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PROGRESS REPORT

(January to October, 1968 inclusive)

November 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

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NOTICE

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I. Japan Atomic Energy Research Institute

A. Neutron Experiments - Reactor

I-A-1. The Total Cross Sections of Some Rare-Earth Elements for 2200 m/sec Neutrons

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

The transmissions of enriched Sm-149, Eu-151, Gd-155, Gd-157, and Dy-164 have been measured for 2200 m/sec neutrons using the JAERI neutron crystal spectrometer and velocity selector.

The velocity selector was used as a filter to remove the higher-order reflected neutrons from the single crystal LiF(200) of the spectrometer. The samples in a form of DNO_3-D_2O solution were sealed into 2 x 5 x 1 cm^3 quartz cells.

The values of the neutron total cross sections for 2200 m/sec neutrons which are summarized in the following table might still be liable to a slight correction due to isotopic composition which are being examined.

Nuclide	Enrichment %	σ_T(2200 m/sec) barns
Sm-149	97.46	37,500 ± 1,000
Eu-151	92.12	9,230 ± 140
Gd-155	94.3	61,900 ± 600
Gd-157	93.7	248,000 ± 4,000
Dy-164	83.23	2,780 ± 60

I-A-2. The Total Cross Sections of ^{155}Gd and ^{157}Gd for Slow Neutrons

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

The neutron transmissions for highly enriched samples of ^{155}Gd (94.3%) and ^{157}Gd (93.7%) have been measured in the energy range of 8×10^{-4} to ~ 1 eV in order to obtain parameters of low-lying resonances. The experiments were performed with a crystal spectrometer and/or a neutron velocity selector at the JRR-2. LiF(200) and Si(111) crystals were used as neutron monochromator. In the energy range of 0.01 to 0.03 eV, higher-order reflected neutrons were removed with the velocity selector, and in the range above 0.03 eV, observed transmissions were corrected for the order contaminations whose values were estimated from both measurement and calculation. For the measurements in the range below 0.01 eV, only the velocity selector was used. The samples in a form of DNO_3-D_2O solution were sealed into quartz cells.

The analysis of the resonances are now in progress, and the measurements are to be extended to the higher energy.

I-A-3. Nuclear Resonant Scattering of Lead-capture Gamma Rays from ^{66}Zn

N. Shikazono and Y. Kawarasaki

Measurement of nuclear resonant scattering of lead-capture gamma rays from natural zinc was carried out, by using a 20 c.c. Ge(Li) detector and the JAERI 10-MW research reactor, JRR-3.

The 7368-keV gamma rays following thermal-neutron capture in lead were found to be resonantly scattered by Zn-66.[1)]

The effective absorption cross section was measured by means of the self-absorption method, and the temperature dependence of the scattering yield was measured in a temperature range of the scatterer from -196°C to 300°C.

Combining these measurements, analysis is in progress to obtain the following quantities;

1) Natural width of the 7368 keV level of ^{66}Zn: Γ_{Zn},
2) Ground state transition width of the 7368 keV level of ^{66}Zn: Γ^{o}_{Zn},
3) Transition width of Pb gamma-ray emitter: Γ_{Pb} , and
4) Energy difference between the energy of the Pb capture gamma rays and that of the resonant level of ^{66}Zn: δ .

Values of these quantities are tentatively assigned as follows;

$$\Gamma_{Zn} = 0.3 \text{ eV}$$
$$\Gamma_{Zn}^{o} = 0.2 \text{ eV}$$
$$\Gamma_{Pb} = 0.3 \text{ eV}$$
$$\delta = 9 \text{ eV} .$$

Reference:

1) Nucl. Phys. 5 A118 (1968) 117 to be published.

