INDC 249

JAERI-memo

No. 2961

NOT FOR PUBLICATION

EANDC (J) 8 "L"

JAPANESE PROGRESS REPORT TO THE EANDC

(January to December, 1967 inclusive)

January 1968

edited by

T. Momota

aided by

T. Fuketa

Japanese Nuclear Data Committee

Japan Atomic Energy Research Institute

Tokai Research Establishment

Tokai-mura, Ibaraki-ken, Japan

NOT FOR PUBLICATION

EANDC (J) 8 "L"

Japanese Progress Report to the EANDC

(January to December, 1967 inclusive)

January 1968

edited by

T. Momota

aided by

T. Fuketa

Japanese Nuclear Data Committee

Japan Atomic Energy Research Institite

Tokai Research Establishment

Tokai-mura, Ibaraki-ken, Japan

Editor's Note

This report is prepared for presentation to the Eleventh Meeting of the European-American Nuclear Data Committee which is to be held on 11-15 March, 1968 in Chalk River, Canada. The editor asked forty-eight physicists to submit reports on those research work which pertained to Nuclear Data in the sense used in the EANDC.

The individual reports, which were submitted to the editor, are all included herein without selection. They are not intended to be complete or formal, and must not be quoted in publications without the permission of the authors.

CONTENTS

CONTENTS (cont'd)

I. Japan Atomic Energy Research Institute

A. Neutron Experiments - Reactor

I-A-1. Parameters of the 0.098 eV Neutron Resonance in Sm-149

Y. Ohno, T. Asami, K. Okamoto, and K. Ideno

Results from the crystal-spectrometer measurement (EANDC(J)7, p.1, 1967) have been analysed and parameters of the 0.098-eV neutron resonance in Sm-149 were obtained as follows:

$E_o = 0.0989 \pm 0.0008$ eV,

$\Gamma_o = 59.5 \pm 0.8$ meV, and

$\Gamma_n = 1.71 \pm 0.03$ meV.

The total cross sections of Sm-149 measured below 0.04 eV show a small deviation from the values calculated with the above parameters. The 2,200 m/sec value of the total cross section is 37,000 ± 1,600 barns.

I-A-2. The Thermal-Neutron Induced (n,α) Reactions in Rare-Earth Elements

K. Okamoto

Measurements of (n,α) reaction induced by thermal neutrons were carried out in a neutron flux ($\sim 1.5 \times 10^7$ n/sec.cm^2) from the thermal column of the JAERI JRR-2 reactor.

The isotopically enriched rare earth oxide target of thickness about 200~300μg/cm^2 on aluminum backing was placed with a surface-

barrier-alpha-detector in an evacuated chamber. The study of alpha spectra of the reaction was presented in the previous report, EANDC (J) 7 "L" (1966).

The reaction cross section for thermal-column neutrons was reduced to the cross section at 2200 m/sec using the thermal column spectrum which was measured with the JAERI velocity selector.

The preliminary results of the reaction cross sections at 2200 m/sec are given in the following table;

Target Nuclei	E α (MeV)	State of Daughter Nuclei		σ (n, α) at 2200 m/sec (mb)
^{149}Sm	9.2	0^+	^{146}Nd	4 ± 2
	8.8	2^+		20 ± 10
	< 8.2	4^+		~ 1
^{143}Nd	9.4	0^+	^{140}Ce	15 ± 5
	< 7.8	2^+		< 1

I-A-3. Thermal Neutron Capture Gamma Rays of Al and Ti

Y. Kawarasaki and N. Shikazono

The measurements of the neutron capture gamma rays have been continued (EANDC (J) 7 "L", p.4). The spectra of Al and Ti have been measured with an improved system.

The main improvements are as follows:

1. Enlargement of side crystals : 5" ϕ × 4",
2. Transistorization of all electronic circuits,
3. Increase in the amount of sample,
4. Adoption of a 1024 channel p.h.a. system.

As the results we became able to get the better S/N ratio and the better energy resolution. Energies and intensities of neutron capture gamma rays of Al are listed in Table. 1. Further studies, construction of level scheme of ^{28}Al and analysis of Ti data are in progress.

Peak No.	Energy (KeV)	Intensity (per 100 captures)	Remarks
1	7722	24.4	
2	7692	2.7	
3	7534	0.47	
4	7252	0.65	
5	6930	0.47	
6	6714	1.04	
7	6616	0.34	
8	6436	0.84	
9	6306	3.35	
10	6178	0.61	
11	6085	3.13	Possibly doublet
12	6036	0.10	partly Fe (n, γ)
13	5998	0.62	
14	5896	0.72	
15	5840	0.24	
16	5795	0.16	
17	5760	0.10	
18	5749	0.35	
19	5718	0.50	
20	5582	0.90	partly N (n, γ)
21	5521	0.09	
22	5442	0.20	
23	5412	1.57	
24	5307	0.46	partly N (n, γ)
25	5248	0.12	
26	5191	0.12	
27	5141	2.29	
28	5131	0.14	
29	4924	0.26	
30	4910	2.07	
31	4824	0.51	partly Fe (n, γ)
32	4771	1.51	
33	4741	5.25	
34	4702	3.70	
35	4672	2.15	
36	4635	0.36	
37	4608	0.19	
38	4590	0.26	
39	4436	0.87	

Peak No.	Energy (KeV)	Intensity (per 100 captures)	Remarks
40	4398	0.27	
41	4280	0.66	
42	4268	5.69	
43	4224	0.19	partly Fe (n, γ)
44	4178	0.36	
45	4138	5.22	
46	4044	0.19	
47	4014	0.84	
48	3935	0.34	
49	3900	0.44	
50	3874	2.21	
51	3848	1.88	
52	3822	0.44	
53	3788	0.44	
54	3704	0.29	partly N (n, γ)
55	3668	0.12	
56	3584	3.68	
57	3554	0.75	
58	3445	5.03	partly Fe (n, γ)
59	3381	0.23	
60	3291	0.66	
61	3261	0.26	
62	3020	7.54	
63	2951	7.05	
64	2812	2.24	
65	2726	0.77	partly Fe (n, γ)
66	2704	1.17	
67	2620	1.00	
68	2584	3.78	
69	2570	1.98	
70	2449	0.59	
71	2280	5.02	
72	2146	2.24	
73	2116	3.29	
74	1994	1.98	partly N (n, γ)
75	1858	3.69	

Table 1. Gamma-ray energies and intensities of neutron capture of aluminum.

B. Neutron Experiments-Linac

I-B-1. Neutron-Resonance Parameters of Cadmium and Antimony

A. Asami*, M. Okubo, Y. Nakajima, and T. Fuketa

A paper on this subject was submitted to the Second Conference on Neutron Cross Sections and Technology, Washington, D.C., U.S.A., March 4-7, 1968 with an abstract as follows:

Transmission measurements on the natural elements of Cd and Sb were carried out with the neutron time-of-flight spectrometer[1] at the JAERI Linac. The metallic samples of different thicknesses, from 0.0047 to 0.306 atoms/barn for Cd and from 0.0036 to 0.183 atoms/barn for Sb, were used. The neutron energy region from a few eV up to several keV was covered with maximum resolution of 10 nsec/m. The transmission measurements with samples at liquid-nitrogen temperature were also made to improve separation of closely spacing resonances. New resonances at relatively low energies were found at 54.2, 59.8 and 62.1 eV in Cd and at 37.9 and 55.2 eV in Sb. The resonance dips in the transmission data have been analyzed by the area-analysis method based on the Breit-Wigner single-level formula. The neutron widths and the gamma-widths will be presented.

---

*Present address: Nuclear Phys. Div., A.E.R.E., Harwell.

[1] A. Asami, T. Fuketa, Y. Kawarasaki, Y. Nakajima, M. Okubo, T. Sakuta, K. Takahashi, and H. Takekoshi, JAERI 1138 (1967).

I-B-2. Resonances in (γ ,n)-Reaction Near Threshold

T. Fuketa and Y. Nakajima

The use of bremsstrahlung radiation to study highly-excited individual nuclear states by means of the (γ ,n)-reaction has been made by several investigators[1, 2] for a few special nuclides with wide level spacings; and, the interest and the importance of this approach were emphasized by L. M. Bollinger[3] at the Conference on Neutron Cross Section Technology in Washington, 1966.

The neutron spectra below a few hundred keV from the (γ ,n)-reactions with several sample elements were measured by using the JAERI Linac Time-of-Flight Neutron Spectrometer[4] with the flight-path length of 50 meters. The whole system of the experiment is usually used for the measurement of neutron total cross section by the transmission method with the exception of the arrangement around the target and a sample. Respective examples of the neutron spectra from lead and bismuth samples are shown in Figs. 1 and 2. The (γ ,n)-resonances were observed at the neutron energies of 41, 30, 10.3, 9.0, 7.3, 7.0 and 1.6 keV for lead; and at 23, 15.7, 14.3, 10.1, 9.1, 8.2, 7.2, 7.05, 6.9, and 1.7 keV for bismuth. Majority of these resonances are assigned to be ones leading to the ground state of the daughter nucleus of the (γ ,n)-reaction. The analysis of the data is now in progress.

References:

1) W. Bertozzi, C. P. Sargent and V. Turchinetz; Phys. Letters 6 (1963) 108.

2) B. L. Berman, G. S. Sidhu, and C. D. Bowman; Phys. Rev. Letters 17 (1966) 761.

3) L. M. Bollinger; Conf. on Neutron Cross Section Technology, March 1966, CONF-660303, p. 1064 (1966).

4) A. Asami, T. Fuketa, Y. Kawarasaki, Y. Nakajima, M. Okubo, T. Sakuta, K. Takahashi, and H. Takekoshi; JAERI 1138 (1967).

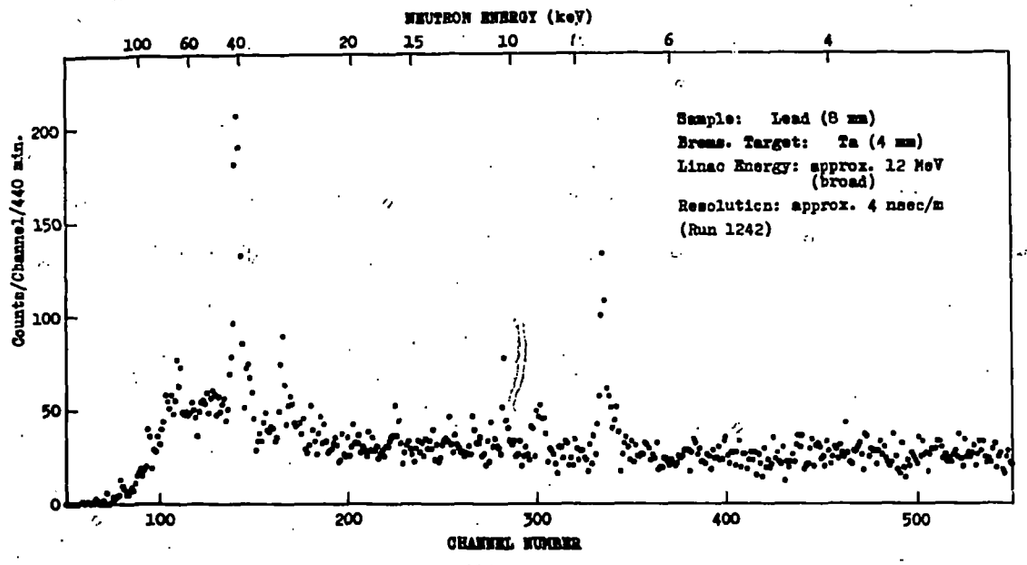

NEUTRON ENERGY (keV)
100 60 40 20 15 10 6 4
Counts/Channel/440 min.
0 50 100 150 200
100 200 300 400 500
CHANNEL NUMBER
Sample: Lead (8 mm)
Brems. Target: Ta (4 mm)
Linac Energy: approx. 12 MeV (broad)
Resolution: approx. 4 nsec/m
(Run 1242)

Fig. 1

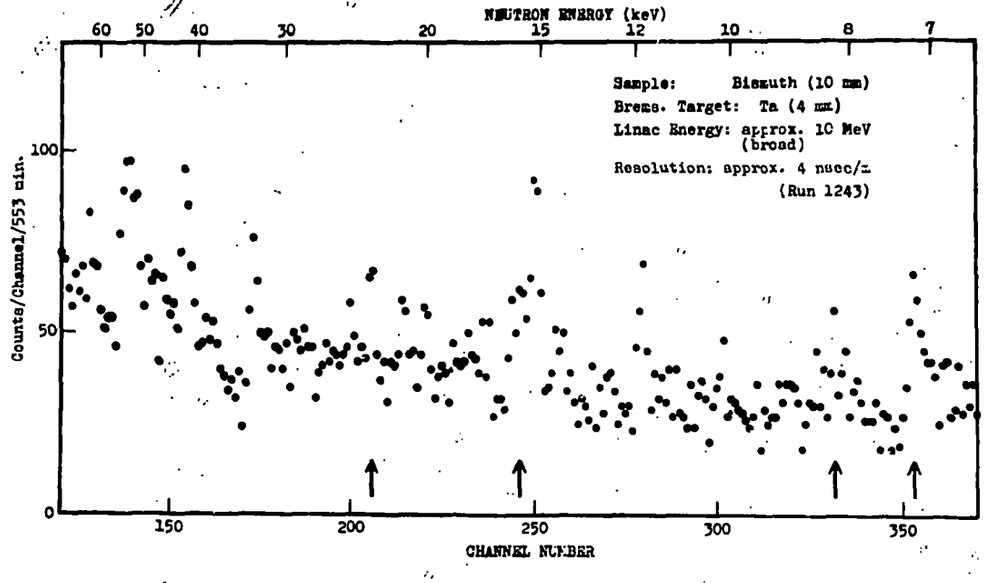

NEUTRON ENERGY (keV)
60 50 40 30 20 15 12 10 8 7
Counts/Channel/553 min.
0 50 100
150 200 250 300 350
CHANNEL NUMBER
Sample: Bismuth (10 mm)
Brems. Target: Ta (4 mm)
Linac Energy: approx. 10 MeV (broad)
Resolution: approx. 4 nsec/m
(Run 1243)

Fig. 2

C. Neutron Experiments - Van de Graaff Accelerator

I-C-1. Neutron Total Cross Section Measurements of La and Pr

K. Nishimura, Y. Yamanouti and S. Kikuchi

Total neutron cross sections of natural lanthanum and natural praseodymium have been measured in the neutron energy range of about 20~240 keV, by using a thin Li-F target and a narrow neutron beam collimator. The collimator is placed at the 100° direction with respect to incident proton beam. The collimator is made of polyethylene and located in a center of a paraffin-lead neutron shield. Behind the neutron shield, twelve BF_3 counters are embedded in the paraffin moderator and set in the ring geometry around a polyethlene scatterer.

The minimum energy step for the measurements of La is about 0.8 keV in the energy range of 100 keV and the energy spread of neutrons is approximately ± 18 keV. The results of the total cross section measurement for La show that there are fluctuations of about 2-keV width, superposing on the gross structure of about 65-keV width. The values of the cross sections are in good agreement with those of Duke University; their neutron spread was about ± 10 keV.

Total cross section for Pr has been measured with the neutron energy spread of about ± 3 keV and with the minimum energy step of about 4.5 keV. The results of the total cross section measurement show also the gross structure of about 35 keV width. This gross structure is gradually smoothed out as the neutron energy increases. The values of cross section obtained are not in good agreement with those of Wisconsin University especially in lower energy region, where their values are generally higher than ours about 10~20%.

Further measurements and detailed analyses are in progress.

I-C-2. Scattering of 1.71 and 2.24 MeV Neutrons from Zinc and Copper

S. Tanaka, K. Tsukada, M. Maruyama, Y. Tomita
and Y. Yamanouti

The differential cross sections for elastic and inelastic scattering of neutrons from zinc and copper have been measured at 1.71 and 2.24 MeV of incident neutrons over angles from 30° to 150° with a step of 10°. The measurement was made by means of a time-of-flight spectrometer, in which the method of two dimensional recording[1] (time spectrum and pulse height spectrum) was employed in order to improve the resolution of the time spectrum and to decrease the background level. Neutron bursts were generated with a 5.5-MV pulsed beam Van de Graaff accelerator and an ion beam bunching system.[2]

The data measured were corrected for flux attenuation, multiple scattering in the sample and source-sample angular spreads using a computer code MULT1.[3] As examples, fig. 1 and fig. 2 show the elastic scattering cross sections for Zn and Cu, and the inelastic cross sections for the first levels in even-even isotopes of zinc, respectively.

We have a plan to extend the incident energies in the present measurement upwards and downwards, and to compare the inelastic data with statistical-model calculations.

---

1) e.g. A.B. Smith et al., Nucl. Instr. Meth. 50 (1967) 277.

2) K. Tsukada et al., Nucl. Instr. Meth. 39 (1966) 249.

3) A. Kohsaka and Y. Tomita, to be published.

