710.	52.	5.	
	5297.	7.1	950.	73.	6.5	0.5	
	5484.	7.5	1330.	150.	9.	1.	
	5562.	7.7	1190.	300.	8.	2.	
	5580.	7.7	2090.	150.	14.	1.	
	5853.	8.3	6900.	770.	45.	5.	
	6024.	8.6	202.	31.	1.3	0.2	
	6400.	9.4	240.	32.	1.5	0.2	
	6715.	10.	740.	82.	4.5	0.5	
	6775.	10.	460.	49.	2.8	0.3	

Table 3 (Continued)

iso- * tope	Energy (eV)	DE (eV)	$2fg\Gamma_n$ (meV)	$D(2fg\Gamma_n)$ (meV)	$fg\Gamma_n^0$ (meV)	$D(fg\Gamma_n^0)$ (meV)	J
	7237.	11.	2550.	340.	15.	2.	
	7283.	11.	1540.	340.	9.	2.	
	7388.	12.	3090.	340.	18.	2.	
	7412.	12.	1720.	340.	10.	2.	
	7470.	12.	3110.	350.	18.	2.	
	7781.	13.	20300.	1800.	115.	10.	
	8077.	13.	7700.	900.	43.	5.	
	8350.	14.	5800.	730.	32.	4.	
	8696.	15.	1680	190.	9.	1.	
	9170.	16.	960.	96.	5.	0.5	
	9424.	17.	2910.	190.	15.	1.	
	9636.	17.	490.	98.	2.5	0.5	
	10157.	19.	810.	100.	4.	0.5	
	10420.	20.	2860.	200.	14.	1.	

* isotopic identification by Maletsky et al. [2] ; A : ^{69}Ga, B : ^{71}Ga
f: isotopic aboundance; f= 0.602 for ^{69}Ga and 0.398 for ^{71}Ga

Table 4 Results

	Present	Previous*
Energy Region	10.4 keV	5.9 keV
Number of levels	54	^{69}Ga 30 (12 p-wave) ^{71}Ga 23 (10 p-wave)
Average Level Spacing	185 ±12 eV	^{69}Ga 230 eV ^{71}Ga 330
s-wave Strength Function	$(1.2\pm0.2)10^{-4}$	^{69}Ga 1.1×10^{-4} ^{71}Ga 1.4

* Maletsky et al. [2]