B. Neutron Experiments - Linac

I-B-1. Neutron Resonance of ^{59}Co at 132 eV

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

The parameters of the neutron resonance at 132 eV in ^{59}Co target nucleus were reported in a previous progress report EANDC (J) 1 "L" p. 13, July, 1965. Further transmission measurements have been carried out and a final report for the experiment is to be submitted to the Journal of Nuclear Science and Technology with an abstract as follows:

Neutron transmission measurements on ^{59}Co have been made for the neutron energies 0.8 eV to 3 keV using the JAERI Linac time-of-flight spectrometer. The maximum time resolution was 10 nsec/m. The resonance parameters of 132 eV resonance were derived from the neutron transmission of several sample thicknesses by the thick-thin method, using an area analysis on the basis of the Breit-Wigner single-level formula. The following results were obtained: $E_0 = 132 \pm 0.5$ eV, $\Gamma = 6.0 \pm 0.2$ eV and $\Gamma_n = 5.15 \pm 0.06$ eV and J = 4. The value of the potential scattering length found from the transmission of the thickest sample was R' = 5.3 ± 0.5 fm.

I-B-2. Total Neutron Cross Section Measurements for Re

K. Ideno, T. Asami, Y. Nakajima, M. Okubo, and T. Fuketa

Total neutron cross section measurements have been made for Re in the energy region of 3 to 330 eV using the JAERI LINAC and its 50-m flight path. The thicknesses of the samples used were 6.05×10^{-3} and 8.43×10^{-4} atoms/b. The maximum time resolution was 10 ns/m. More than one hundred levels were resolved. Below 10 eV, the transmission measurements were made at 77°K to investigate the Doppler-broadening in the 4.42 eV resonance. Resonance analyses are in progress.

I-B-3. Neutron Transmission Measurements

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

A sample changer and collimator system for small-sample transmission measurements was installed in the neutron time-of-flight spectrometer[1] at the JAERI Linac. The width of the neutron beam at the sample position can be changed continuously from zero to 100 mm while the height being fixed at 20 mm. Measurements have been made on thallium with this small-sample system.

A simple beam-position detector[2] for the linac electrons was installed in front of the neutron-source target to adjust and monitor the electron-beam position relative to the target. The detector consists of two pairs, horizontal and vertical, of fine metallic thread electrodes and utilizes the ionization between the electrodes. The signal from the beam-position detector is also used as a zero-time signal instead of the signal from the ferrite-ring beam pick-up which has hitherto been used. The ferrite-ring was subject to exchange in a few months because of deterioration of its magnetic permeability by radiation damage[1]; this problem is now eliminated and the S/N ratio of the zero-time signal is also improved.

References:

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

2) T.Fuketa, and H.Takekoshi; to be published in Rev. Sci. Instr. (1968).

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

The measurements of the total neutron cross section of natural lanthanum and natural praseodymium have been continued from the previously reported one[1]. The result for praseodymium is shown in fig. 1.

Analyses of the data are still in progress.

References:

1) K. Nishimura, Y. Yamanouti, and S. Kikuchi, EANDC (J) 8 'L' 10 .

2) D.M. Miller, R.K. Adair, C.K. Bockelman, and S.E. Dargen, Phys. Rev. 88 (1952) 83.