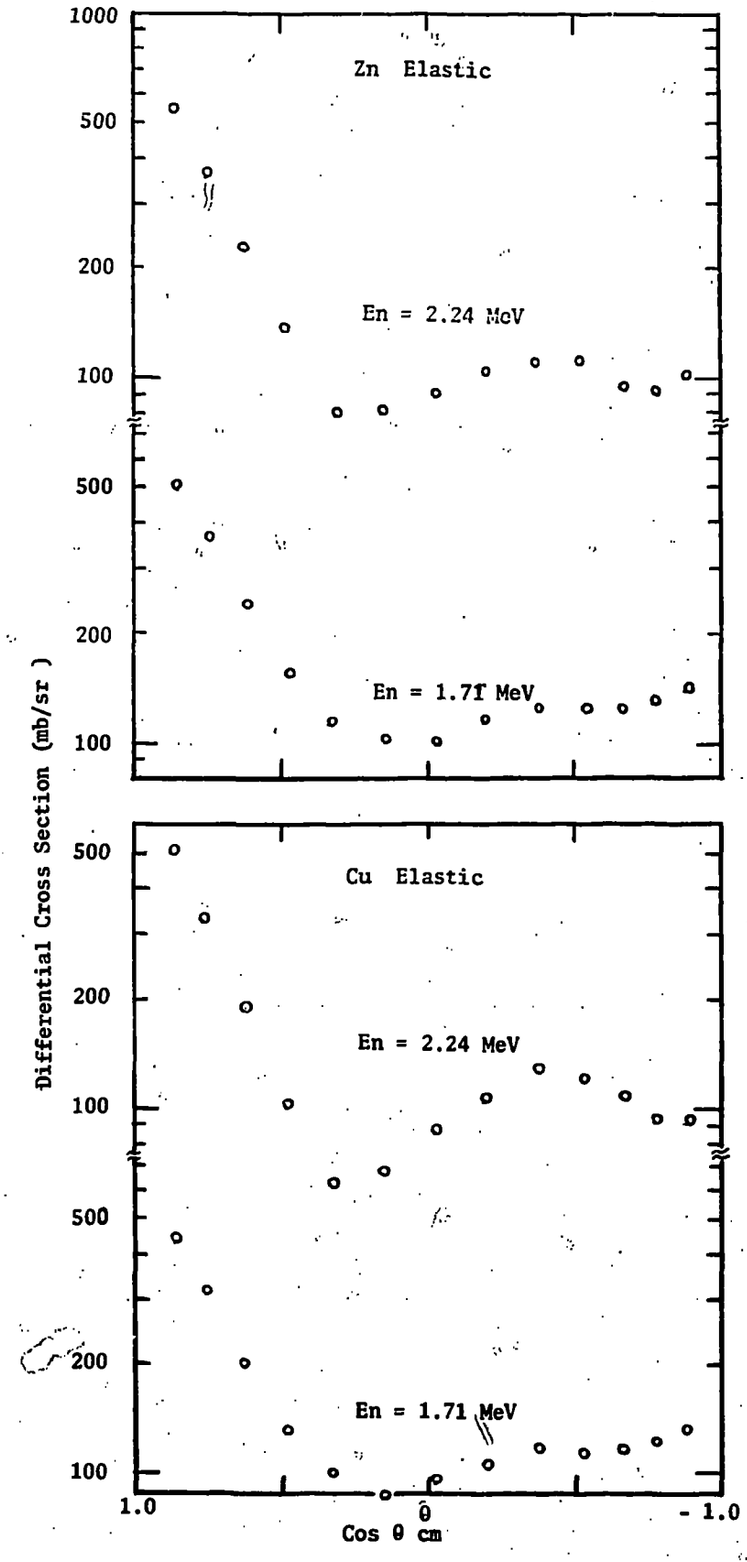

Zn Elastic
En = 2.24 MeV
En = 1.71 MeV
Cu Elastic
En = 2.24 MeV
En = 1.71 MeV
1000
500
200
100
500
200
100
500
200
100
500
200
100
Differential Cross Section (mb/sr)
1.0
0
- 1.0
Cos θ cm

Fig. 1

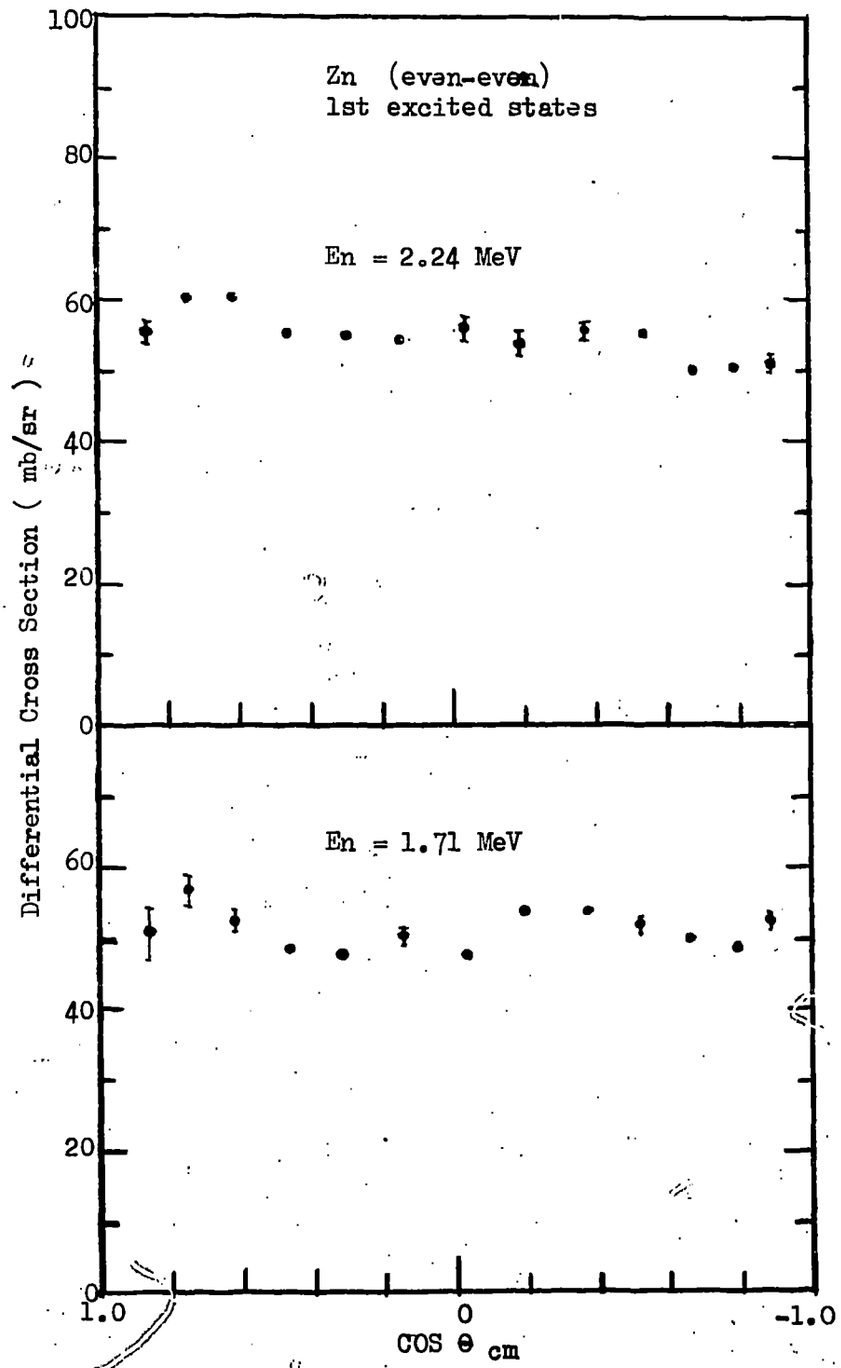

Zn (even-even)
1st excited states
En = 2.24 MeV
En = 1.71 MeV
Differential Cross Section (mb/sr)
100
80
60
40
20
0
60
40
20
0
1.0
0
-1.0
COS θ cm

Fig. 2

I-C-3. Scattering of 4.5 to 8 MeV Neutrons from Sulphur and Zinc

S. Tanaka, K. Tsukada, M. Maruyama and Y. Tomita

The differential cross sections for elastic and inelastic scattering of neutrons from sulphur and zinc have been measured[1] at 4.48, 5.92 6.97 and 7.99 MeV of incident neutrons with a time-of-flight spectrometer. Scattered neutrons were observed at angles from 30° to 150° with a 10° step.

Optical-potential parameters were obtained from the comparison of the optical-model calculation[2] and the elastic scattering data. For sulphur the comparison was made after subtraction of the compound-elastic cross sections.[2] The inelastic scattering cross sections measured were compared with the Hauser-Feshbach (H-F)[2] and DWBA[3] calculations, the latter being applied to the excitation to some particular levels. The competition between the direct and the compound processes was studied quantitatively. It was found that the direct process was predominant for the excitation to the 1st levels (2^+) in ^{32}S and $^{64,66,68}Zn$ in the whole energy region studied and for 5.01-MeV level (3^-) in ^{32}S at the highest energy.

As examples, fig. 1 and fig. 2 show the differential cross sections of inelastic scattering leading to the 1st (2^+) and the 5.01 MeV states (3^-) in ^{32}S, respectively. Open circles denote the present data. Triangles and squares are data of Petitt et al.[4] and of present authors[5] previously reported, respectively. The full curves show the results of the least-squares fit of the DWBA calculation plus the H-F calculation to the experimental data. The dotted curves represent the results of the H-F calculation multiplied by a parameter k which represents the rate of decrease of the compound process. Some values of the deformation parameter were extracted from such a comparison.

The present study is to be published.

References:

1) K. Tsukada, S. Tanaka, M. Maruyama and Y. Tomita, EANDC(J) 1 "L" (1965) 12.
2) A computer code ELIESE-2 was used.
3) A FORTRAN IV version of a computer code DWBA 2 was used.
4) G.A. Petitt et al., Nucl. Phys. 79 (1966) 231.
5) K. Tsukada et al., Physics of fast and intermediate reactors (IAEA, Vienna, 1962) p. 75.

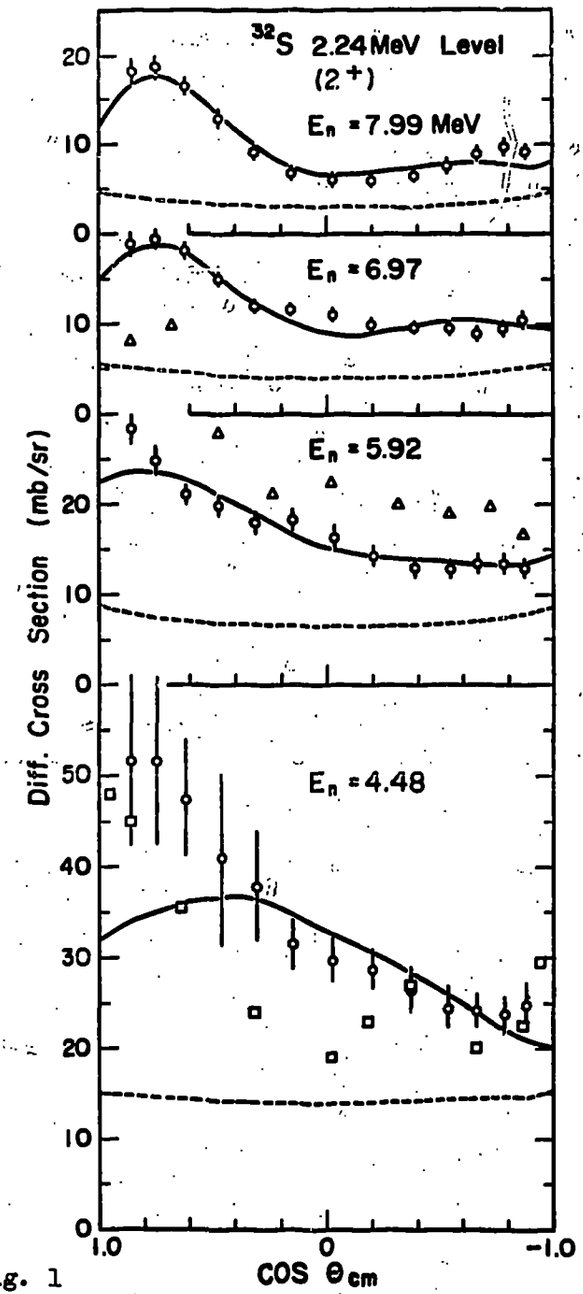


Fig. 1

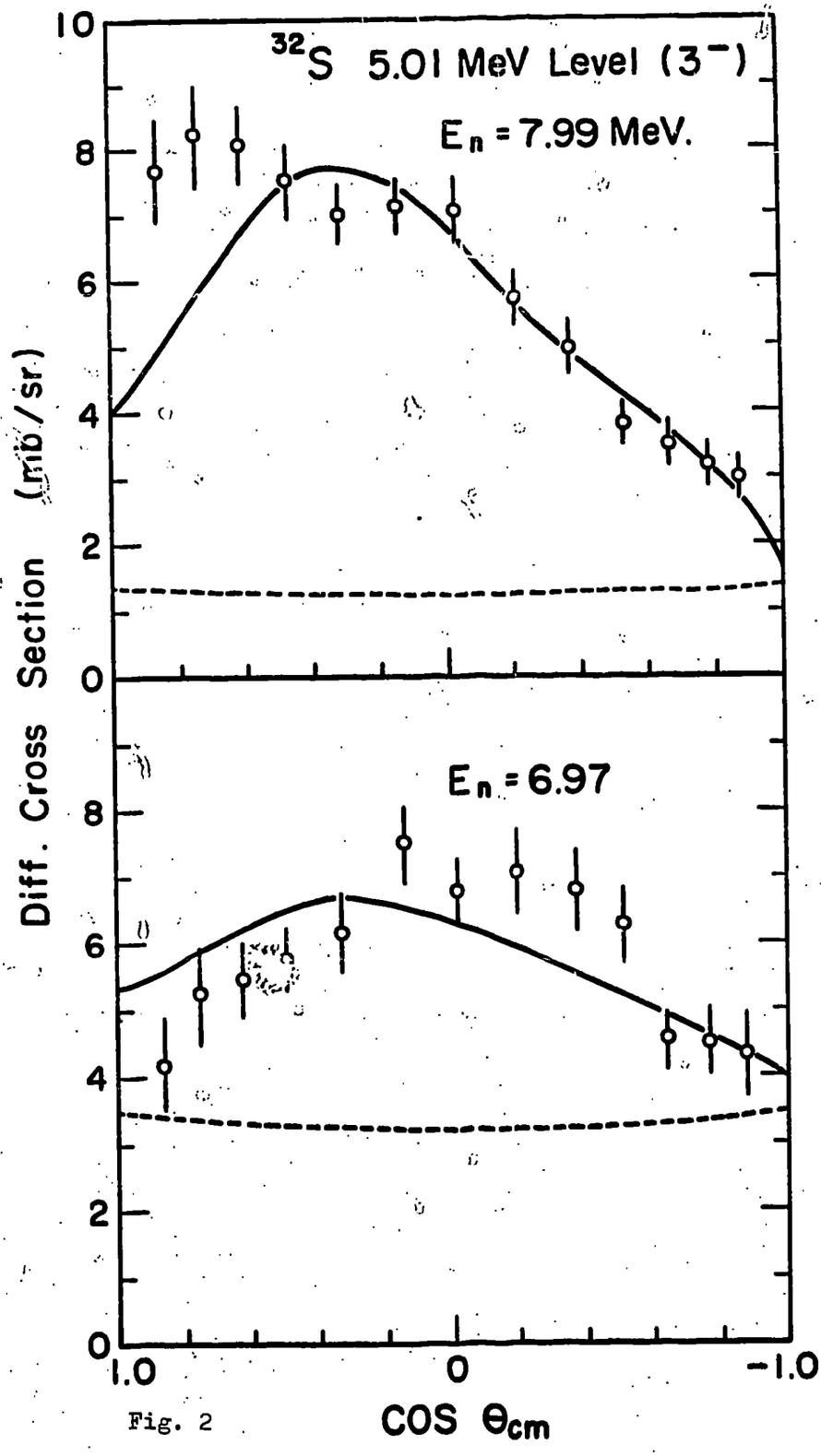

^{32}S 5.01 MeV Level (3$^-$)
E_n = 7.99 MeV.
E_n = 6.97
Diff. Cross Section (mb/sr)
COS θ_{cm}
10
8
6
4
2
0
1.0
0
-1.0

Fig. 2

I-C-4. Elastic and Inelastic Scattering of Fast Neutrons from Fe, Ni and W

K. Tsukada, S. Tanaka, Y. Tomita and M. Maruyama

Differential cross sections for elastic and inelastic scattering of neutrons by Fe, Ni and W have been measured with a time-of-flight spectrometer. Angular distributions were taken at incident neutron energies of 1.37, 1.71, 2.01, 2.65 and 3.26 MeV for Fe, 2.01, 2.65 and 3.26 MeV for Ni and 1.37 and 2.01 MeV for W. Excitation functions were measured at 90° in the energy range 1.37 to 4.49 MeV for Fe, 2.0 to 4.49 MeV for Ni and 0.964 to 2.24 MeV for W with a 200 keV step. The measured cross sections are compared with the optical-model, Hauser-Feshbach and Moldauer calculations. The corrections of level-width fluctuation and resonance interference are applied for both of the elastic and inelastic scatterings. Best-fit sets of the potential parameters are obtained.

As examples, figs. 1 and 2 show respectively the differential cross sections of elastic and inelastic scattering leading to the first level of ^{56}Fe. The experimental results are indicated by closed circles. The vertical bars show their errors. The curves represent the results of the optical-model and Hauser-Feshbach calculations. The upper curves in fig. 1 and the solid curves in fig. 2 are obtained using the overall-fit sets of the potential parameters with smooth energy dependence of V and W which were searched so as to reproduce the elastic data in a whole energy range. The lower curves in fig. 1 and the broken curves in fig. 2 are obtained using the best-fit potential parameter sets. The dotted curves in the both figures correspond to those with the Wilmore-Hodgson potential.[1] The label

Q = 0 or 1 on the curves shows the calculation with the corrections of the level width fluctuation and the resonance interference, where Q is the parameter for the resonance interference correction defined by Moldauer.[2] The label H-F is for the calculation without the corrections. Figure 3 shows the excitation function of the inelastic scattering for the first level of ^{56}Fe, together with the total neutron cross section of Fe. The curve "exp." is obtained by smoothing the total cross sections compiled in BNL 325[3]. The other curves in the same figure are the results of the calculations with the overall-fit sets of the optical-model-potential parameters.

The present study is to be published.

Reference

1) D. Wilmore and P. E. Hodgson, Nucl. Phys. 55 (1964) 673

2) P. A. Moldauer, Phys. Rev. 135 (1964) B642

3) M. D. Goldberg et al., BNL 325 (1966) 2nd ed. Suppl. 2.