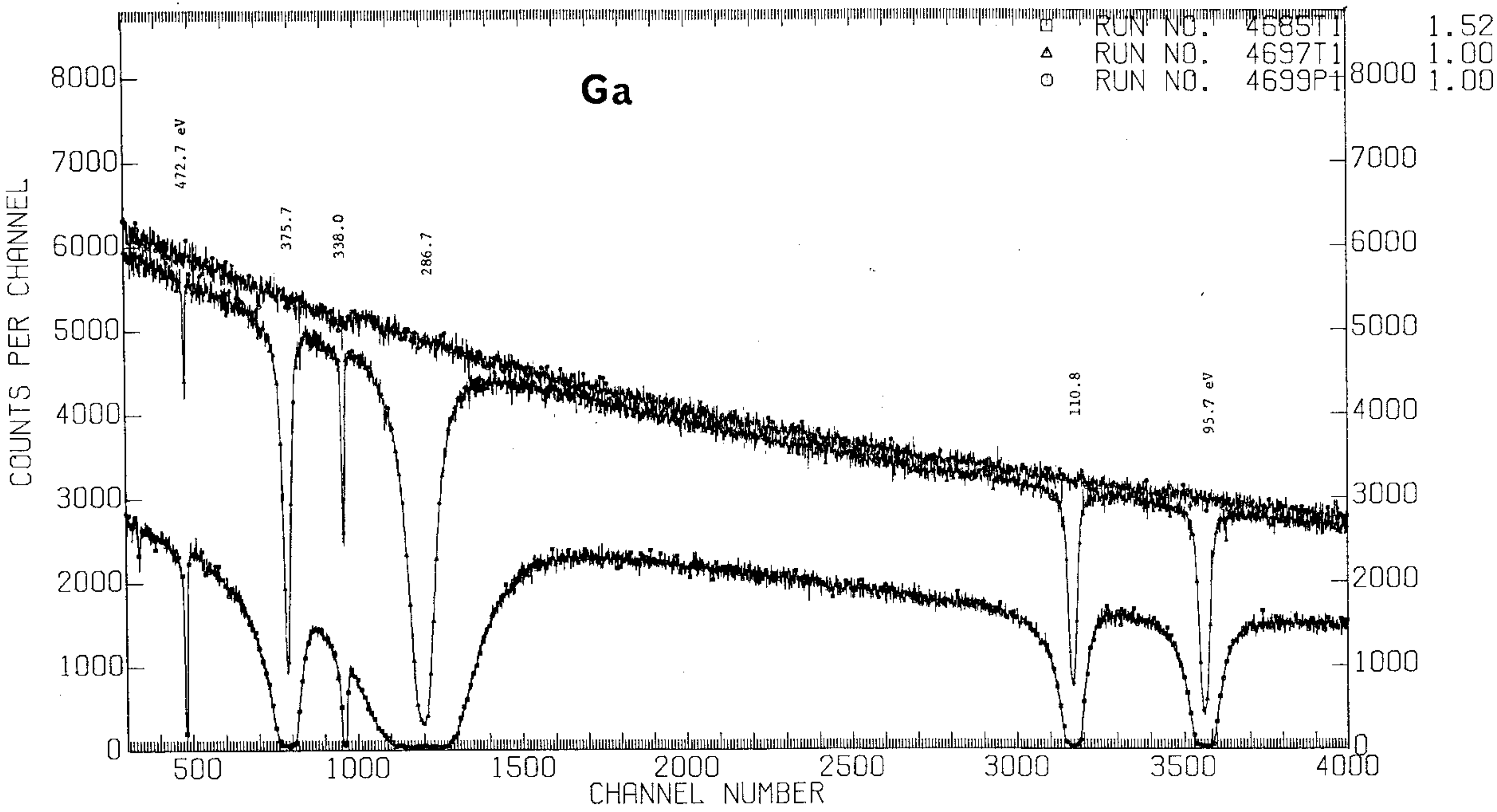

Fig. 1 Raw data of transmission measurements (Neutron counts vs. TOF channels) for the open beam (without sample), thin sample-in (0.00215A/B) and thick sample-in (0.0510A/B) beams, in the energy region below 1 keV. The channel width was 62.5ns.

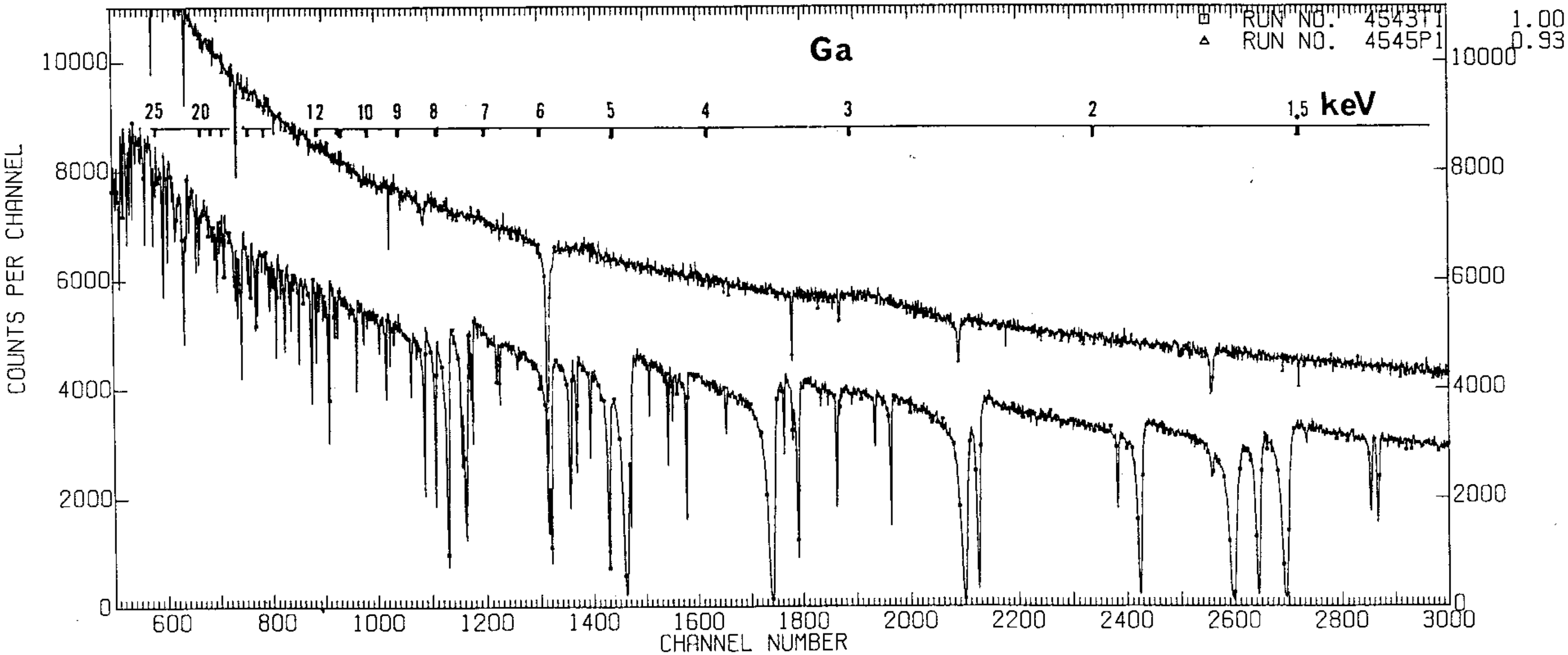

Fig. 2 Raw data of transmission measurements for the open beam and thick sample-in (0.0258A/B) beam in the energy region from 1 to 30 keV. The channel width was 31.25ns.