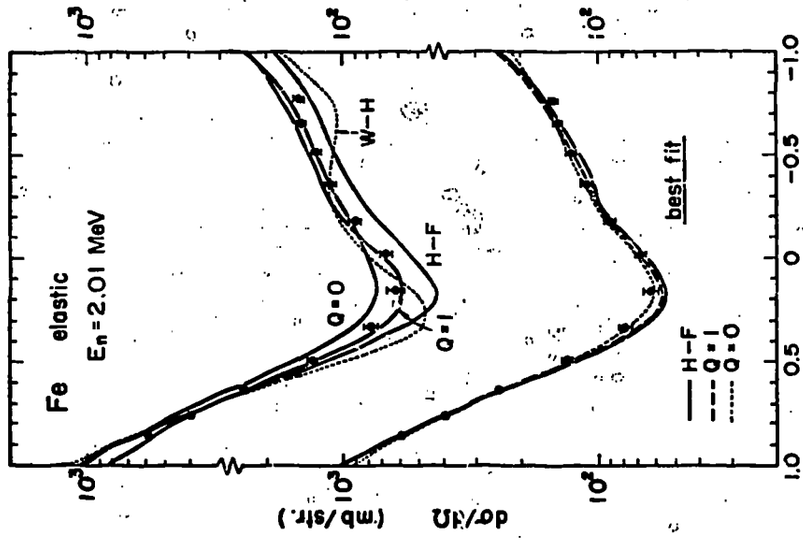

Fe elastic
E_n=2.01 MeV
Q=0
Q=1
W-H
H-F
best fit
H-F
Q=1
Q=0
dσ/dΩ (mb/str.)
COS θCM
(c)

Fig. 1

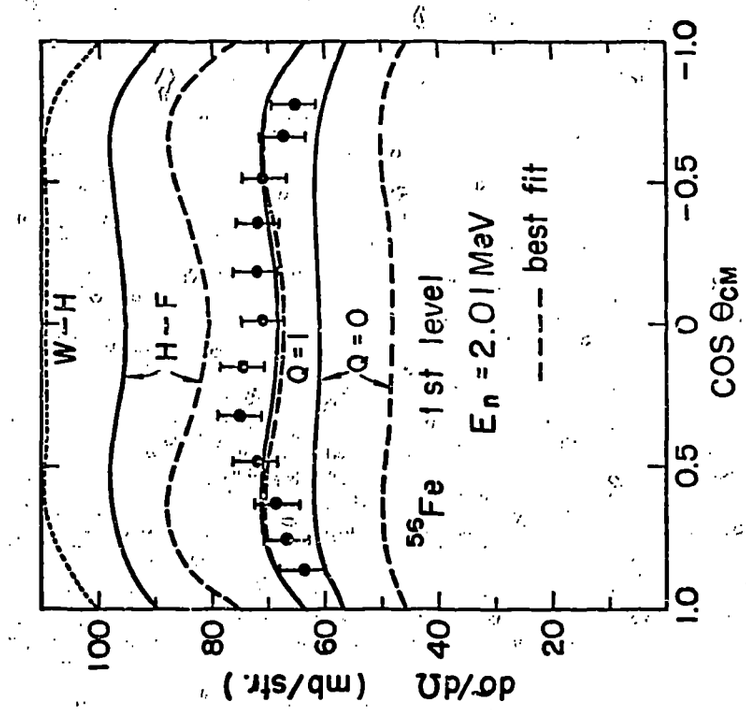

W-H
H-F
Q=1
Q=0
^{56}Fe 1st level
E_n = 2.01 MeV
best fit
dσ/dΩ (mb/str.)
COS θCM
(c)

Fig. 2

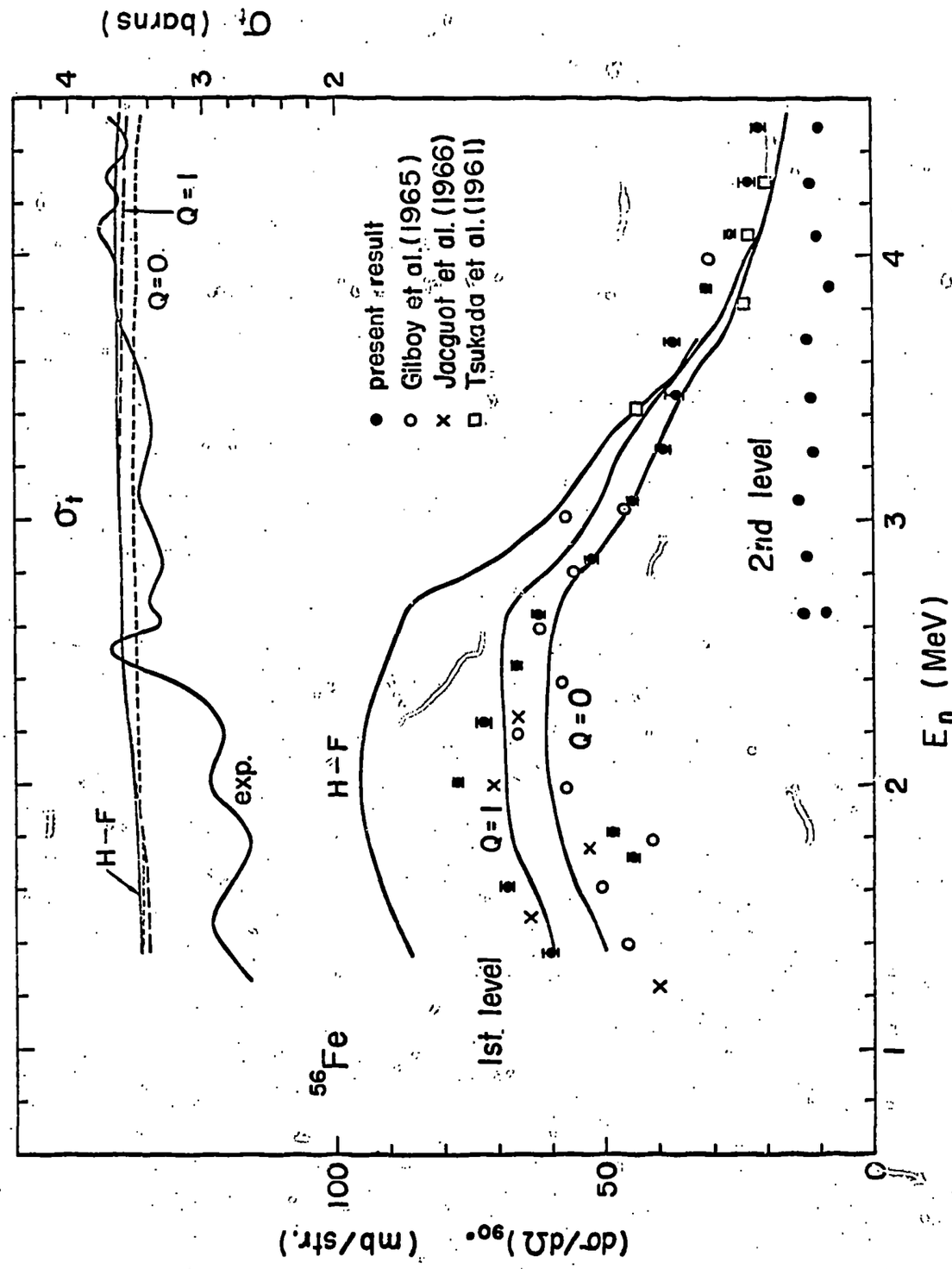

σ_t (barns)
4
3
2
σ_t
Q=0
Q=1
H-F
exp.
present result
Gilboy et al.(1965)
Jacquot et al.(1966)
Tsukada et al.(1961)
H-F
Q=1
Q=0
2nd level
1st level
^{56}Fe
100
50
0
$(d\sigma/d\Omega)_{90°}$ (mb/str.)
1
2
3
4
E_n (MeV)

Fig. 3

I-C-5. High Resolution Measurement of Gamma-Rays from Neutron Inelastic Scattering

S. Kikuchi, Y. Yamanouti, M. Maruyama and K. Nishimura

A large coaxial type Li-Ge detector associated with a pulsed beam time-of-flight technique has been used for the measurements of gamma-rays from neutron inelastic scattering. A block diagram of the instrumentation is shown in fig. 1. The volume of the Li-Ge detector is about 17 cc and the energy resolution is about 7 keV at 1 MeV associated with a FET preamplifier circuit. The flight path is 60 cm from the scatterer to the detector and the time resolution of about 9 nsec is obtained for the gamma-ray peak in the time spectrum. This peak is separated from the peaks which are due to the interactions of neutrons with the detector. A typical time spectrum is shown in fig. 2.

A pulsed proton beam is accelerated by the JAERI 5.5 MV V.D.G. and a tritium metal target is used to produce neutron bursts. The pulse width of the pulsed beam is about 2 ns associated with a bunching magnet of Mobley type, and the peak current is about 2.5 mA with a repetition rate of 1 MHZ. The channel width of the 4096 multichannel analyzer is 0.87 ns/channel. By setting the time window for the gamma-ray peak in the time spectrum, the energy spectra of gamma-rays from neutron inelastic scattering have been obtained. A typical energy spectrum for natural zinc is shown in fig. 3.

The measurements of angular distribution for the gamma-rays from neutron inelastic scattering are now in progress along with this instrumentation.

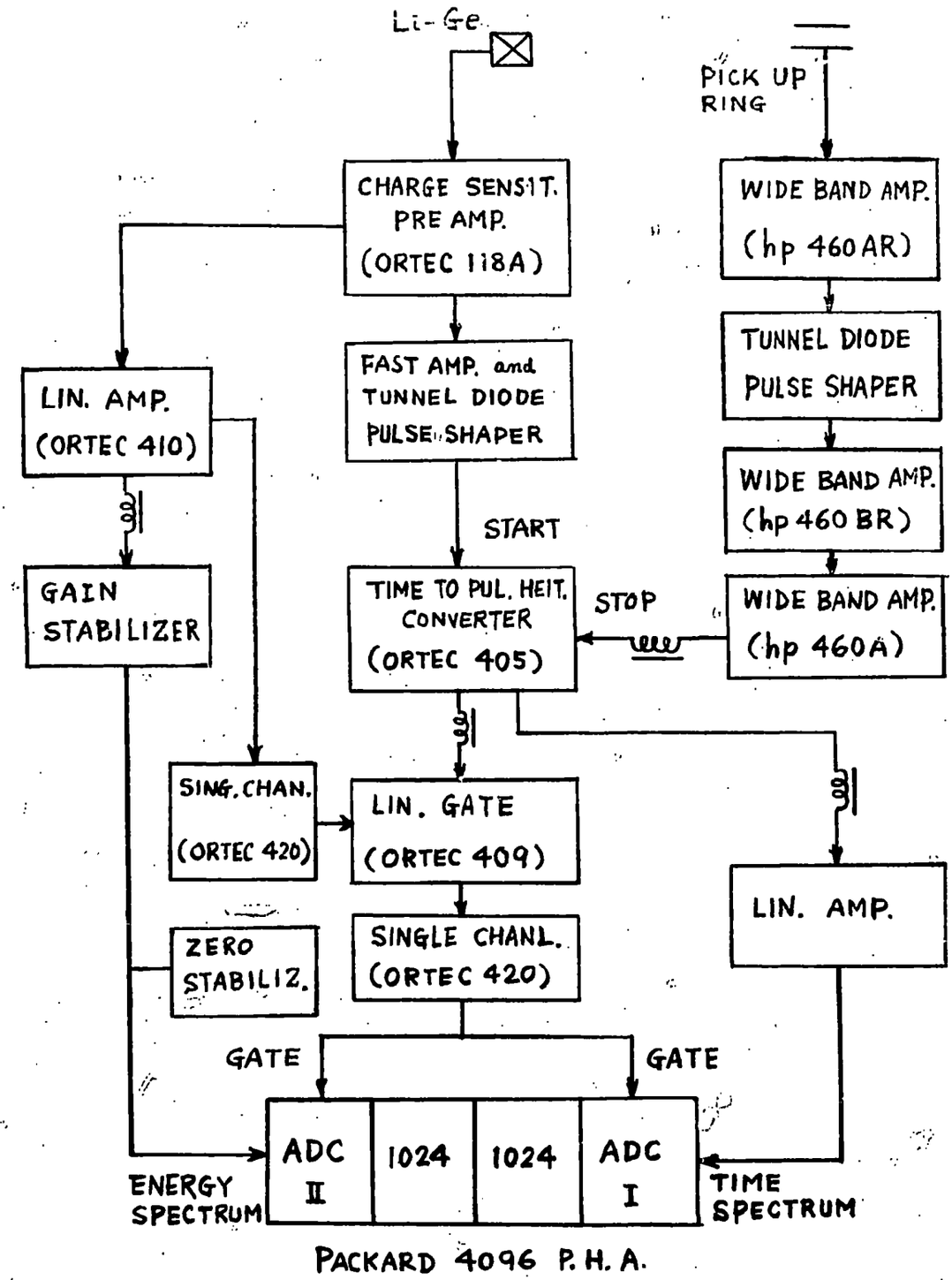


Fig. 1 Block Diagram of the Time of Flight System for (n,n' γ) Measurements

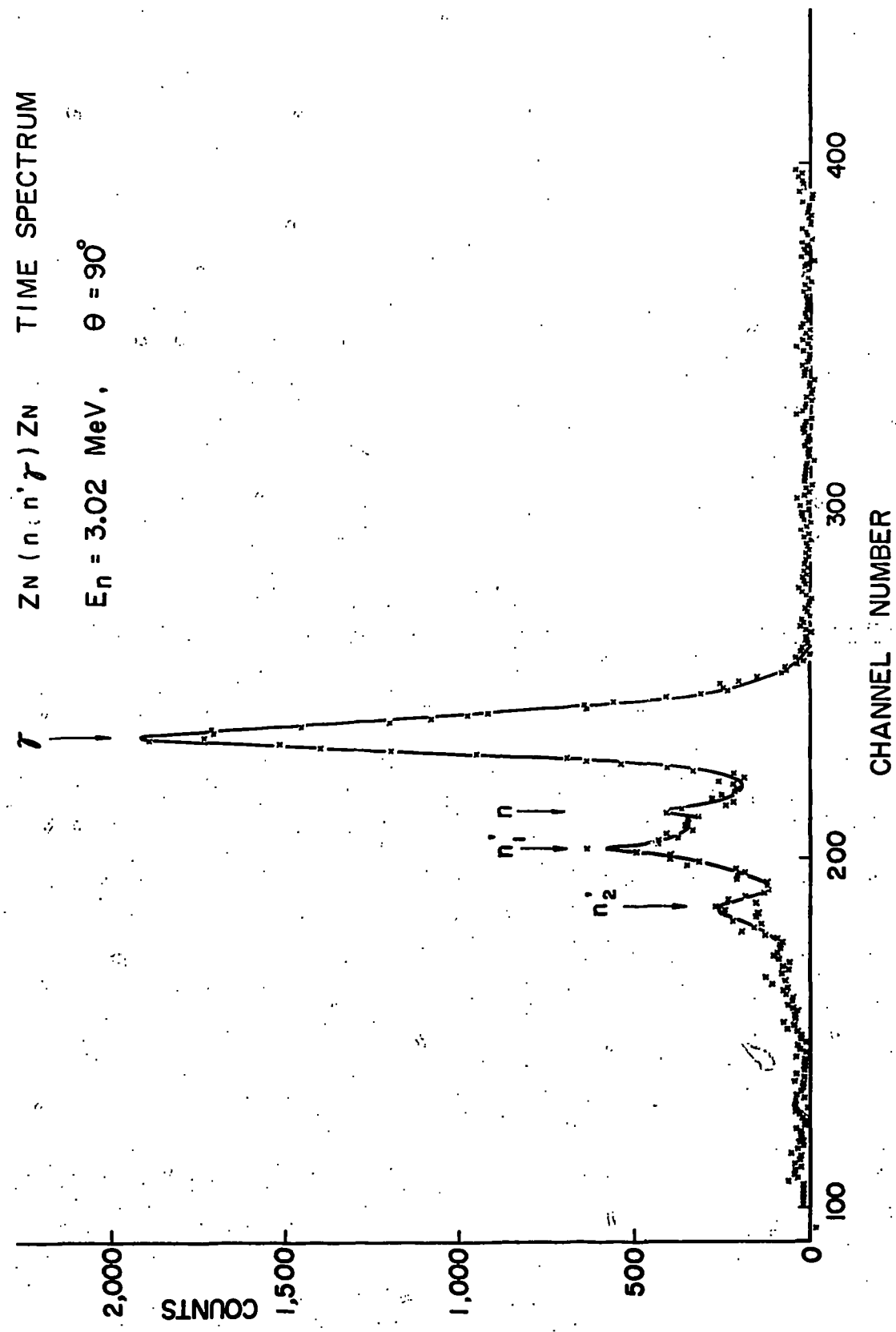

Zn (n, n'γ) Zn TIME SPECTRUM
En = 3.02 MeV, θ = 90°
γ
n'1 n
n'2
COUNTS
2,000
1,500
1,000
500
0
100
200
300
400
CHANNEL NUMBER

Fig. 2

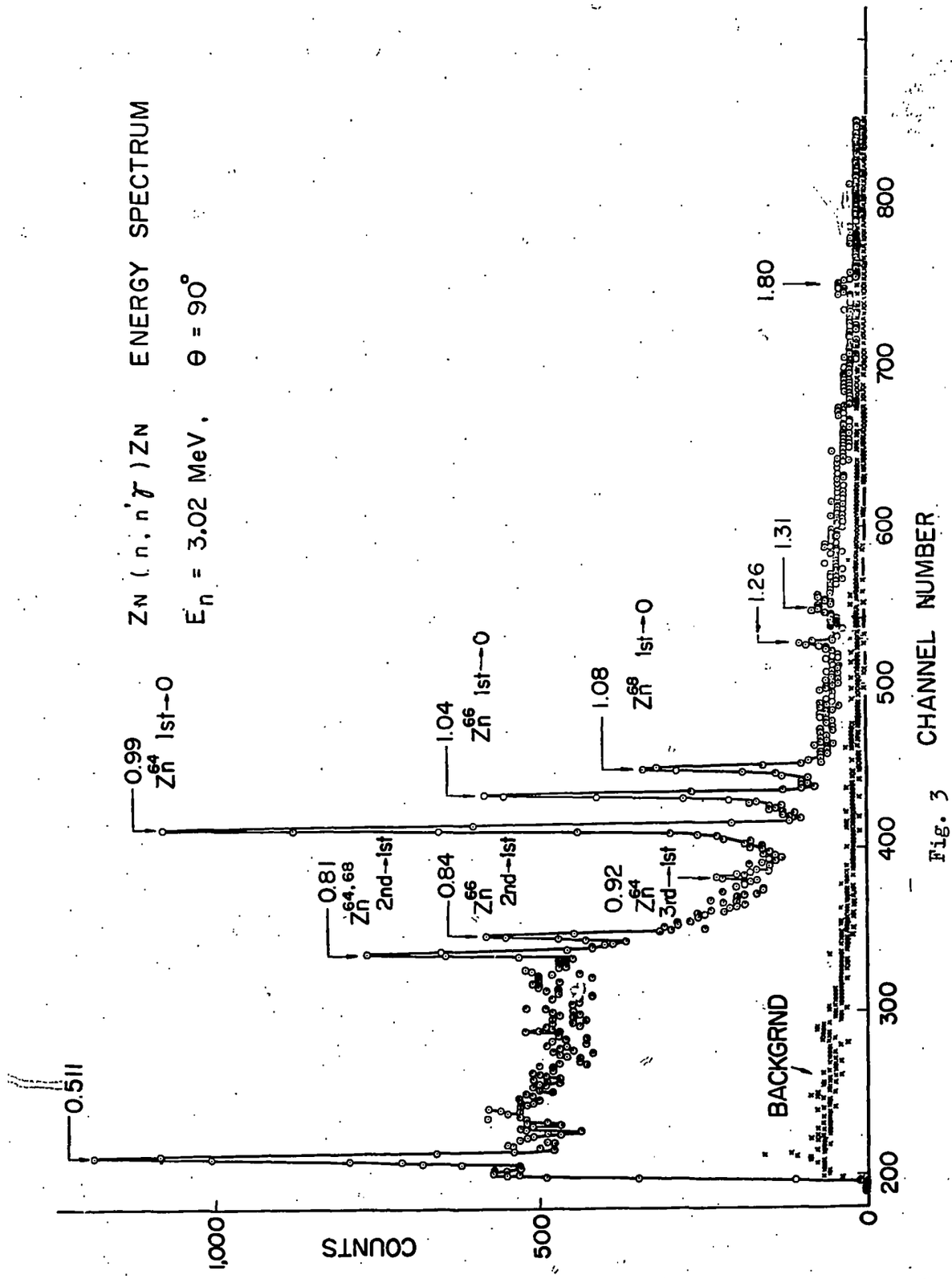

ZN (n, n'γ) ZN ENERGY SPECTRUM
En = 3.02 MeV. θ = 90°
0.511
0.99
Zn64 1st→0
0.81
Zn64,68 2nd→1st
0.84
Zn66 2nd→1st
0.92
Zn64 3rd→1st
1.04
Zn66 1st→0
1.08
Zn68 1st→0
1.26
1.31
1.80
BACKGRND
COUNTS
1,000
500
0
200
300
400
500
600
700
800
CHANNEL NUMBER

Fig. 3

I-C-6. Energy Dependence of the Nuclear Level Density

M. Maruyama, K. Tsukada, S. Tanaka, Y. Tomita and Y. Yamanouti

As the continuation of the work[1-3] previously reported for Co, Cu, As, Br, Nb, Ag, In, I, La, Ta and Au, the energy spectra of neutrons inelastically scattered from Sb, Cs, Ba, Ce and Pr have been measured in the energy range 3.5-8.5 MeV (every 0.5 MeV step) of incident neutrons by means of the time-of-flight technique with a 6-MV pulsed-beam Van de Graaff accelerator and a beam-bunching system of Mobley type. The energy dependence of the level densities $\rho(E)$ in the excitation energy 2 to 7.5 MeV was carefully derived from the observed spectra. The inverse compound nucleus formation cross sections $\sigma_c(E_n,0)$ for several forms of the optical model potential were used in the derivation.