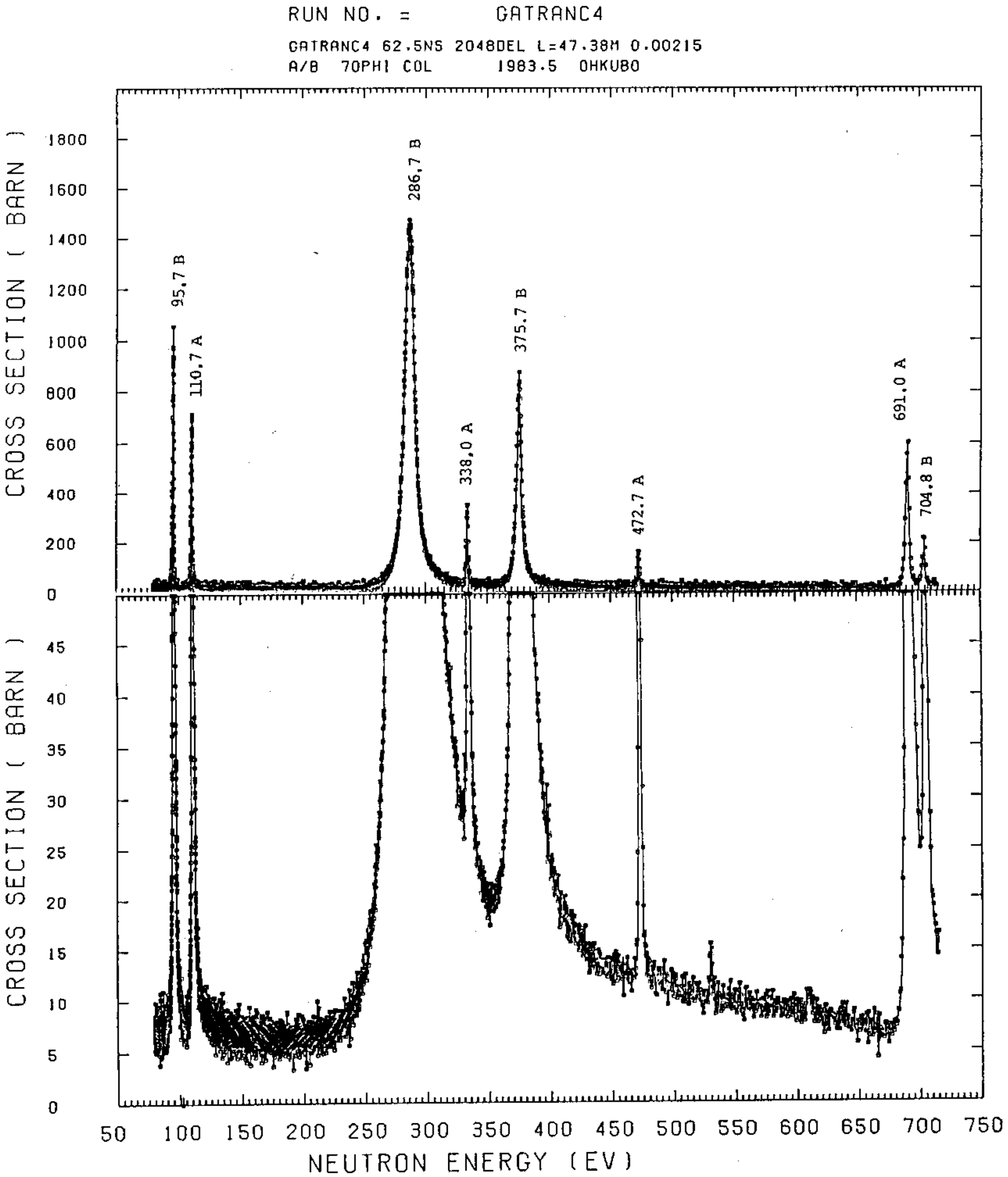

Fig. 3 Observed total cross section of natural gallium from 80 to 715 eV. The upper figure illustrates peak cross sections, and the lower one trough values between resonances. A: ^{69}Ga, B: ^{71}Ga