The χ^2-fitting of two types of the level density function for the observed level densities was tried by using a digital computer IBM-7044 in order to examine the functional forms of the level densities for those nuclei and also for the nuclei previously measured. As a result, the function $E^{-2}\exp 2(aE)^{\frac{1}{2}}$ of the Fermi-gas type is fitted very well to the observed level densities of Co, Cu, As, Br, Ag, I, Ta and Au. On the other hand, the constant-temperature type formula $\exp[E/T]$ is fitted exclusively to those of Ba, La, Ce and Pr. For niobium, the two functional forms can be equally fitted to some extent. The level densities of In, Sb and Cs have more complex forms. Fig. 1 shows the energy dependence of the level densities $\rho(E)$ of In, I and La, respectively of the complex form, the Fermi-gas form, and of the constant-temperature form. Curves show the best fits of $E^{-2}\exp[2(aE)^{\frac{1}{2}}]$ for In and I and of $\exp[E/T]$ for lanthanum. The results of the analysis mentioned above are summarized in Table I. The values of nuclear temperature T and the level-density parameter a obtained by using

the method of least squares are shown in the 5th and the 6th columns of the table, respectively. Spreads of the values of T or a for the same element are due to different choices of the inverse compound formation cross sections which cause no significant change in the fitting. The energy dependence of the constant-temperature or the complex type, as seen in the table, appears near the proton or neutron-magic nuclei (P = 50 or N = 82). This phenomenon seems to be due to the existence of shell effect on the level density form. In order to confirm this expectation, further measurements for Ni, Sr, Y, Sn and Ho and counting of the nuclear levels on the basis of the shell model using the computer are now in progress.

References:

1) K. Tsukada, S. Tanaka, M. Maruyama and Y. Tomita, EANDC (J) 1 "L" (1965) 16

2) K. Tsukada, S. Tanaka, M. Maruyama and Y. Tomita, Nuclear Physics 78 (1966) 369

3) K. Tsukada, S. Tanaka, M. Maruyama and Y. Tomita, EANDC (J) 3 "L" (1966) 10

Table I Summary of the results

	Element	Number of proton	Number of neutron	Functional form	T (MeV)	a (MeV^{-1})	χ^2
P=28→	Co	27	32	$E^{-2}\exp[2(aE)^{1/2}]$		12.3-13.9	0.96
	Cu	29	34,36	$E^{-2}\exp[2(aE)^{1/2}]$		14.1-15.4	1.77
	As	33	42	$E^{-2}\exp[2(aE)^{1/2}]$		17.2-19.2	0.83
N=50→	Br	35	44,46	$E^{-2}\exp[2(aE)^{1/2}]$		17.0-20.2	0.99
	Nb	41	52	$E^{-2}\exp[2(aE)^{1/2}]$		(14.6-22.7)	0.67
				or $\exp[E/T]$	(0.60-0.78)		0.98
	Ag	47	60,62	$E^{-2}\exp[2(aE)^{1/2}]$		19.3-23.7	0.71
P=50→	In	49	66	complex			1.44
	Sb	51	70,72	complex			1.79
	I	53	74	$E^{-2}\exp[2(aE)^{1/2}]$		22.2-24.8	0.87
	Cs	55	78	complex			2.05
N=82→	Ba	56	79,80,81,82	$\exp[E/T]$	0.52-0.58		1.08
	La	57	82	$\exp[E/T]$	0.64-0.73		0.88
	Ce	58	82,84	$\exp[E/T]$	0.47-0.53		0.58
	Pr	59	82	$\exp[E/T]$	0.45-0.51		1.00
	Ta	73	108	$E^{-2}\exp[2(aE)^{1/2}]$		21.5-26.7	0.92
	Au	79	118	$E^{-2}\exp[2(aE)^{1/2}]$		19.7-26.1	1.03

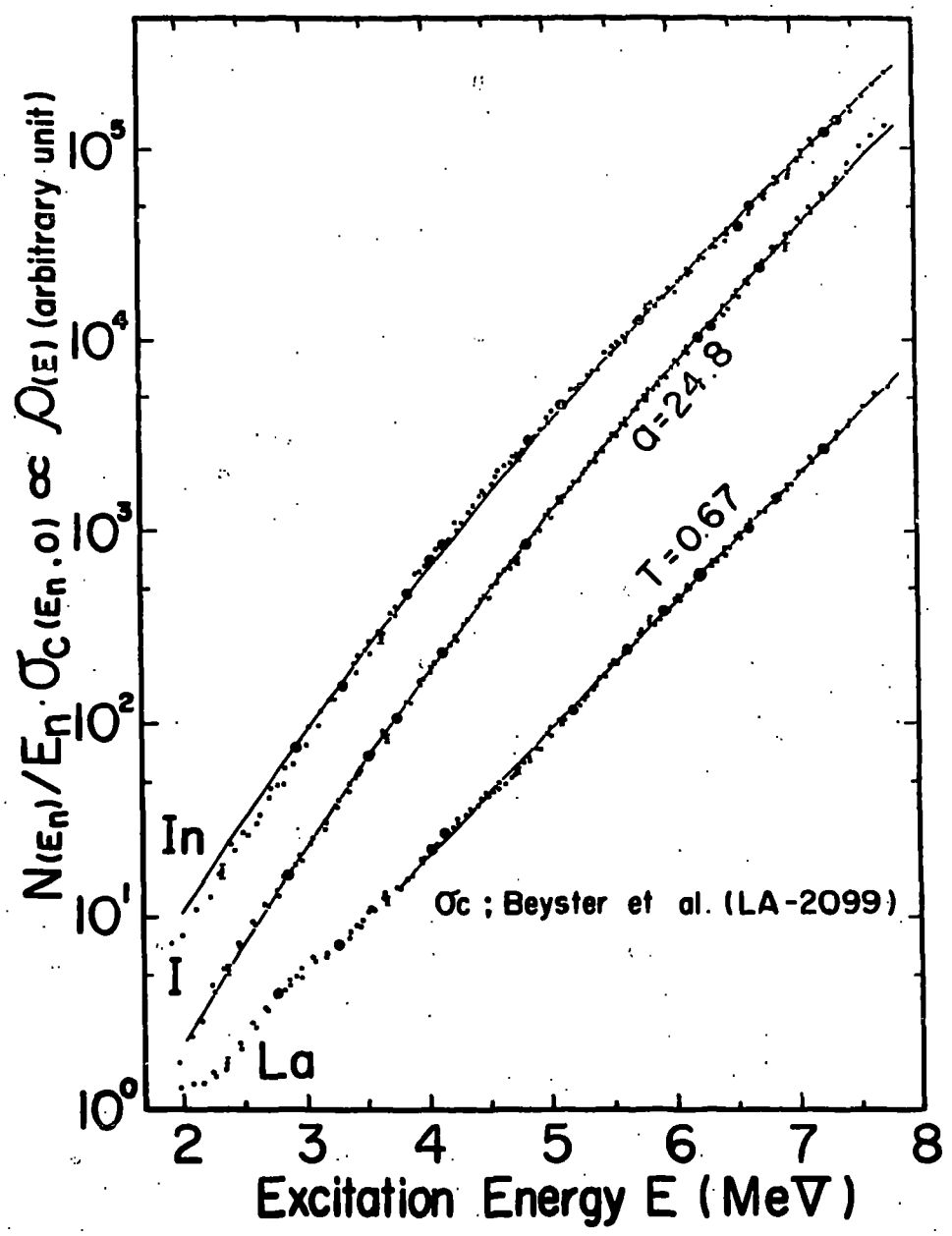


Fig. 1. Energy dependence of the level densities $\rho(E)$ of In, I and La. The ordinate scale is of arbitrary units, not common to the elements. For the derivation of the level densities $\sigma_c(E_n, 0)$ of Beyster et al. is used. Vertical bars show typical errors of the points. Curves show the best fits of $E^{-2}\exp[2(aE)^{\frac{1}{2}}]$ for In and I and of $\exp[E/T]$ for lanthanum.

I-C-7. Investigation of the $^{9}Be(^{3}He,n)^{11}C$ Reaction in the Energy Range 3.5 to 10 MeV

K. Okano*, S. Kikuchi, K. Nishimura, and K. Harada

The $^{9}Be(^{3}He,n)^{11}C$ reaction has been studied by several investigators in the energy range up to 5.8 MeV.[1,3] These authors revealed the direct interaction character of the reaction, especially at higher energy region. But the agreements of the experimental data with the results of the DWBA calculations have not always been satisfactory. We have extended the energy region up to 10 MeV and attempted to make the comparison of the experimental angular distributions with the results of DWBA calculations based on the two nucleon stripping process. The excitation functions and angular distributions of neutrons from the $^{9}Be(^{3}He,n)^{11}C$ reaction leading to the ground and first excited states of ^{11}C have been measured in the bombarding energy range from 3.5 to 10 MeV. Singly and doubly charged helium ions from the JAERI 5.5 MV V.D.G. were used and the neutrons were detected by a gamma-discriminated stilbene detector.

The behaviour of the excitation curves and oscillatory pattern of angular distributions indicate that a direct interaction process is predominant at the incident energies above 5 MeV. The contributions of the knock-on process are estimated to be small in the higher energy region. At lower bombarding energies, the reaction process seems to be more complicated and the agreement with the results of the DWBA calculations are rather poor.

A part of this work has been presented as a contributed paper in Nuclear Structure Conference at Tokyo (September, 1967). A full paper will be submitted to Nuclear Physics soon.

---

* Present address: Research Reactor Institute, Kyoto University
Kumatori-cho, Sennan-gun, Osaka, JAPAN

References :

1) J. L. Duggan, P. D. Miller and R. F. Gabbard, Nuclear Physics, 46 (1963) 336

2) J. H. Towle and B.E.F. Macefield, Nuclear Physics 66 (1965) 65

3) G.U. Din and J.L. Weil, Nuclear Physics, 71 (1965) 641

D. Others

I-D-1. Accurate Half-Life Measurements of Short-Lived Nuclides with Aids of Chemical Separation

T. Ishimori, K. Kimura, K. Ueno, Y. Kobayashi, M. Hoshi, M. Saeki, R. Ono, T. Kon, M. Hagiya, and K. Awa

This note is the abstract of a report presented at the 8th Japan Conference on Radioisotopes, (1967).

Introduction Recent developments in radiochemical separation make it possible to get better knowledges on radioactive disintegration processes. Especially rapid separation techniques are sometimes indispensable for studying short-lived nuclides.

In the present study, entirely new or somewhat modified methods were established for the purification of titanium from scandium, calcium from scandium, yttrium from zirconium, niobium from zirconium, rhodium from ruthernium, barium from cesium and protactinium from thorium. By using these methods, short half-lives of titanium-45, 51, calcium-49, yttrium-89m, niobium-97m, 97, rhodium-103m, 105, 106, barium-137m and protactinium-234m were determined. The decay curves for simple [A → B] type disintegration were analysed on an IBM-7044 computer, using Roger's FRANTIC program in order to calculate values of half-life very accurately. For [A → B → C] type disintegration a careful graphical method was applied to analyse.

Experiment Radioactivity measurements —— Beta activity was measured with a proportional gas-flow counter while γ - activity with a scintillation counter. For short-lived nuclides, a 400-channel multiscaler was also used. Gamma-ray spectra were read by a 256-channel pulse-height analyser and 3" x 3" NaI(Tl) scintillation crystal covered with plastic absorber. Reagents —— All chemical reagents used were of analytical grade, unless otherwise stated.

Results Separation procedures utilized and values of half-lives obtained are given in Tables 1 and 2.

The half-life value shown on this table was a weighted mean of some individual determinations. The standard deviation was estimated on the basis of the statistical error.

Comparison with previously published data leads to the conclusion that the present half-life values fall on the close vicinity of the corresponding previous values and that they look more accurate with smaller standard deviations ranged from 0.03 to 1.18%.

The detail of the present note will be published in a JAERI report.

Table.1 Preparations and disintegration rate measurements of the short-lived nuclides

Nuclide	Nuclear Reaction	Chemical purification method		γ-ray Energy (MeV)	γ-ray Relative intensity	Number of measurements (max) per Half-life	Number of measurements (max) per min.	Length of observation Half-life unit	Length of observation Time
Ca-49	$^{48}Ca(n,\gamma)^{49}Ca$	Ca oxalate pptn.		3.09 4.06 4.67		6	0.6	12	1.8 h
Sc-49	$\xrightarrow{\beta^-}{}^{49}Sc$			—		2	0.03	6	5.8 h
Ti-45	$^{46}Ti(\gamma,n)^{45}Ti$	Solvent extraction	100%TBP-8NHCl	0.511	1.00	5	0.027	8	25 h
-51	$^{50}Ti(n,\gamma)^{51}Ti$			0.322 0.62 0.94	1.00 0.018 0.07	6	1	8	45 m
Y-89 m	$^{90}Zr(\gamma,n)^{89}Zr \xrightarrow{\beta^+}{}^{89m}Y$		100%TBP-10NHCl	0.913	1.00	15	60	10	2.6 m
Nb-92	$^{93}Nb(\gamma,n)^{92}Nb$		100%TBP-8NHF·6NHCl	0.934 1.84		32	0.0023	10	100 d
-97 m	$^{96}Zr(n,\gamma)^{97}Zr \xrightarrow{\beta^-}{}^{97m}Nb$			0.76		5	5	8	7.5 m
-97	$\xrightarrow{IT}{}^{97}Nb$			0.665 1.02		6	0.1	13	6.6 d
Rh-108m	$^{102}Ru(n,\gamma)^{103}Ru \xrightarrow{\beta^-}{}^{103m}Rh$		CCl_4-HClO Soln.	0.04		2	0.08	8	7.5 h
-105	$^{104}Ru(n,\gamma)^{105}Ru \xrightarrow{\beta^-}{}^{105}Rh$			0.2819 0.3077 0.3205 0.4425	0.00075 0272 1.00 0.000028	3	0.0016	14	207 d
-106	$^{106}Ru \xrightarrow{\beta^-}{}^{106m}Rh$			0.513 0.624		80	60	7	8.5 m
Ba-137m	$^{137}Cs \xrightarrow{\beta^-}{}^{137m}Ba$	Ion ite.C-1NHNO$_3$		0.66	1.00	15	6	10	2.6 m
Pa-234m	$^{234}Th \xrightarrow{\beta^-}{}^{234m}Pa$	Solvent extraction	DiPK-7NHCl	0.69 0.77 0.78 1.02 1.26 1.55 1.76 1.87	0.089 0.349 0.189 1.00 0.041 0.034 0.032 0.059	7	6	9	10 m

Table.2 The half-lives of the short-lived nuclides

Nuclide	Decay type	Half-life		
		Literature value	Present work	
			value	obtaind
Ca- 49	β^-	8.75 ± 0.20 m	8.69 ± 0.04_5 m [4]	Graphically
Sc- 49	β^-	57.5 ± 0.1 m	57.2_6 ± 0.3_9 m	by Least-squares
Ti- 45	β^+	3.09 ± 0.03 h	3.078 ± 0.001 h [5]	by Computer
- 51	β^-	5.79 ± 0.03 m	5.752 ± 0.007 m	by Computer
Y - 89m	IT	16.2 ± 0.1 s [1]	15.65 ± 0.02 s [6]	by Computer
Nb- 92	β^+	0.15 ± 0.03 d	10.09 ± 0.02_2 d	Graphically
- 97m	IT	60 ± 8 s [2]	57.9_5 ± 0.5_2 s [7]	Graphically
- 97	β^-	74.0 ± 0.2 m	73.74 ± 0.04 m	by Computer
Rh-103m	IT	57.5 ± 0.5	56.6_2 ± 0.6_4 m [8]	by Computer
-105	β^-	35.88 ± 0.02 h	35.47 ± 0.08 h	by Computer
-106	β^-	30 s	29.7_8 ± 0.1_0 s	by Computer
Ba-137m	IT	2.60 ± 0.05 m	2.53 ± 0.03 m	by Computer
Pa-234m	β^- IT	1.21 ± 0.03 m [3]	1.181 ± 0.004 m [9]	by Computer

All literature values other than these with a reference number were obtaind from Nuclear Data Sheets, National Academy of Sciences, National Research Council.

I-D-2. The Spontaneous Fission Uranium - 238

T. Ishimori, K. Ueno, K. Kimura, E. Akatsu, Y. Kobayashi, J. Akatsu, R. Ono and M. Hoshi.

The present note is the abstract of a paper published in Radiochimica Acta 7, 95 (1967)

A study of the spontaneous fission mass distribution and the half-life was carried out during the trial runs of an experimental reprocessing plant of the JAERI. Yttrium, cerium and silver nuclides were separated from the solution of the fission-products fraction, which comes out of the first pulsed column. The resultant data were used for calculating the half-life, together with the data already reported by other authors. The half-life for the spontaneous fission of ^{238}U was thus estimated to be $(7.191 \pm 0.036) \times 10^{15}$ years. The gamma-ray spectrum of the ^{143}Ce separated, the decay curves of ^{143}Ce, ^{141}Ce, and ^{93}Y, ^{91}Y and ^{90}Y, and mass distribution curve are shown.

I-D-3. Phonon Spectrum of Light Water Ice

Y. Nakahara

The phonon spectrum of light water ice has been computed by means of the root sampling method for a sampling of 1050 points in an irreducible zone of the first Brillouin zone. The force model we used in our computation is a non-central force model by E. Forslind, in which interactions with the first nearest neighbors are taken into consideration.

We consider H_2O molecule as unit and that molecules with mass of 18 are arranged at positions of oxygen atoms. Each molecule is surrounded by four immediate neighbors in tetrahedral arrangement. In other words, we neglect the internal degrees of freedom of H_2O molecule. The phonon spectrum, therefore, does not contain modes corresponding to the molecular vibrations and rotations.

The unit cell of ice contains four molecules. The cell dimensions, as measured by Megaw, and corrected according to Owston and Lonsdale, are

$$a = 4.5226 \text{ Å}$$
$$c = 7.3670 \text{ Å}$$

at $0^{\circ}C$.

Values of seven atomic force constants are determined from the experimental values of the elastic constants of Voigt obtained by Jona and Scherrer and are given in Table 1.

Table 1. Values of atomic force constants

α = 379 dyne/cm	θ = 2830
β = 4445	ε = 1616
γ = 3600	κ = 21549
δ = 2830	

The secular equation based on the Forslind model was solved for 1,050 points in the irreducible zone and 12,600 values of eigen-frequencies are sampled by the FREDAM-B1 code on the IBM-7044. The phonon spectrum obtained is given in Fig. 1. Dispersion relations in the direction of the crystallographic a-axis and c-axis are also shown in Fig. 1. Since the unit cell contains four molecules, eigen-frequencies have twelve branches in general.

Using our phonon spectrum, the calculation of the scattering law and the scattering cross section of ice are being carried on.

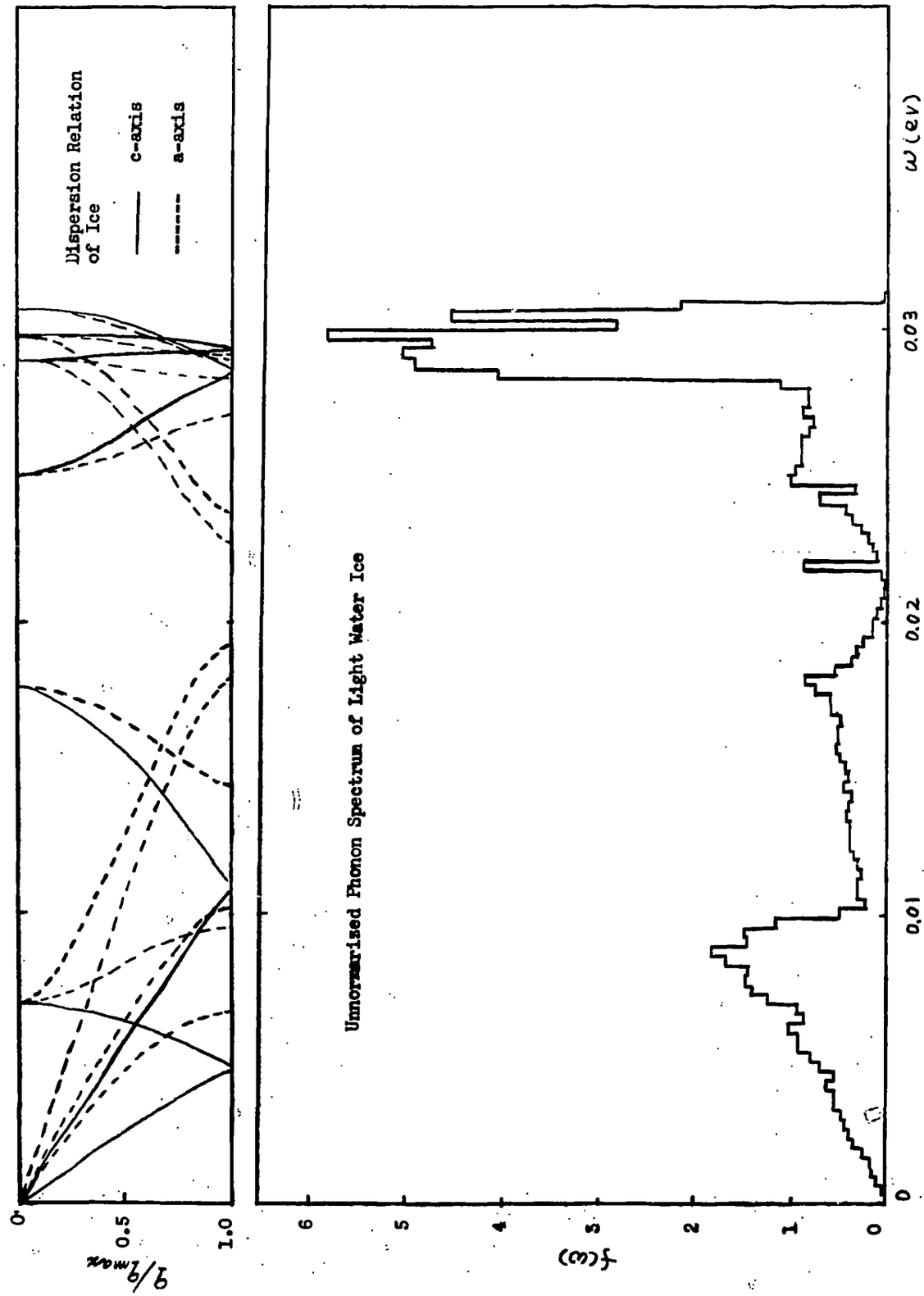

Dispersion Relation of Ice
c-axis
a-axis
0
0.5
1.0
q/q_{max}
Unnormalised Phonon Spectrum of Light Water Ice
0
1
2
3
4
5
6
$f(\omega)$
0
0.01
0.02
0.03
ω (eV)

Fig. 1

E. Japanese Nuclear Data Committee

The Committee has continued activities mentioned in the previous report, EANDC (J) 7 "L".

Following reports represent main results of the programme coordinated by the Committee.

I-E-1. Neutron Total Cross Section of Carbon

K. Nishimura, S. Igarasi, S. Tanaka and T. Fuketa

The problem for compilation and evaluation of data related to nuclear energy standards was discussed in the EANDC subcommittee at Washington, D.C. in May 1965. The request for evaluation of those cross sections such as H(n,n), ^{3}He(n,p), C(total), ^{6}Li(n,α), ^{10}B(n,α), Au(n,γ), Pb(total), ^{235}U(n,f), ^{239}Pu(n,f) and ^{252}Cf(υ) were proposed at that time. Among these standard cross sections, Japanese group has interest in the evaluation for total neutron cross sections of carbon and lead. The evaluation work for carbon has been started this year as one of activities of the Japanese Nuclear Data Committee.

The numerical data of neutron total cross section of carbon were obtained from SCISRS through CCDN, and plotted on graphical papers by using a Calcomp plotter to make the evaluation work easier.

Recently, a retrieval of carbon data of up-to-date has been sent from CCDN and is used for confirming that previous compiled data of

SCISRS have not missed any important new material.

As requested from EANDC proposal, the energy range of interest for carbon is from thermal to 2 MeV. There is no marked resonance structure in neutron total cross section of carbon up to 2 MeV, except for two resonances of ^{13}C which is contained 1.11% in natural carbon. All compiled data obtained indicate that there is three marked resonances in carbon between 2 and 4 MeV. In the present stage, we understand that there are two different values of cross sections (4.95^b and 4.71^b) at thermal energy.

In the keV ~ MeV region we have 8 groups of measurements, each of which contains more than 100 data points. Looking at all these data we find that their values of cross section scatter about ±3~5%. What kinds of weight should be allotted to these data? How to evaluate these experimental results? These are major problems to be resolved. In order to deduce a recommended curve of carbon cross section, critical review, analyses, and discussions are now in progress.

I-E-2. Review of Some Fast Neutron Cross Section Data

Y. Kanda* and R. Nakasima**

(This is the abstract prepared for contributing paper to the 2nd Conference on Neutron Cross Sections and Technology.)

Some of the existing cross-section data which are usually adopted as standards in fast neutron experiments are reviewed. The cross-section data compiled for this purpose are those for $^{27}Al(n,\alpha)$, $^{56}Fe(n, p)$, $^{63}Cu(n, 2n)$ and $^{65}Cu(n, 2n)$ reactions in the energy range from threshold to 20 MeV. The raw data points are so much scattered that recommendation of the cross-section value is difficult to make within the accuracy of 10%. This is mainly due to the ambiguity in determining the flux of neutrons and to the statistical fluctuations in the number of counts. In some cases, the inaccuracy in the neutron energy determination may lead to serious discrepancy. Discussions are presented in concern with the activation method and with the rejected data. Most likely excitation function is obtained for each reaction by means of the least squares method.

---

* Tokyo Institute of Technology, Tokyo

** Hosei University, Tokyo

I-E-3. A Computer File of Resonance Data

T. Fuketa, Y. Nakajima, and K. Okamoto

A paper on this subject was submitted to the Second Conference on Neutron Cross Sections and Technology, Washington, D.C., U.S.A., March 4-7, 1968 with an abstract as follows:

A computer programme to make a computer file of resonance data (COMFORD) was prepared. In the COMFORD, the neutron resonance data, that is, resonance energies, spins, neutron widths, capture widths, average level spacings, strength functions, and so on are stored in a magnetic tape in the order of atomic number. Different blocks of data for the same atomic number are stored in the order of publication date and a control number which facilitates the identification of a data block. Symbols, which are equivalent to certain comments, can be attached to the individual numerical data in order to give an idea about the quality of the data, and these symbols may be used to classify the data when they are read out from the COMFORD. The primary purpose of the COMFORD is to use it as an input-data tape for variety of the computer analyses to investigate the statistical property of the neutron resonances; and, thorough and complete storage of the all published data into the COMFORD is not intended.

I-E-4. Activities of the Group Constants Working Group

S. Katsuragi and H. Sakata

1. Evaluation of the Data Library Prepared in 1966

The MUFT-type data library prepared in 1966 (EANDC (J) 7 p.25) was modified by correcting minor errors in the processing of the angular distribution of scattering cross sections and of the inelastic scattering matrix. The evaluation of the data library has been done by comparing the calculated and experimental results on the UO_2 fuel and light water moderator system and the PuO_2 fuel and light water moderator system. In the case of UO_2 and light water system, the calculated values for age of water and the fast neutron fission effects are smaller than those of experiments but for the effective resonance integral of ^{238}U, the diffusion length of H_2O and the disadvantage factor are larger. Thus it leads to a value of effective multicative factor about 0.5% smaller than the measured one, though the larger calculated values have been obtained from other data libraries. The calculations are now in progress for the case of PuO_2-UO_2 and light water system, and a tentative estimation of the results seems to show that the accuracy of our data library is quite satisfactory. This project of developing more reliable data library will be continued with more accurate microscopic nuclear data.

Preparation of Data Library for Fission Product Nuclides

A project of developing a data library for fission product nuclides has been started in order to make more accurate burn-up

calculations of reactors. This project consists of the following four steps:

1) Compilation of the nuclear data, the fission yield, and the half-life for about 450 nuclides of interest,
2) Calculations of the isotopic concentration of nuclides in the burn-up process, taking account of the absorption cross sections and the life times.
3) Calculations of the resonance integral and reactor multi-group constants
4) Making up of pseudo-fission products through classification (5 groups) of fission products in accordance with their importance in reactor calculations, together with the calculations of the reactor constants for each group.

In the first step (1), the focus was put on compilation and examination of thermal neutron cross sections and resonance parameters with the aid of BNL-325 mainly. Further, compilation and examination of nuclear data needed for the calculations of (2) and (3) was also made in this stage, in parallel with the wide investigation of data for the 16 nuclides of much importance.

In the second step, the focus was put on the preparation of a computer program for calculating the changes of the concentration of fission product nuclides; actual calculations were performed by use of two group constants taking a thermal reactor into account. In the third step, the main purpose was to prepare a computer code in consideration of resonance parameters; The single level formula was

applied for the resolved resonance region and the statistical theory was used for the unresolved resonance region. Calculations are now in progress for such nuclides as those for which resonance parameters are provided.

So far obtained are about 95 nuclides which provide data on 3 resonance parameters as well as about 160 nuclides which provide thermal neutron cross sections. Nuclear data needed for reactor calculations are excessively lacking in quantity, and increase of useful data are wanted. The fourth step (4) will be our future task to be completed in connection with the fuel burn-up calculations and by use of the results from the works in the third step.

3. Preparation of a Processing Code for a Data Library

In order to evaluate various data compiled, comparison of the respective datum is needed as an important procedure. A computer plotting code was developed in this concern for the purpose of making graphs for evaluated data. The data library ENDF-A was adopted as a basic format of input data.

Since the data provided in the CCDN are different in their form in the file, from those in the ENDF-A, a processing code PROF GROUCH-M, also developed by ourselves, is not applicable to the CCDN data file. Thus a code for changing the CCDN format to that of ENDF was developed.

II. Konan University

II-1. The (n,α) Reaction on ^{14}N with 14.1-MeV Neutrons

K. Yuasa, N. Fujiwara, B. Saeki, and M. Ohta

For the cluster structure investigation in the light nuclear region, the angular distributions of the alpha particles from the $^{14}N(n,\alpha)^{11}B$ reaction with 14.1-MeV neutrons have been measured by means of the counter telescope with two proportional counters filled with 5 cm-Hg argon and a silicon surface barrier detector with 2 cm^2-sensitive area.

The distance between the neutron source with the flux of 10^8 neutrons per sec into 4π and the melamine target (1.62 mg/cm^2) was 13 cm, and that between the target and the SSD was also 13 cm.

The results are shown in the following figures, in which it is considered that the angular distribution of alpha particles from the formation of the ground state of ^{11}B is dominantly due to the ^3He pick-up process and that of the first excited state of ^{11}B is the mixture of the pick-up and the heavy particle stripping processes. The possibility of the alpha clusters in the nucleus such as ^{12}C and ^{16}O is not seen in ^{14}N.

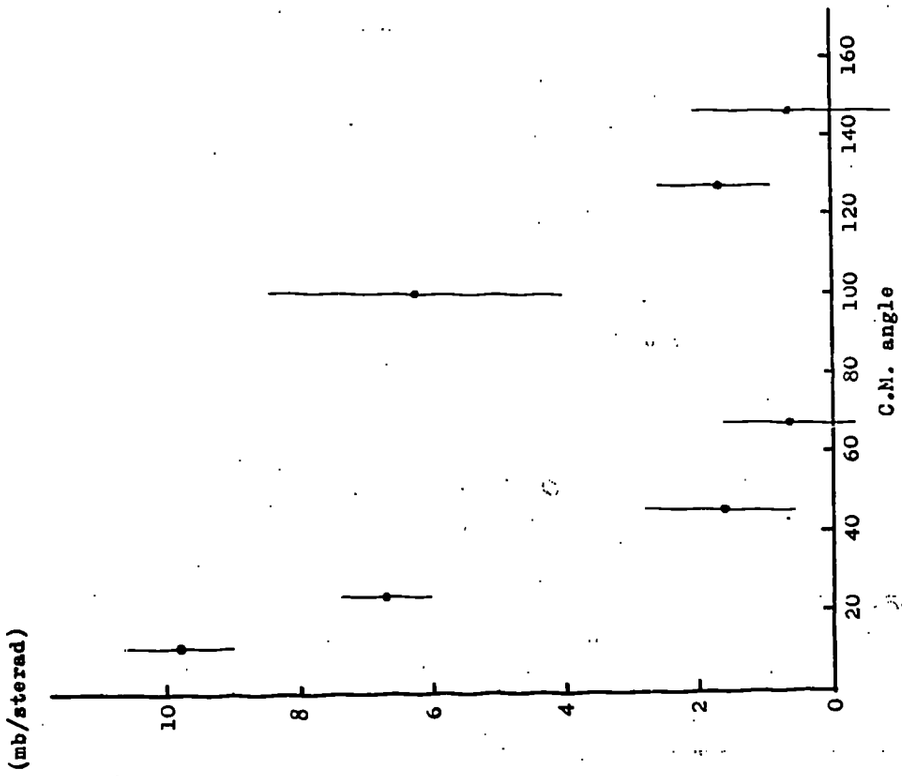


Fig. 2 Angular distribution of alpha particles from $^{14}N(n, \alpha_1)^{11}B_{first}$ reaction.

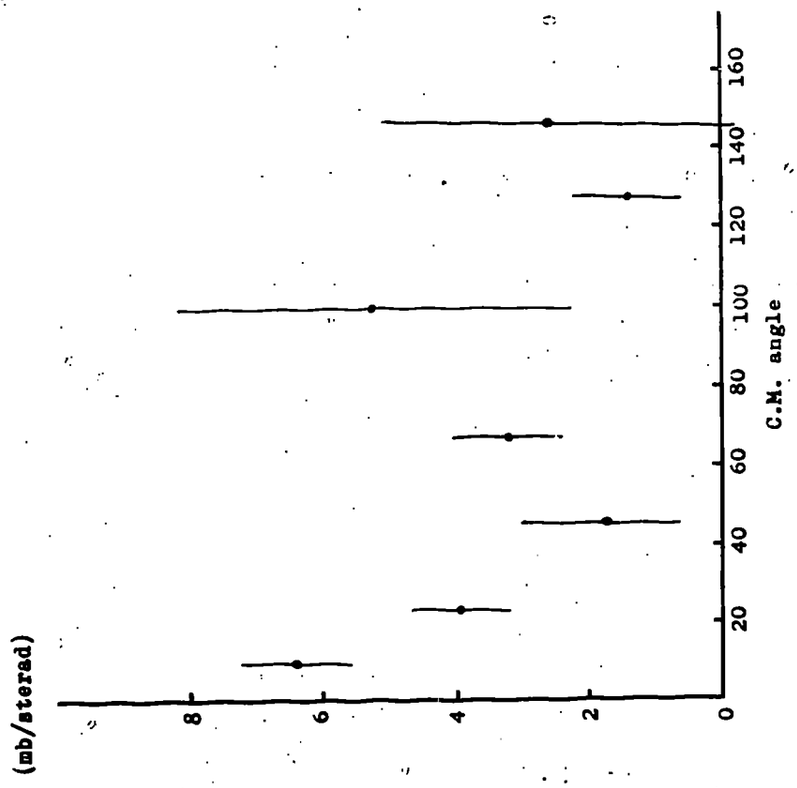


Fig. 1 Angular distribution of alpha particles from $^{14}N(n, \alpha_0)^{11}B_{ground}$ reaction.

III. Kyoto University Research Reactor Institute

III-1. Cross Section Measurement for the $^{103}Rh(n,n')^{103m}Rh$ and $^{115}In(n,n')^{115m}In$ Reactions*

I. Kimura, K. Kobayashi and T. Shibata

Since the remarkable discrepancies have existed in the cross section data for the $^{103}Rh(n,n')^{103m}Rh$ and $^{115}In(n,n')^{115m}In$ reactions, they have been carefully measured. Monoenergetic neutrons have been produced with a 2 MeV Van de Graaff accelerator**. A thin NaI(Tl) scintillator with a beryllium window has been used to measure the activity of ^{103m}Rh. For its absolute activity measurement, a standard ^{103m}Rh source has been made from the ruthenium trichloride irradiated with thermal neutrons. In this case, the electrodeposition technique has been introduced. To measure the activity of ^{115}In, a 3" × 3" NaI(Tl) scintillator has been used.

The experimental results of both reaction cross sections are shown in Fig. 1 and Fig. 2. From these data, the effective cross section σ_0 and the cross section averaged over the fission spectrum

---

* To be published as a technical report of the Research Reactor Institute, Kyoto University, (KURRI-TR) and also to be submitted to the Journal of Nuclear Science and Technology.

** This work was partly performed under the support by the National University Program for the Joint Use of JAERI Facilities.

neutrons $\bar{\sigma}$ can be calculated and are shown in Table 1 and Table 2.

In order to check the obtained cross sections for both reactions, rhodium foils and indium foils were irradiated at the several points in the water beside the core of the Kyoto University Reactor, KUR, which is a 1000 KW tank type reactor with 90% enriched uranium fuels. Fig. 3 shows the induced activities which have been compared with the theoretical calculation where the neutron spectra were calculated by the NIOBE code by V. V. Verbinski et al.[1]. From this, we may conclude that the present cross sections seem to be reasonable.