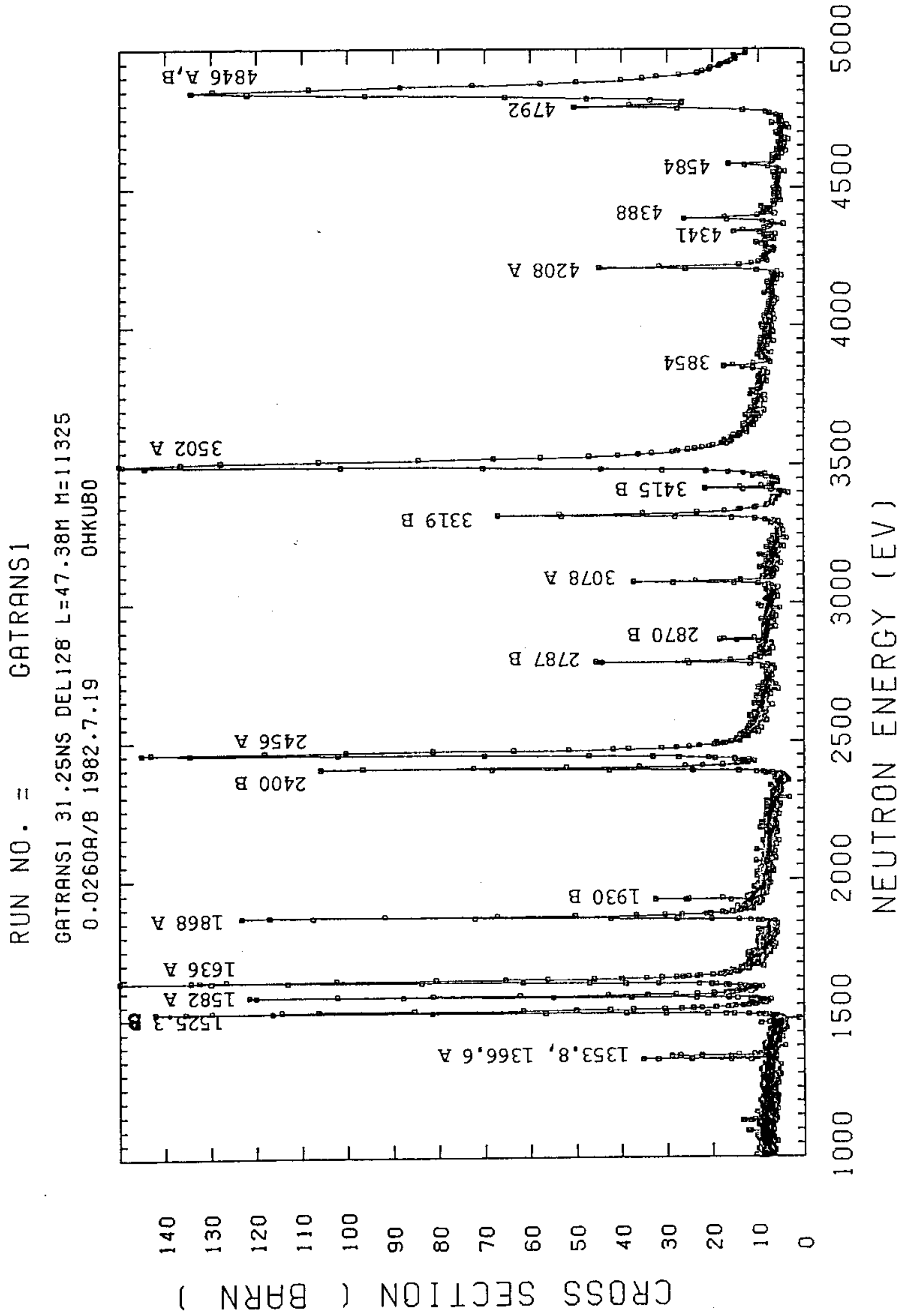

Fig. 4 Observed total cross section of natural gallium from 1 to 5 keV.