References

1) V. V. Verbinski et al., Nucl. Sci. Eng. 27 283 (1967)
2) J. C. Roy et al., AECL-1994 (1964)
3) K. H. Beckurts and K. Wirtz, "Neutron Physics" Springer-Verlag, Berlin (1964)
4) H. C. Martin et al., Phys. Rev. 93 197 (1954)
5) I. Heertje et al., Physica 30 775 (1964)
6) B. Margolis, Phys. Rev. 93 204 (1954)
7) K. Fährmann, ZfK-RN 27 (1964)
8) W. L. Zijp, RCN-37 (1965)
9) G. Berwanger, Atomkernenergie 10 451 (1965)
10) P. Delattre, EANDC(E) 51 "L" (1964)
11) A. M. Bresesti et al., Nucl. Sci. Eng. 29 7 (1967)
12) taken from the above reference (2)

Table 1. $^{115}In(n,n')^{115m}In$ Cross Section Data

References	σ_0 (mb)	$\bar{\sigma}$ (mb)	E_{eff}(MeV)	E_{th}(MeV)
Present Data	368 ± 22	177 ± 10	1.65	-
Fährmann[7]	360	170	1.5	-
Beckurts and Wirtz [3]	350	171	1.65	0.335
Zijp[8]	-	179	1.5	-
Berwanger[9]	370	-	1.766	-
Delattre[10]	-	-	1.5	-
Bresesti et al.[11]	-	155 ± 5	-	-

Table 2. $^{103}Rh(n,n')^{103m}Rh$ Cross Section Data

References	σ_0 (mb)	$\bar{\sigma}$ (mb)	E_{eff}(MeV)	E_{th}(MeV)
Present Data	785 ± 65	519 ± 43	1.05	-
Roy et al.[2]	-	535.8	-	0.04
Fährmann[7]	-	-	1.1	-
Beckurts and Wirtz [3]	1500	1093	0.9	0.04
Zijp[8]	-	1093	0.6	-
Delattre[10]	-	-	0.8	-

Fig 1 $^{103}Rh(n,n')^{103m}Rh$
Cross Section Curve

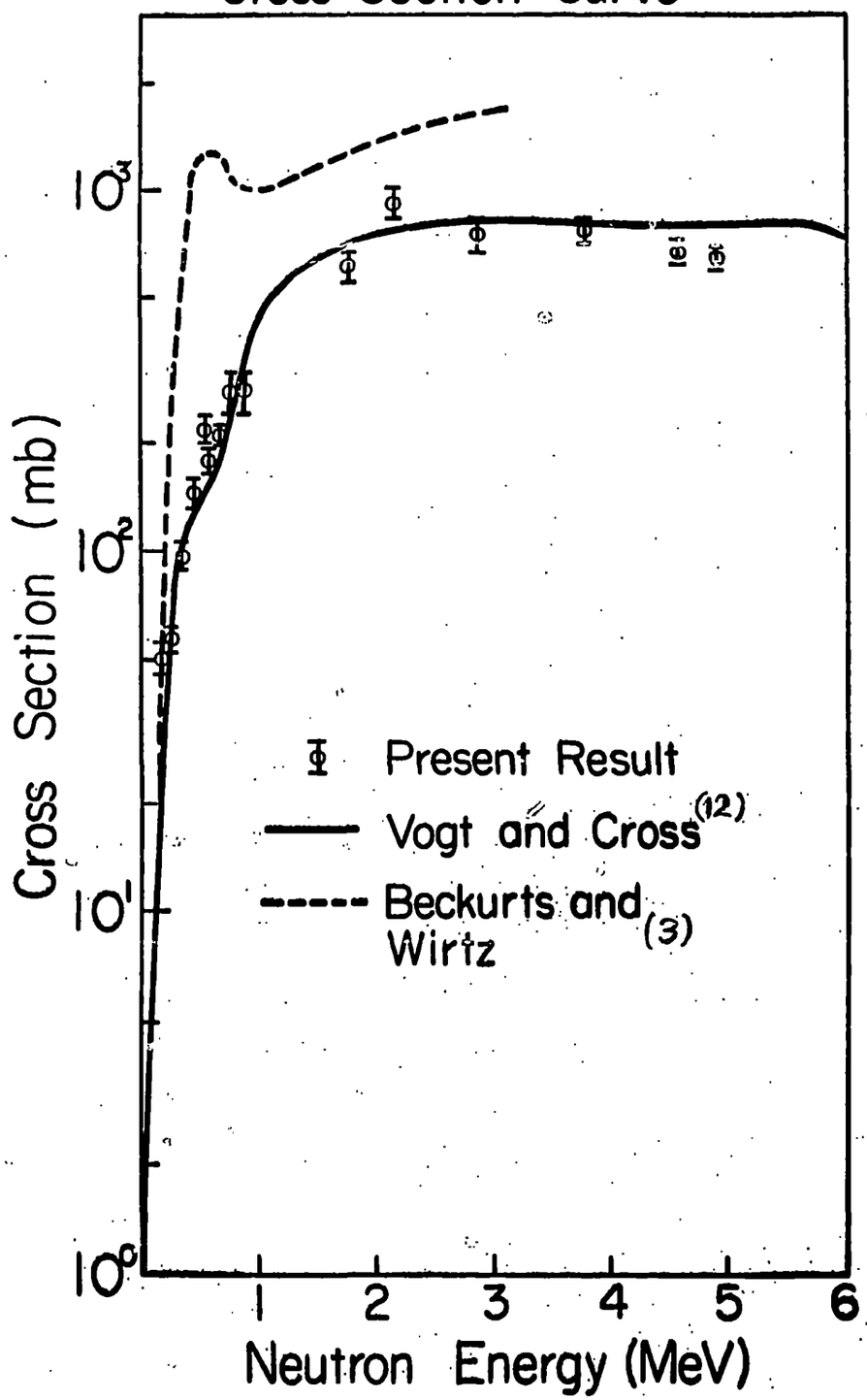
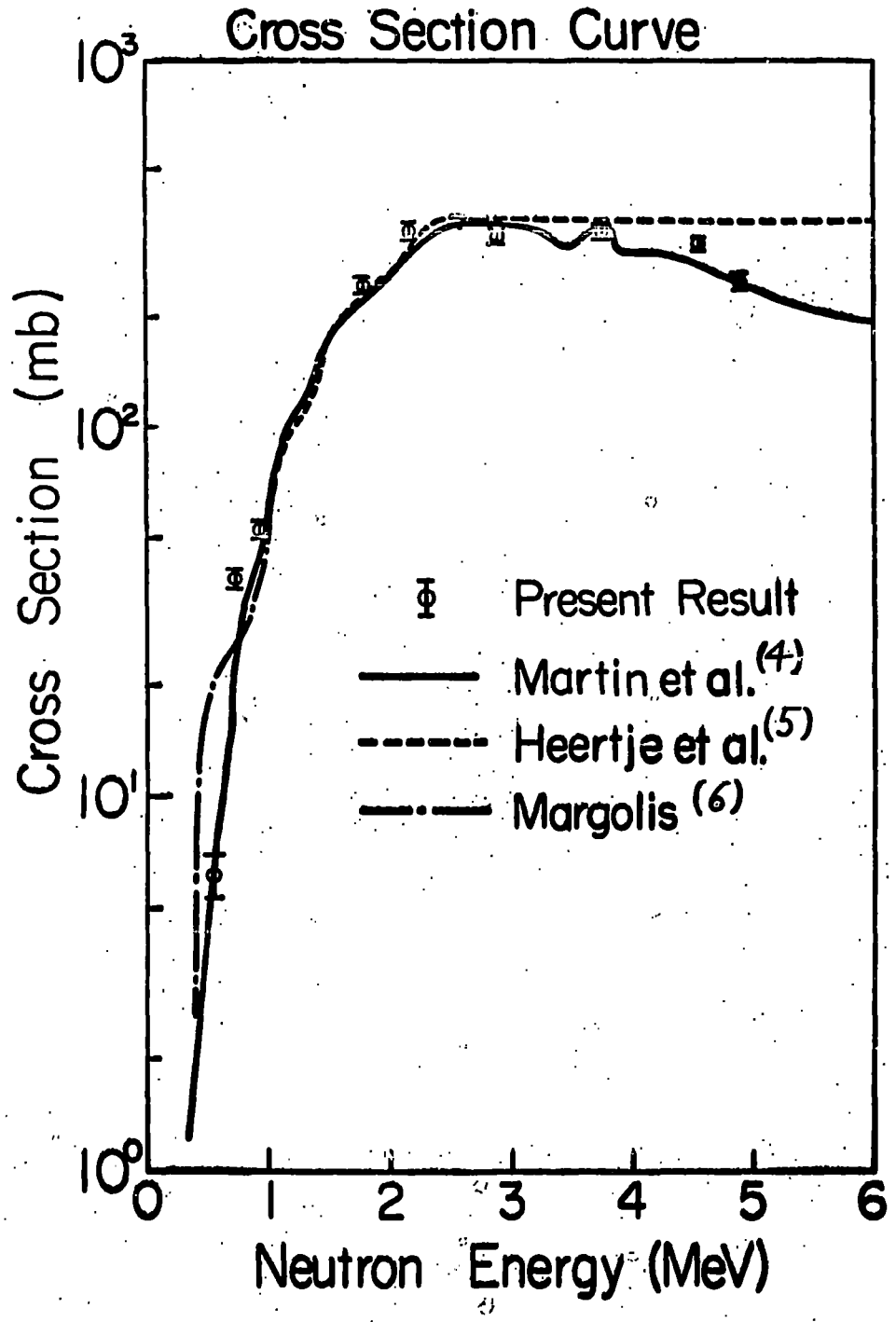


Fig. 2 $^{115}In(n,n')^{115m}In$ Cross Section Curve



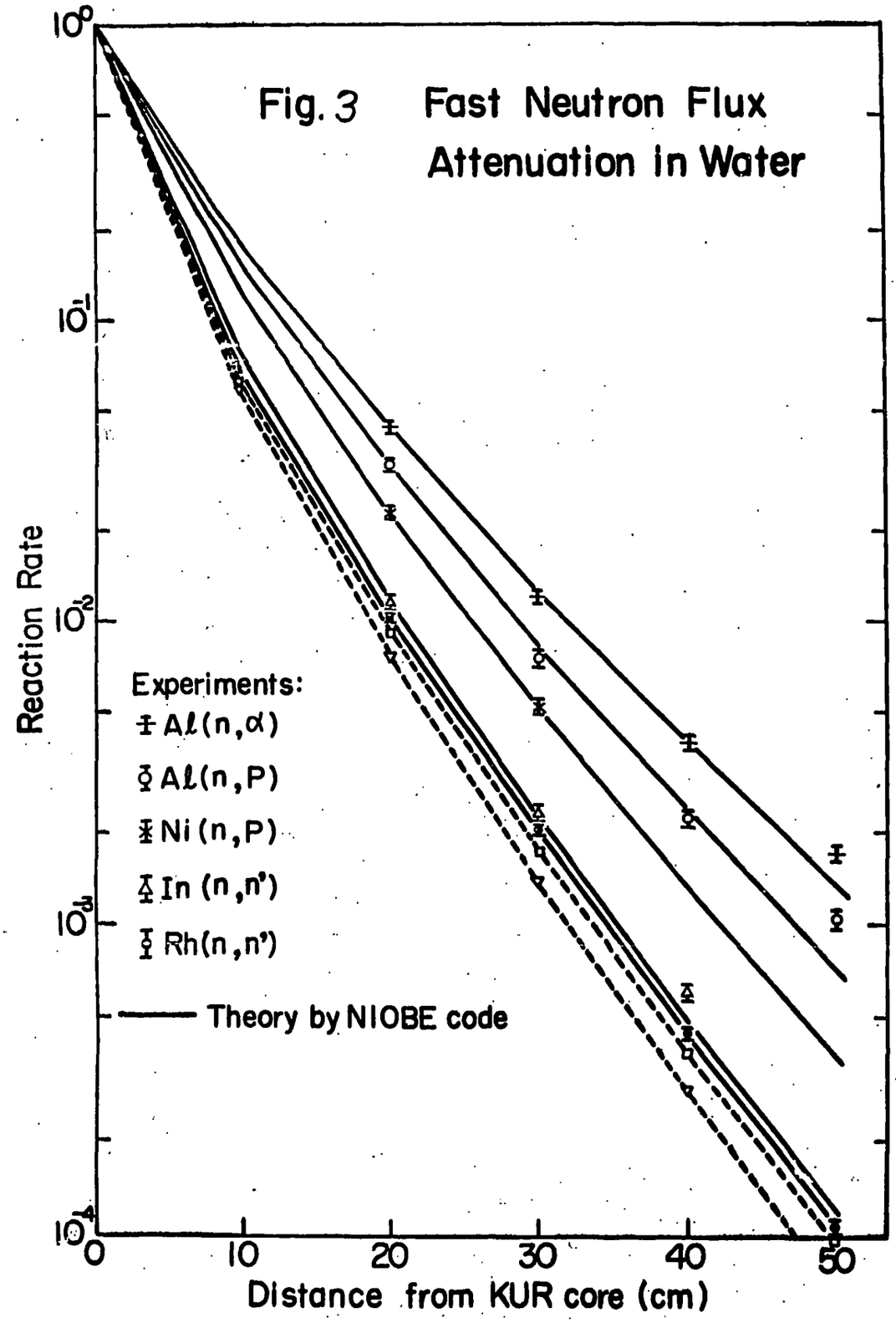


Fig. 3 Fast Neutron Flux Attenuation in Water
Reaction Rate
Distance from KUR core (cm)
Experiments:
Aℓ(n,α)
Aℓ(n,P)
Ni(n,P)
In (n,n')
Rh(n,n')
Theory by NIOBE code
10^0
10^-1
10^-2
10^-3
10^-4
0
10
20
30
40
50

IV. Kyushu University
Department of Nuclear Engineering

IV-1. (n, p) and (n, np) Reactions of Ca^{40}

A. Katase, T. Akiyoshi*, M. Sonoda and M. Seki**

Analyses of the (n, p) and (n, np) reactions of Ca^{40} induced by 14.1 MeV neutrons have been completed. A paper describing the details of the results has been accepted for publication in Nuclear Physics. The abstract follows:

"The constant-temperature formula for level density fits the energy distribution for backward angles and yields the nuclear temperature of 1.34 ± 0.04 MeV for K^{40}. The angular distributions of the protons emitted through compound process are nearly symmetric around 90° for the higher and lower energy regions. The spin cut-off parameter is estimated to be about 2.0 from the angular distribution of protons emitted only by the (n, p) reaction. The cross sections for the (n, p) and (n, np) reactions through compound process are 471 ± 21 mb and 180 ± 32 mb, respectively.

The direct (n, p) reaction has a cross section of about 11 mb.

---

* Present Address: Research Reactor Institute, Kyoto University

** Present Address: Department of Applied Physics, Hiroshima University

IV-2. (n, p) Reaction of Zn

I. Fujita, K. Iwatani*, M. Sonoda, A. Katase,
M. Seki* and Y. Wakuta

Further analyses on the data measured previously for Zn^{64} and Zn^{66} have been nearly completed. The angular distributions are symmetric about 90°. Fitting the angular distributions to Knox's formula, the values of spin cut-off parameter are derived for some intervals of proton energies. The results are shown in Table I, the details of which will soon be submitted for publication.

Table I

	Tp (MeV)	a (MeV^{-1})	$\sigma_{n,p}$**	$\sigma_{n,np}$**
Zn^{64}	1.06 ± 0.06	3.9 ± 0.4	188 ± 13	200 ± 31
Zn^{66}	1.35 ± 0.05	2.5 ± 0.3	53.5 ± 2.5	37.0 ± 75

IV-3. (n, n') Reactions

I. Fujita, M. Sonoda, A. Katase, Y. Wakuta,
M. Hyakutake, K. Iwatani* and H. Tawara

Using a time-of-flight method, continuous energy spectra were measured for inelastically scattered neutrons from 12 natural targets;

---

* Present Address: Department of Applied Physics, Hiroshima University

** The cross-sections have been calculated, using the constant temperature formula.

Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ge and As. The energy of incident neutrons was 14.1 MeV. The values of the nuclear temperature and level density parameter for the residual nuclei were derived using three different assumptions about the values of σ_c ; I) σ_c calculated with Perry-Buck potential, II) σ_c calculated with Bjorklund-Fernbach potential, and III) σ_c assumed to be constant. The results are shown in Fig. 1.

The values of level density parameter calculated with the assumption I and II are coincident with each other within the experimental errors. The values calculated with the assumption III deviate for the nuclei of lower mass number. The same effect is found for the values of nuclear temperature. The trend of the value of level density parameter as a function of mass number is expressed by Newton's formula.

$$a = k(j_p + j_n + 1),$$

where the shell effect is taken into account.

However, the value of k determined by Lang (k = 0.0748) is too small to fit the formula to the values of level density parameter derived experimentally.

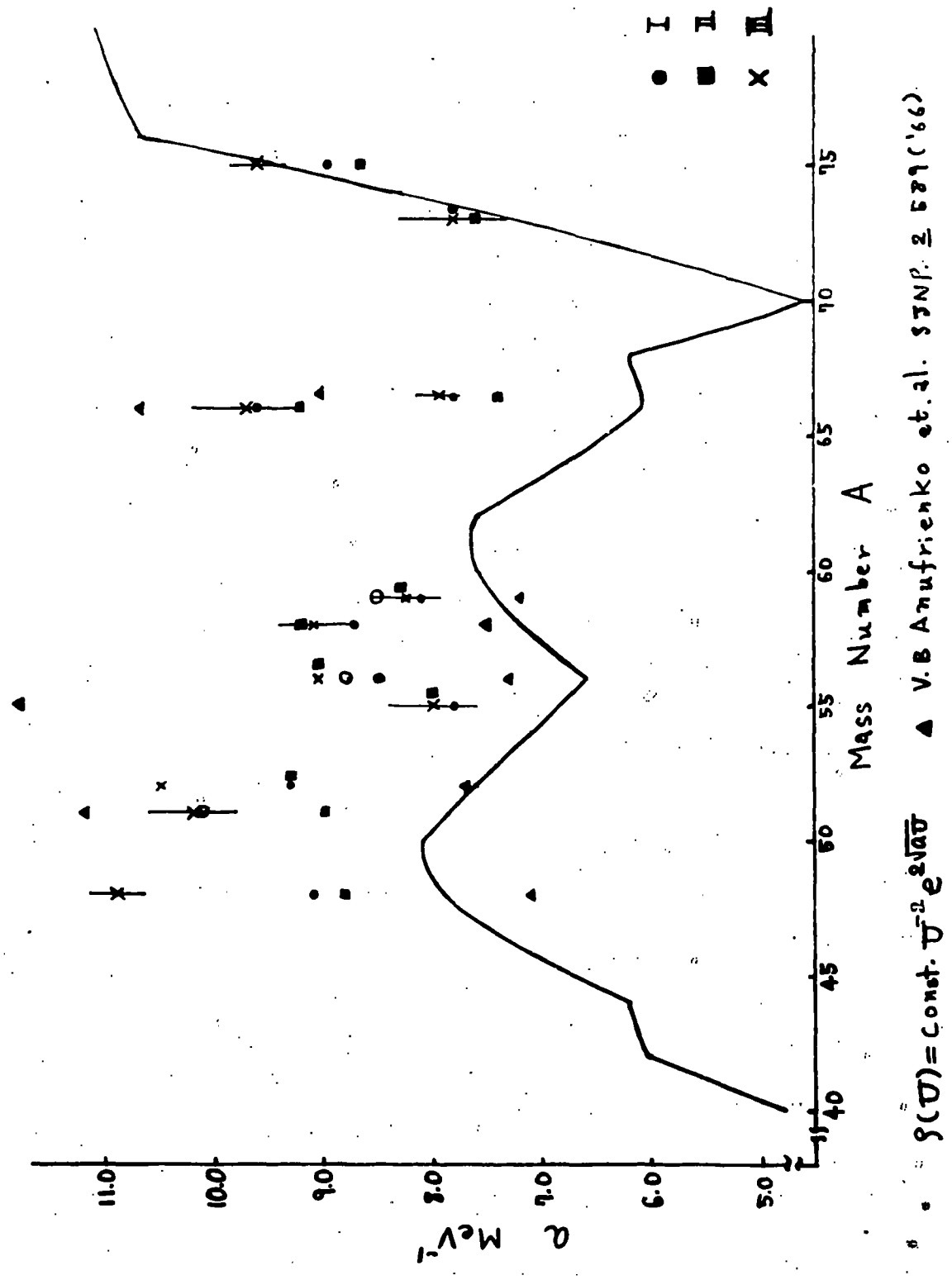

α MeV⁻¹
11.0
10.0
9.0
8.0
7.0
6.0
5.0
40
45
50
55
60
65
70
75
Mass Number A
I
II
III
▲ V.B Anufrienko et.al. SJNP. 2 589('66)
O D.B. Thomson Phys. Rev. 129 1649 (63)
ρ(σ) = const. σ⁻¹ e^{2√aσ}

Fig. 1

IV-4. (n, n') Reaction of S^{32}, Ca^{40} and Co^{59}

A. Katase, M. Sonoda, Y. Wakuta, M. Hyakutake,
H. Tawara and I. Fujita

Further experiments on S^{32}, Ca^{40} and Co^{59} have been completed. In contrast to other nuclei, S^{32} and Ca^{40} show the exceptional feature in the (n, p) reaction that the lower energy protons are anisotropic though the ratio σ (n, np)/σ (n, p) is small. This fact is not consistent with Bodansky's suggestion that the lower energy protons due to the (n, p) reaction are isotropic and those due to the (n, np) reaction are anisotropic.