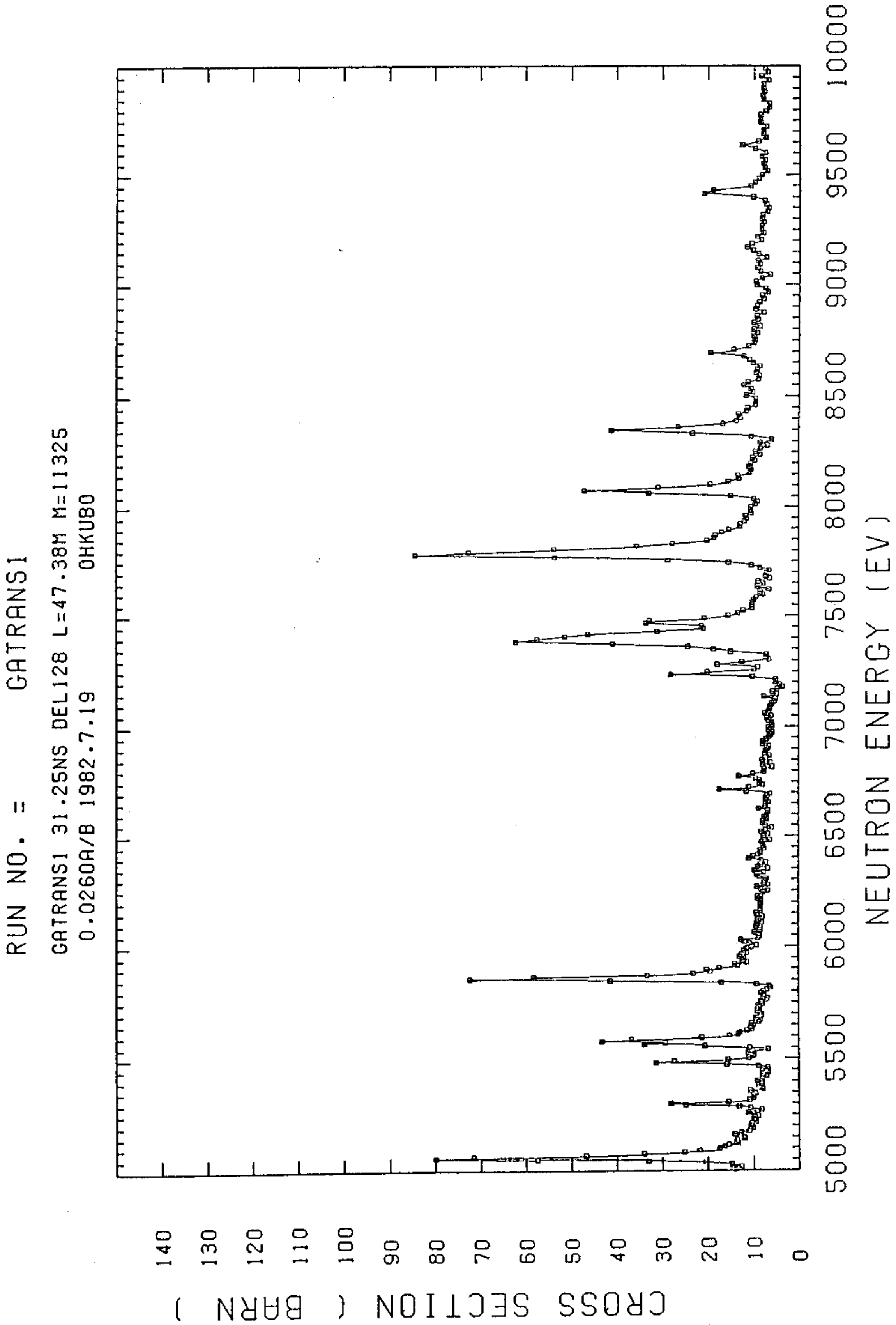

Fig. 5 Observed total cross section of natural gallium from 5 to 10 keV.

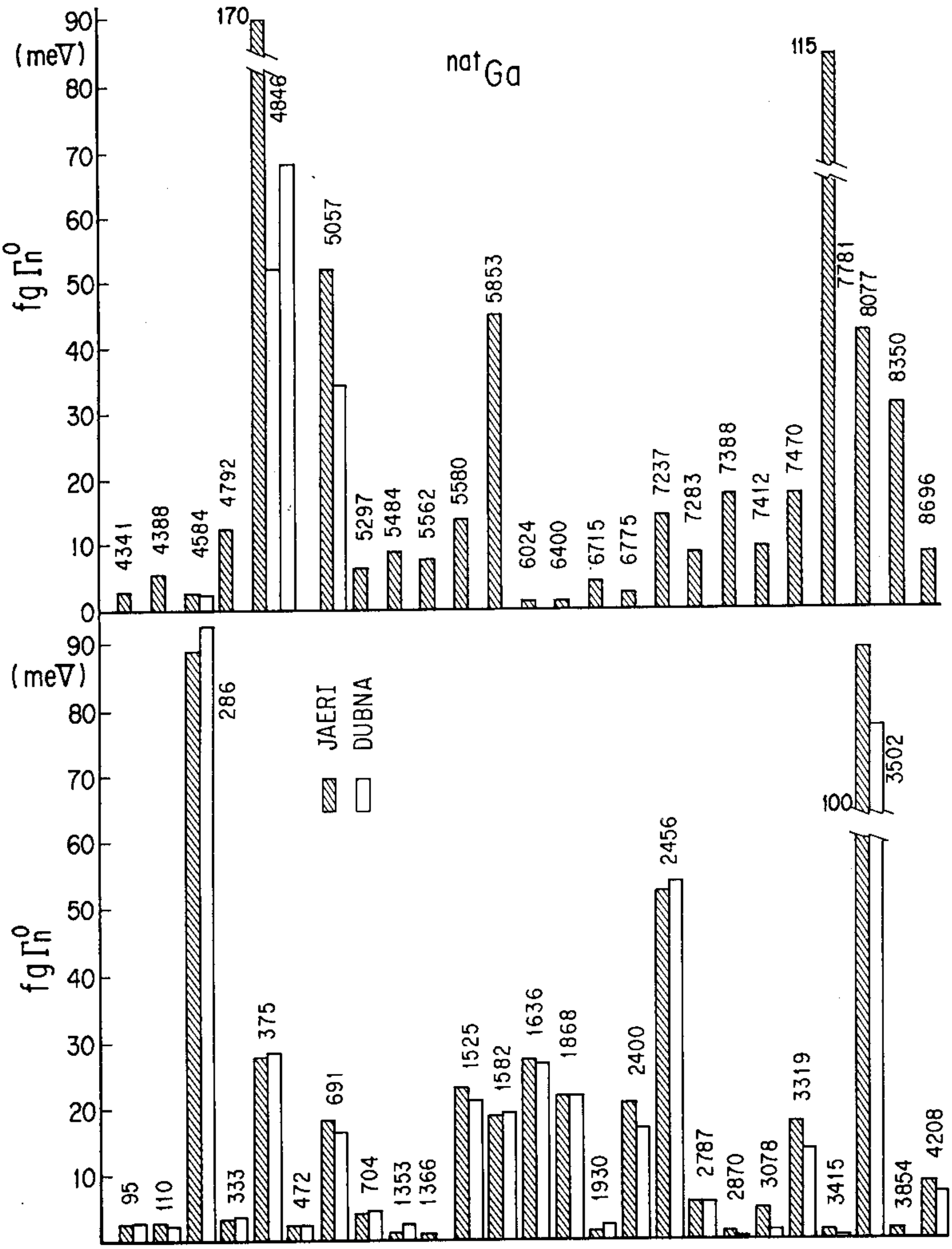

Fig. 6 Comparison of the resonance parameters; present values and the previous ones.[2]

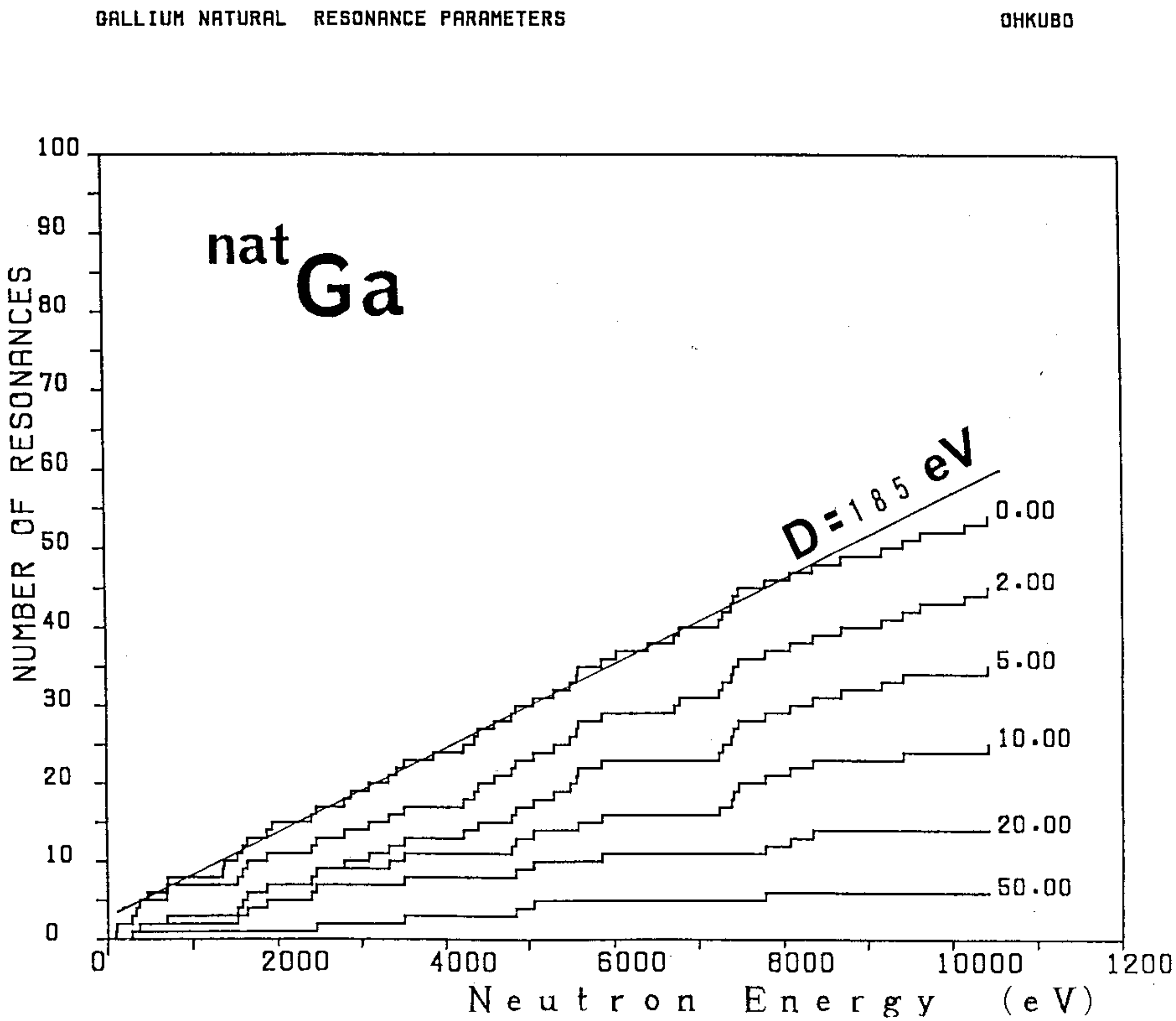

Fig. 7 Cumulative numbers of resonance levels vs. neutron energy. The average level spacing is deduced to be 185 eV.