The present experiment was undertaken to investigate whether this effect is also found in the (n, n') reaction. The measurement on Co^{59} was made for the sake of comparison. Angular and energy distributions were measured both for the continuous and discrete energy regions of inelastically scattered neutrons. Analysis is now in progress.

IV-5. (γ , f) Reactions

Y. Wakuta, A. Katase, M. Sonoda, I. Fujita, M. Hyakutake, K. Iwatani and M. Seki*.

The previous experiments, carried out for U and Th nuclei in the γ -ray energy region of 200-750 MeV, were extended to higher energies up to 1.1 GeV.

The results obtained in the previous experiments, that a resonance corresponding to the (3-3) resonance in π -meson production appeared in the fission excitation function and that the angular distribution of fission fragment changes appreciably at the resonance, have been reconfirmed. Furthermore, a new resonance was found at the γ -ray energy of about 770 MeV, which corresponds to the second resonance in π -meson production. Analysis of the data is still underway.

The fission cross sections were measured for the nuclei of lower mass number; Bi, Pb, Au and Ta and also for U and Th, using solid state nuclear track detector.

Scanning is now in progress.

---

* Present Address: Department of Applied Physics, Hiroshima University

IV-6. Analysis of Ternary Fission

Akira Katase

Trajectory calculation was made for each component of ternary fission, using three-point-charge assumption and two-dimension approximation. From many systematic computations, some relations were deduced between the initial values of the parameters describing the scission state and the final values of the parameters measured experimentally. For example, if D_A and D_F denote the distance of the initial emission point of the third light particle from the light fragment and the distance between two fission fragments respectively, the final kinetic energy E_A of the third particle is approximately given by a quadratic equation of x ($= D_A/D_F$)

$$E_A = A\,(x - x_0)^2 + C,$$

where A, C and x_0 are the constants which depend on the parameters other than x describing the scission state. These relations have been useful to derive the values of the initial parameters from those of the final parameters measured experimentally, without making trajectory calculations. The values of the initial parameters are very important to elucidate the mechanism of fission.

The method of analysis was applied to the long range alpha particle fission of Cf^{252} and found to be quite satisfactory.

The details are to be submitted for publication in Journal of The Physical Society of Japan.

This method will also be applied to the analysis of ternary fission of U^{235} induced by thermal neutrons.

V. Osaka University

V-1. Inelastic Scattering of Thermal Neutrons by Rotating Molecules*

T. Sekiya**, K. Sakamoto**, C. Nishida** and Y. Watari**

In the calculation of scattering laws of thermal and cold neutrons for various moderator molecules the translational and rotational degrees of freedom play an important role. About translational motion there are many authors who tried to take into account the effect of diffusion motion of molecules in liquid. About rotational motion, however, we find a very few theoretical treatments[1) 2)] especially in the case of asymmetric molecules. In such molecules there are usually the other rotational effect such as intra- and inter-molecular rotations. Thus we are now studying the problems along two lines. The first is to treat the problem as exactly as possible about simple rigid model and to find a general feature of scattering law for free rotation of molecules. The second is to make concrete models of molecules about intra- and inter-rotational structures. Last year we succeeded in determining the potential barrier height of intra-molecular rotation of organic moderator molecule —— biphenyl.[3)] This year our efforts are concentrated to determine the intermolecular rotation-barrier-heights for solid phenyl molecules by using NMR and Raman data. From these results we get an interpretation of neutron scattering data reported by several authors.

---

* The work was supported by the Japanese Nuclear Data Committee.

** Department of Nuclear Engineering, Faculty of Engineering

(1) The Calculation of Scattering Law of Asymmetric Top Molecules. (ASTOM code): The calculation method of scattering law developed by Volkin for rigid molecules having a specified angular momentum J is generalized to average over statistical distribution about J. A SUBROUTINE is also added to calculate the coefficients of expansion of asymmetric top wave functions in the series of symmetric top wave functions. The results show a possibility that there are singularities in $S(\alpha, \beta)$ curves originated from the limits of auguments of elliptic functions. We also find a similar tendency in the experimental results obtained by Gläser about water vapor. To ascertain this feature the code is now being improved to include the translational effects. We also find a general principle to add higher quantum corrections by using the following relation for non-commutative variables X, Y:

$$\delta\ (X+Y) = \delta\ (X) + \frac{\delta'(X)}{1\,!}\, G_1(X,\ Y) + \frac{\delta''(X)}{2\,!}\, G_2(X\ ,\ Y) + \ldots,$$

$$G_{n+1}(X,\ Y) = G_n(X,\ Y)Y - X,\ G_n(X,\ Y)\quad ,$$

$$G_o(X,\ Y) = 1.$$

In our problem

$$X = \epsilon + \tau + \frac{\kappa^2}{2\,M} + C\ ,$$

$$Y = A + B\ ,$$

where A, B, C, ϵ , κ are defined in Volkin's paper and τ is Fourier inverse space variable of t of translational matrix element.

(2) The rotational barrier heights of inter-molecular rotations of a benzene molecule are determined by the NMR data[4] of spin-lattice relaxation time T_1 and the rotational frequencies are calculated

by them. The results agree with the Raman spectra measured by Fruhling[5] within the limit of experimental errors and suggest that the low frequency peaks in neutron scattering data obtained by Gläser,[6] Zemlyanov[7], Ross[8] and Tarina[9] correspond to the inter-molecular rotations.

In the table our results evaluated from molecular theory and Andrew's data are compared with Raman spectra in solid benzene and with neutron scattering data in liquid benzene.

Table Level spacings of hexad axis rotation (in 10^{-3}eV)

Solid			Liquid (293°K)		
Our results		Raman spectra by Fruhling (273 ± 2 °K)	Neutron scattering data		
from molecular theory(270°K)	from Andrew's data(90~270°K)		by Zemlyanov	by Gläser	by Ross
7.6	8.2 ± 0.2	8.5 ± 0.5	7.6	≃ 10	7.5

We also calculated the level spacing of diffusion in liquid benzene using the potential barrier height 2.0 kcal/mol determined by the spin echo method.[10] The value is the same order as the peak at 1.8 mev in Zemlyanov's data. So this peak supposedly originates from molecular diffusion. We also find a correspondence between these peaks and Tarina's neutron scattering data in liquid and solid benzene.

References:

1) T. J. Krieger and M. S. Nelkin; Phys. Rev. 106, 290 (1957)

2) H. C. Volkin; Phys. Rev. 113, 866 (1959)

3) T. Sekiya, K. Sakamoto and C. Nishida; Tech. Repts Osaka Univ., 16, 431 (1966)

4) E. R. Andrew and R. G. Eades; Proc. Roy. Soc. London, A, 218 537 (1953)

5) A. Fruhling; Ann. de Phys., 12, 26 (1951)

6) W. Gläser; Nucleonik 7, 64 (1965)

7) M. G. Zemlyanov and H. A. Chernoplekov; Atomnaya Energiya 14, 257 (1963)

8) D. K. Ross, F. P. Szabo and Y. Sanalan; Symposium on Neutron Thermalization and Reactor Spectra SM96/1 (1967)

9) V. Tarina; J. Chem. Phys., 46, 2273 (1967)

10) R. Hauser, G. Maier and F. Noack; Z. Naturforschg. 21a, 1410 (1966)

V-2. Slow Neutron Scattering and Space-Time Correlation Functions

S. Sunakawa*, S. Yamasaki*, and T. Nishigori**

The detail on this work, which was outlined in the previous progress report (EANDC (J) 7 "L"), has been published in Prog. Theor. Phys. 37 (1967), 1051.

* Department of Physics, College of General Education.

** Department of Nuclear Engineering, Faculty of Engineering.

V-3. Theory of Multiple Scattering of Slow Neutron

T. Nishigori*, S. Yamasaki**, and S. Sunakawa**

The cross section formula for the multiple scattering of slow neutron reported in the previous progress report, EANDC (J) 7 "L"[1], is improved so as to satisfy the condition of detailed balance. The scattering operator T can be rearranged in the form

$$T = \sum_{\alpha} T_{\alpha} + \sum_{\alpha} \sum_{\beta \neq \alpha} T_{\alpha} G T_{\beta} + \sum_{\alpha} \sum_{\beta \neq \alpha} \sum_{\gamma \neq \beta} T_{\alpha} G T_{\beta} G T_{\gamma} + \cdots, \qquad (1)$$

where

$$T_{\alpha} = V_{\alpha} + V_{\alpha} G V_{\alpha} + V_{\alpha} G V_{\alpha} G V_{\alpha} + \cdots\cdots . \qquad (2)$$

The scattering operator T_{α} describes the scattering of a neutron by a single atom α in the target system, and G refers to the propagator of the neutron. In the evaluation of the matrix element of (1), two approximations are used. The first is that the propagator G in the single scattering operator (2) is approximated by that of the free neutron, although G in (1) is retained as it is. This approximation is based on the assumption that the single scattering by an atom is affected little by the presence of other atoms and that the many-particle-effect is important for the intermediate stages of a neutron among successive single scatterings by different atoms. In the previous formulation[1], the propagator in (1) was also replaced by the free one, which led to the violation of the condition of detailed balance. On the other hand, the improvement of this approximation corresponds to the inclusion of the correct recoil effect to the intermediate neutron, and to the satisfaction of the requirement of detailed balance.

---

* Department of Nuclear Engineering, Faculty of Engineering.

** Department of Physics, College of General Education.

The second approximation is for the treatment of the off-energy-shell matrix elements like $\langle \mathbf{k}_f | t(\varepsilon_i) | \mathbf{k}_i \rangle$, where the scattering operator $t(\varepsilon_i)$ is produced by extracting out the variables of target atoms from the single scattering operator. For the slow neutrons it is permitted to approximate this matrix element by a scattering length a .

By making use of these two approximations, we reach the following expression for the scattering cross section;

$$\frac{d^2\sigma(i\to f)}{d\Omega_f\, d\varepsilon_f} = \sum_{\substack{m=0\\ n=0}}^{\infty} a^2 \frac{k_f}{k_i} \frac{1}{2\pi\hbar} \int_{-\infty}^{\infty} dt\, e^{i(\varepsilon_f-\varepsilon_i)t/\hbar} \int_{-\infty}^{\infty} dt_1' \cdots dt_m'\, dt_1 \cdots dt_n$$

$$\times \int dx_0'\, dx_1' \cdots dx_m'\, dx_0\, dx_1 \cdots dx_n\, e^{i\mathbf{k}_f(x_0'-x_0)} e^{-i\mathbf{k}_i(x_m'-x_n)} \tag{3}$$

$$\times K_i^{(-)}(x_m'-x_{m-1}', t_m'-t_{m-1}') \cdots K_i^{(-)}(x_1'-x_0, t_1'-0) \cdot K_i^{(+)}(x_0-x_1, 0-t_1) \cdots K_i^{(+)}(x_{n-1}-x_n, t_{n-1}-t_n)$$

$$\times G(x_m', t_m'; x_{m-1}', t_{m-1}'; \cdots; x_0', 0 \,|\, x_0, t; x_1, t+t_1; \cdots; x_n, t+t_n),$$

where the (m+n+2)-particle space-time correlation function G is defind by

$$G(x_m', t_m'; x_{m-1}', t_{m-1}'; \cdots; x_0', 0 \,|\, x_0, t; x_1, t+t_1; \cdots; x_n, t+t_n)$$

$$= \sum_{\alpha'} \cdots \sum_{\nu' \neq \mu'} \sum_{\alpha} \cdots \sum_{\nu \neq \mu} \Big\langle\!\Big\langle \delta(x_m' - \mathbf{r}_{\nu'}(t_m'))\, \delta(x_{m-1}' - \mathbf{r}_{\mu'}(t_{m-1}')) \cdots \delta(x_1' - \mathbf{r}_{\beta'}(t_1')) \tag{4}$$

$$\times\, \delta(x_0' - \mathbf{r}_{\alpha'}(0)) \cdot \delta(x_0 - \mathbf{r}_{\alpha}(t))\, \delta(x_1 - \mathbf{r}_{\beta}(t+t_1)) \cdots \delta(x_n - \mathbf{r}_{\nu}(t+t_n)) \Big\rangle\!\Big\rangle,$$

and the propagation functions $K_i^{(\pm)}(\mathbf{r}, t)$ are given by

$$K_i^{(\pm)}(\mathbf{r}, t) = \left(\pm \frac{i}{\hbar}\right) \theta_{\pm}(t)\, K_i(\mathbf{r}, t), \tag{5}$$

and

$$K_i(\mathbf{r},t) = \frac{2\pi\hbar^2}{m} a \int \frac{dk}{(2\pi)^3} e^{i(\varepsilon_i - \varepsilon_k)t/\hbar} e^{i\mathbf{k}\mathbf{r}} .$$

The functions $\theta_\pm(t)$ in (5) are defined by

$$\theta_+(t) = \begin{cases} e^{-\epsilon|t|/\hbar} & \text{for } t \geqslant 0, \\ 0 & \text{for } t < 0, \end{cases} \quad \text{and} \quad \theta_-(t) = \begin{cases} 0 & \text{for } t > 0, \\ e^{-\epsilon|t|/\hbar} & \text{for } t \leqslant 0. \end{cases}$$

The time-dependence of $K_i^{(\pm)}(\mathbf{r},t)$ is caused by the recoil effect of the target atom to the neutron.

The leading term ($n = m = 0$) in (3) is the contribution from the single scattering and coincides with the Van Hove formula. The higher terms are that from the multiple scattering. The expression (3) satisfies the condition of detailed balance

$$\varepsilon_i e^{-\varepsilon_i/kT} \frac{d^2\sigma(i\to f)}{d\Omega_f\, d\varepsilon_f} = \varepsilon_f e^{-\varepsilon_f/kT} \frac{d^2\sigma(f\to i)}{d\Omega_i\, d\varepsilon_i} .$$

A well-defined classical approximation for the multiple scattering process is also studied along the line of reasoning of our preceding report in this article.

The detail of the present note will be published in Prog. Theor. Phys. 39 (1968).

Reference : 1) S. Sunakawa, Y. Fukui, and T. Nishigori, Prog. Theor. Phys. 35 (1966), 228.

VI. Radiation Center of Osaka Prefecture

VI-1. Double Scattering of Neutron in a Stilbene Scintillator

J. Furuta, M. Fujishiro and T. Azuma

The efficiency of the neutron detection of the stilbene scintillator has been investigated. The efficiency was calculated first taking only the single scattering into account, and second the effect of the double scattering process, in which an incident neutron collided with carbon nucleus and then with hydrogen in the scintillator. Experimental check on the efficiency for 3.0- and 14.1-MeV neutrons was made by using four cylindrical scintillators of 2.5-cm diameter and respective thicknesses of 0.3, 0.5, 1.0 and 1.5 cm. For 3.0-MeV neutrons and the scintillator thicker than 1.0 cm, the discrepancy between the measured efficiency and the calculated one based on the single scattering assumption was apparent. For 14.1-MeV neutrons, however, the above discrepancy was within an experimental error of ±6% even with the thickest scintillator. These results were in agreement with the expectation, derived from the calculation, that for scintillators of usual thickness, the double scattering effect is negligible against neutrons of energy above 10 MeV, but it can no longer be negligible for neutrons of energy below a few MeV.

VII. Rikkyo (St. Paul's) University
Department of Physics

VII-1. Measurements of the Cross Sections of the D(n,n)d and D(n,p)2n Reactions at 14.1 MeV

S. Shirato and N. Koori

Recoil deuterons and breakup protons from deuterons bombarded with 14.1 MeV neutrons have been measured with a counter-telescope consisting of tandem proportional counters followed by a lithium-drifted silicon detector*. Deuterated paraffin of 8.3 mg/cm^2 thick and deuterated polyethylene of 5.1 mg/cm^2 thick were used in this experiment.

The differential cross section of the n-d elastic scattering in the laboratory system has been determined to be 488 ± 25 mb/sterad at the angle between the telescope axis and the incident neutron axis θ_0 of 0° (i.e., the mean angle $\bar{\theta}$ of 3.9° ± 2.0°). The result of the measured angular distribution of the recoil deuterons was analyzed, as shown in Fig. 1 where the other experimental data as well as the theoretical curves of Christian-Gammel and Aaron-Amado-Yam were given for comparison.

The result of the energy spectrum of the breakup protons measured at θ_0 of 0° has presented a pronounced n-n enhancement peak at the high energy side of the spectrum. Fig. 2 shows the high energy part of the measured spectrum (the absolute differential cross section), with which the smeared theoretical results of Watson and Aaron-Amado were compared.

* S. Shirato and N. Koori: Nucl. Instr. Meth. (1967, in press).

The present result was not inconsistent with the experimental data of Ilakovac et al. and Voitovetskii et al. It is noted that the experimental value of the differential cross section of the D(n,p)2n reaction was considerably different from the predictions based on simple theories, while a more precise theory of Aaron-Amado seemed to present better agreement although it would give somewhat smaller values of the cross sections not only for the breakup reaction but also for the elastic scattering.