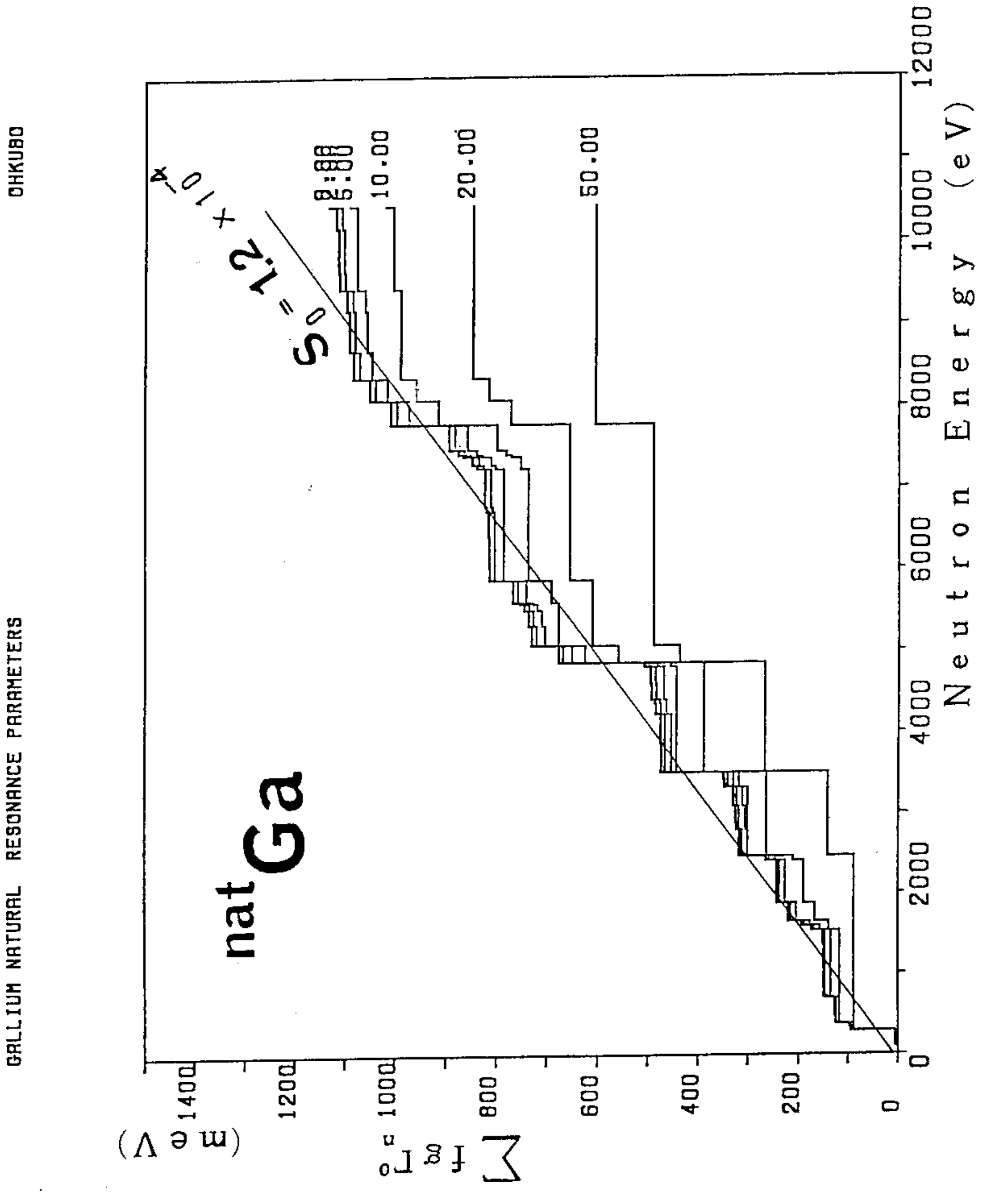

Fig. 8 Cumulative values of $fg\Gamma_n^0$ vs. neutron energy.
The s-wave strength functions for natural gallium is deduced to be $(1.2 \pm 0.2)10^{-4}$