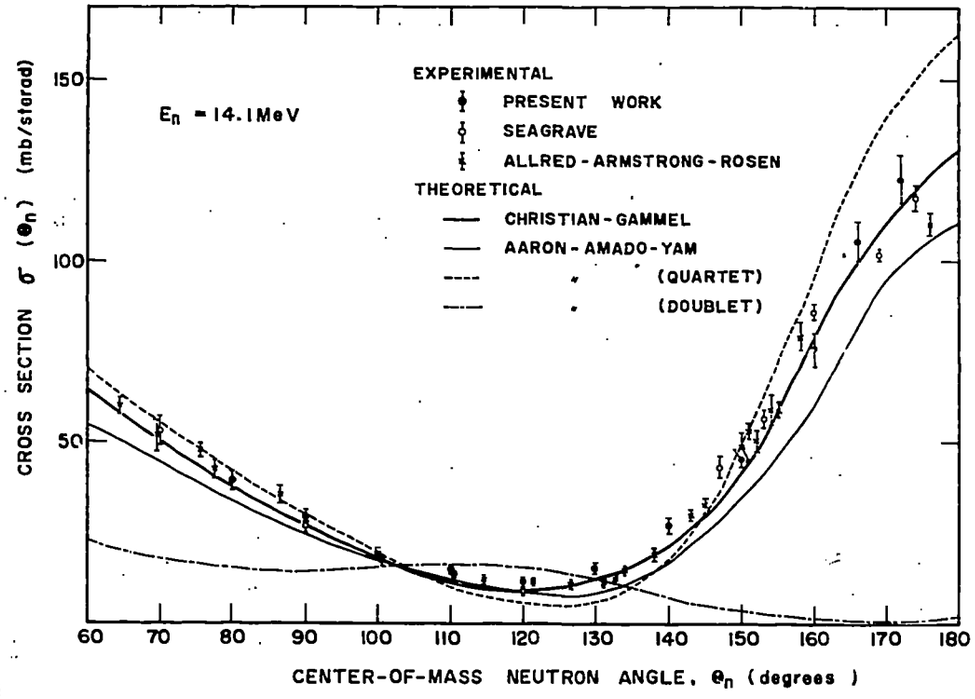


Fig. 1. Angular distribution of the n-d elastic scattering in the center-of-mass system.

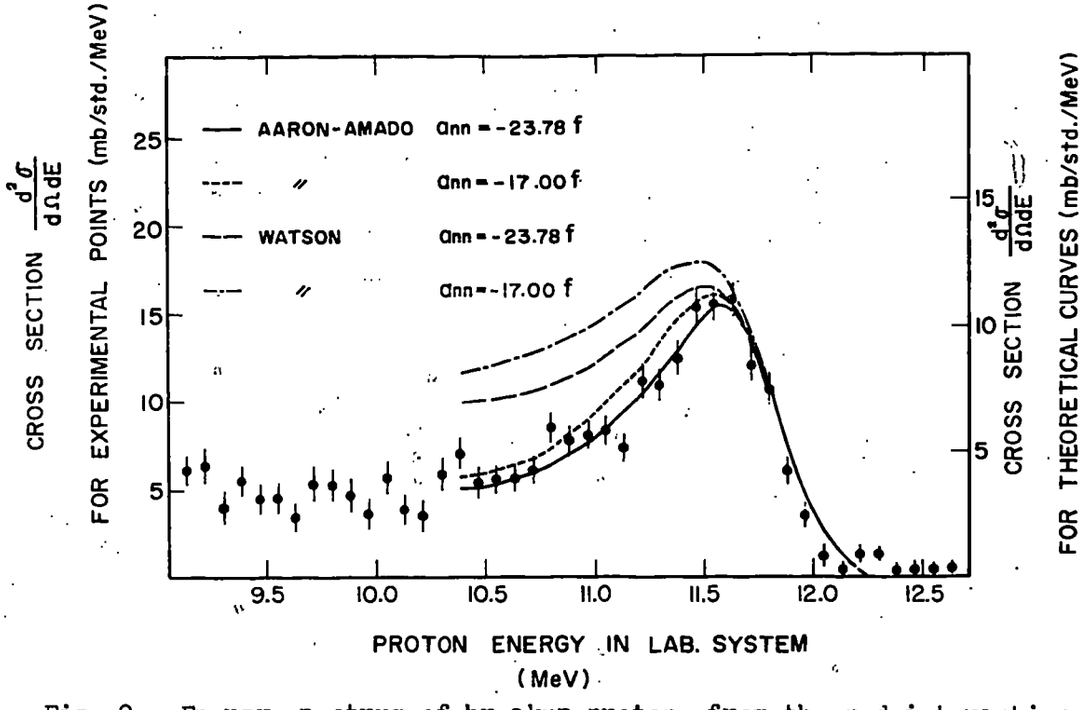


Fig. 2. Energy spectrum of breakup protons from the n-d interaction in the laboratory system.

VIII. Tohoku University

VIII-1. Energy Spectra of Photoneutrons from Al^{27}, Si^{28}, P^{31}, Ta^{181} and Bi^{209}

N. Mutsuro, N. Kawamura, T. Osawa, H. Tsubota, T. Fuketa*, Y. Kawarasaki*, Y. Nakajima*, T. Ishizuka**

The fast photoneutron energy spectra from the (γ ,n)-reactions of Al^{27}, Si^{28}, P^{31}, Ta^{181} and Bi^{209} were measured with the JAERI 20-MeV electron linear accelerator and the nanosecond time-of-flight system.

The neutron energy resolution of 40 KeV at 2 MeV and of 500 KeV at 10 MeV were obtained.

The report of this work will shortly be completed and submitted to the Journal of Physical Society of Japan.

---

* Japan Atomic Energy Research Institute, Tokai.

** Saitama University, Urawa, Japan

IX. Tokyo Institute of Technology
Research Laboratory of Nuclear Reactor

IX-1. $^{12}C(n,\alpha)^{9}Be$ Reaction Induced by 14-MeV Neutrons

H. Kitazawa, Y. Kanda and N. Yamamuro

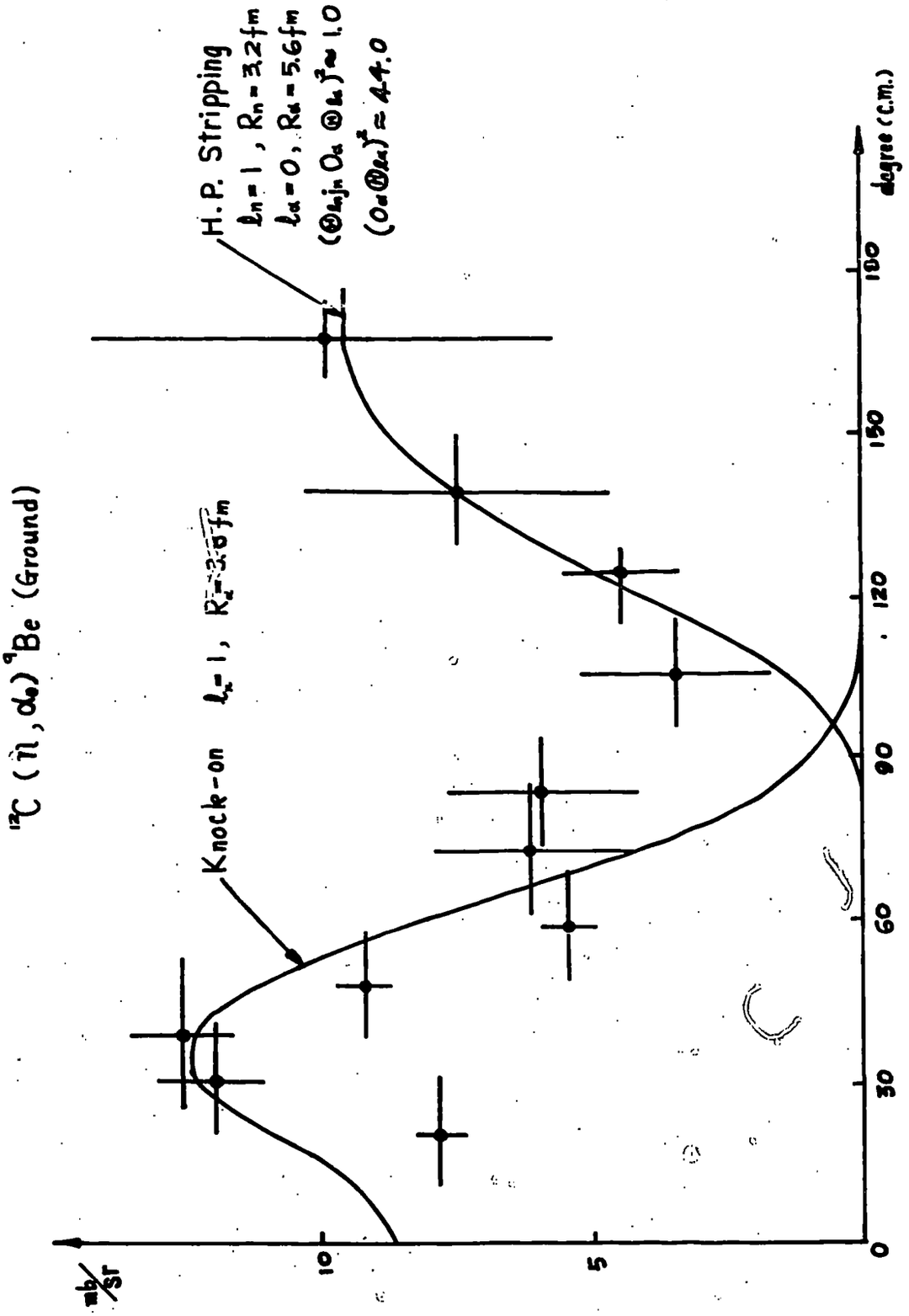
The $^{12}C(n,\alpha)^{9}Be$ reaction leading to the ground state of ^{9}Be has been investigated by bombarding a thin polyethylene film with 14-MeV neutrons. The alpha-particles from the target were detected with a CsI(Tl) scintillation counter. The particle identification was made by the pulse-shape discrimination method. The angular distribution of the emitted alpha-particles exhibited a feature of direct process, having two peaks at 30° and 180° in the center of mass system. The former was analyzed in terms of knock-on process[1] and the other in terms of the heavy-particle stripping process.[2] The $4\hbar\omega$ oscillation 3s state in the ^{8}Be(ground state)-α-cluster representation, assigned by Wildermuth[3], was adopted for the ground state of ^{12}C. The reduced width of the alpha-particle $(0_{\alpha}\,\theta_{\ell\alpha})^{2}$ was determined for the ground state of ^{12}C. The total cross section for the $^{12}C(n,\alpha)^{9}Be$ reaction leading to the ground state of ^{9}Be was about 74 mb.

References:

1) T. Honda, Genshikaku Kenkyu, 10 (1965) 114

2) T. Honda and H. Ui, Prog. Theor. Phys. 25 (1961) 613

3) K. Wildermuth and Th. Kannellopoulos, Nucl. Phys. 7 (1961) 150


^{12}C (π^-, α_0) ^9Be (Ground)
H.P. Stripping
$l_n = 1$, $R_n = 3.2$ fm
$l_\alpha = 0$, $R_\alpha = 5.6$ fm
$(\Theta_{l_n j_n} O_\alpha \otimes l_\alpha)^2 \approx 1.0$
$(O_\alpha \otimes l_\alpha)^2 \approx 44.0$
Knock-on $l_\alpha = 1$, $R_\alpha = 3.0$ fm
mb/sr
10
5
0
30
60
90
120
150
180
degree (C.M.)

X. University of Tokyo
Institute for Solid State Physics

X-1. Polarization of Neutrons from the $C^{12}(d,n_0)N^{13}$ Reaction below 1.8 MeV Deuterons Energies

K. Katori, A. Uchida, M. Imaizumi and S. Kobayashi

The $C^{12}(d,n_0)N^{13}$ reaction has Q = -0.281 MeV and so is expected to show strong direct interaction effect even at low energies of the bombarding deuterons. As an extension of Meier et al.'s results[1] to the lower bombarding energy, the polarization of neutrons from the reaction has been measured at three deuteron energies between 1.5 and 1.8 MeV. Measurements were performed by using a liquid helium time-of-flight neutron polarimeter[2] with a spin precession solenoid. An attempt has been made to fit both the differential cross section and the polarization by using the same optical parameters in DWBA calculations. In this energy range the differential cross section for the reaction changes rapidly with the bombarding energies. By means of the same analysis that was applied to the 4.02 MeV resonance by Fulbright et al.[3], the direct interaction mode was extracted from least-square fitting of the excitation function measured by Elwyn et al.[4] The extracted direct component of the cross section at E_d = 1.62 MeV is compared with the results of DWBA calculation. Since carbon is a light nucleus, a potential of Woods-Saxon form is assumed. Five typical sets of parameters are shown in the figure and are tabulated below. The differential cross sections are normalized to the

experimental value at the maximum. All sets of parameter give rise to the valley at $\theta_{C.M.} \simeq 20^{o}$. This disagreement suggests that the angular distribution of neutron polarization may be strongly affected by compound nuclear process. The polarization at the forward angle may be to some extent decreased by applying the same analysis done for the cross section.

References:

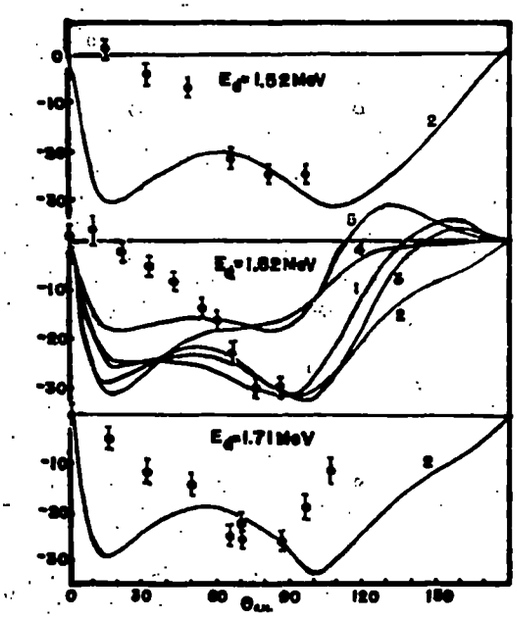
1) M. M. Meier et al.: P. R. 150 (1966) 821

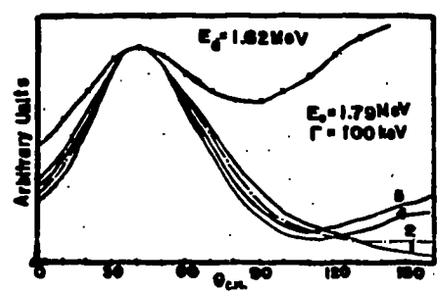
2) K. Katori et al.: Tech. Rep. of ISSP (1967)

3) H. W. Fulbright et al.: N. P. A94 (1967) 214

4) A. Elwyn et al.: P.R. 116 (1959) 1490

5) L. Rosen: Ann. of Phys. 34 (1965) 96





No.	V_d (MeV)	W_d (MeV)	V_d^{so} (MeV)	V_n (MeV)	W_n (MeV)	V_n^{so} (MeV)
1	122	14	0	43.0	5.75	5.5[5]
2	122	14	0	43.5	9.6	7.2
3	122	14	0	43.5	9.6	0
4	122	14	0	50.0	9.6	7.2
5	122	14	6	43.5	9.6	7.2

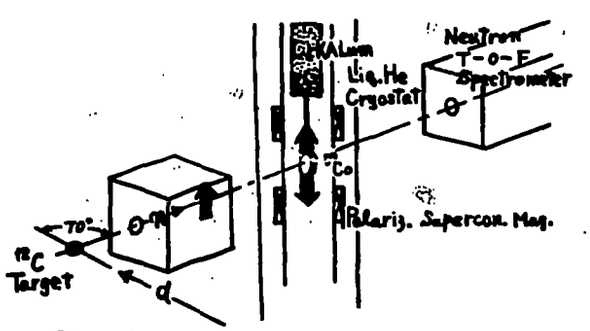
X-2. The Spin-Spin Interaction of 1.19 MeV Polarized Neutrons with Polarized ^{59}Co Nuclei*

S. Kobayashi, K. Nagamine, M. Imaizumi, A. Uchida and K. Katori

Recently there have been a number of investigations for the spin-spin interaction in nuclear reactions, and in the experiments with polarized ^{165}Ho nuclei[1)-3)] such an interaction has been sought. In the present experiment a high degree of nuclear polarization of ^{59}Co ($P_I \simeq 0.30$) was attained by using a polycrystalline metal of the $Co_{0.90}$-$Fe_{0.10}$ alloy (1.5 cm diameter and 0.15 cm thickness) at a temperature of 0.03°K and an external magnetic field of 2 kOe. The chrome alum heat sink of 200 gr was adiabatically demagnetized, and large thermal contact area (2000 cm^2) between the salt and the target sample was established using silver wires. It took 2 or 3 hours for the whole system to be warmed up to 0.05°K. The degree of polarization was estimated using the hfs coupling constant and the temperature of the sample obtained from both γ-ray anisotropy from ^{60}Co embedded in the target and magnetic susceptibility of the heat sink. The $^{12}C(d,n_0)$ reaction was used at a laboratory angle $\theta = 70°$ providing a source of 1.19 ± 0.06 MeV neutrons with a polarization of -0.37 ± 0.03. Short time interval measurements were repeated in the sequences $T^{(o)}$, $T^{(p)}$, $T^{(o)}$, $T^{(a)}$, $T^{(o)}$, ... where $T^{(o)}$, $T^{(p)}$ and $T^{(a)}$ mean the transmitted intensity of neutrons with the target polarization at random, parallel and antiparallel to that of neutron, respectively. Each of the $T^{(p)}$

* Work supported in part by the Nishina Memorial Foundation.

and $T^{(a)}$ values was divided by the average value $\overline{T}^{(o)}$ of the two adjacent $T^{(o)}$ values and the degree of target polarization. Thus $T^{(p)}/\overline{T}^{(o)}\cdot P_I - T^{(a)}/\overline{T}^{(o)}\cdot P_I = -0.0084 \pm 0.0190$ was obtained. If σ_{ss} is defined by $(\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow})/2P_I\cdot P_S$, $\sigma_{ss} = 0.98 \pm 2.20$b was obtained. The instrumental asymmetry was checked by performing another similar measurement, in which the ^{59}Co target was cooled to 4.2 K. $T^{(p)}/\overline{T}^{(o)} - T^{(a)}/\overline{T}^{(o)} = -0.0001 \pm 0.0048$ was obtained. In order to estimate the magnitude of the spin-spin interaction, the D.W.B.A. formalism[1),4)] was applied to σ_{ss}, assuming $-\alpha f(r) I.S$ as the form of the spin-spin interaction. The main optical potential parameter was chosen following Perey's systematics and f(r) was taken as the real part of the central potential, then the acceptable limits on the strength α are -6.5 MeV $\leq \alpha \leq 2.5$ MeV. But the result is still insufficient in statistics, so more precise measurements with larger sample are in progress.



Schematic experimental arrangement

References

1) S. Kobayashi et al.: J. Phys. Soc. Japan 22 (1967) 368.

2) R. Wagner et al.: Phys. Rev. 139 (1965) B29

3) T. R. Fisher et al.: Phys. Rev. Letters 17 (1966) 36

4) K. T. R. Davies and G. R. Satchler: Nuclear Phys. 53 (1964) 1