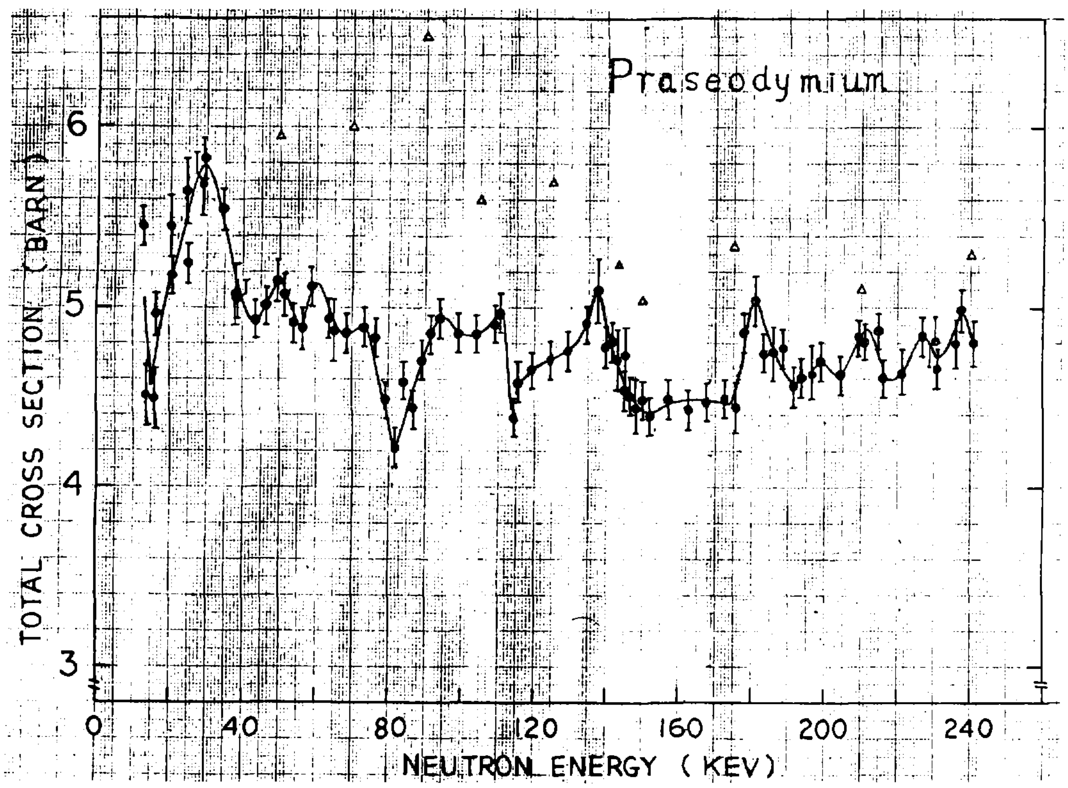

Figure 1. Total neutron cross section of praseodymium.

Closed circles and triangles are of our data and Wisconsin data[2], respectively.

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 elastic and inelastic cross sections measured for zinc and copper, which was reported in EANDC(J) 8 "L" p. 11, are now under analysis by means of the optical-model and statistical-model calculations.

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

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

A full paper of this work, which was outlined in the previous report (EANDC (J) 7 "L" p. 12 and EANDC(J) 8 "L" p. 14), has been submitted to Nuclear Physics.

I-C-4. Elastic and Inelastic Scattering of Fast Neutrons from Iron, Nickel and Tungsten

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

A full paper on this subject, which was outlined in the previous report (ENDC (J) 7 "L" p.10 and EANDC (J) 8 "L" p.17), has been submitted to Nuclear Physics.

I-C-5. Scattering of 4.8 to 8-MeV Neutrons by Aluminium and Silicon

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

The differential cross sections for elastic and inelastic scattering of neutrons by aluminium and silicon have been measured at neutron energies of 4.81, 5.96, 7.02 and 8.03 MeV with a time-of-flight spectrometer. Scattered neutrons were observed at angles from 30° to 148° in 10° steps.

The present work was made with the same intent as that of "Scattering of 4.5 to 8 MeV Neutrons from Sulphur and Zinc"[1),2)], i.e. to study quantitatively the transition from dominance of the compound process to dominance of the direct process for the inelastic scattering leading to low-lying states.

At present, corrections for flux attenuation and multiple scattering in the sample, and optical-model and statistical-model analyses for the differential cross sections are in progress. We can see, however, even from the preliminary results for the inelastic scattering leading to the first excited state in silicon-28 (fig. 1) that the compound process may be predominant in the present energy range. This is a remarkable contrast to the inelastic scattering for the first excited state in sulphur-32[2)], which is mainly caused by the direct process in the energy range higher than 5.9 MeV.

References:

1) S. Tanaka, K. Tsukada, M. Maruyama and Y. Tomita, EANDC(J) 7 "L" (1967) p. 12.

2) S. Tanaka, K. Tsukada, M. Maruyama and Y. Tomita, EANDC(J) 8 "L" (1968) p. 14.

3) G. A. Petitt et al., Nucl. Phys. 79 (1966) 231.

4) K. Tsukada et al., Physics of Fast and Intermediate Reactors (IAEA, Vienna, 1962) p. 75.

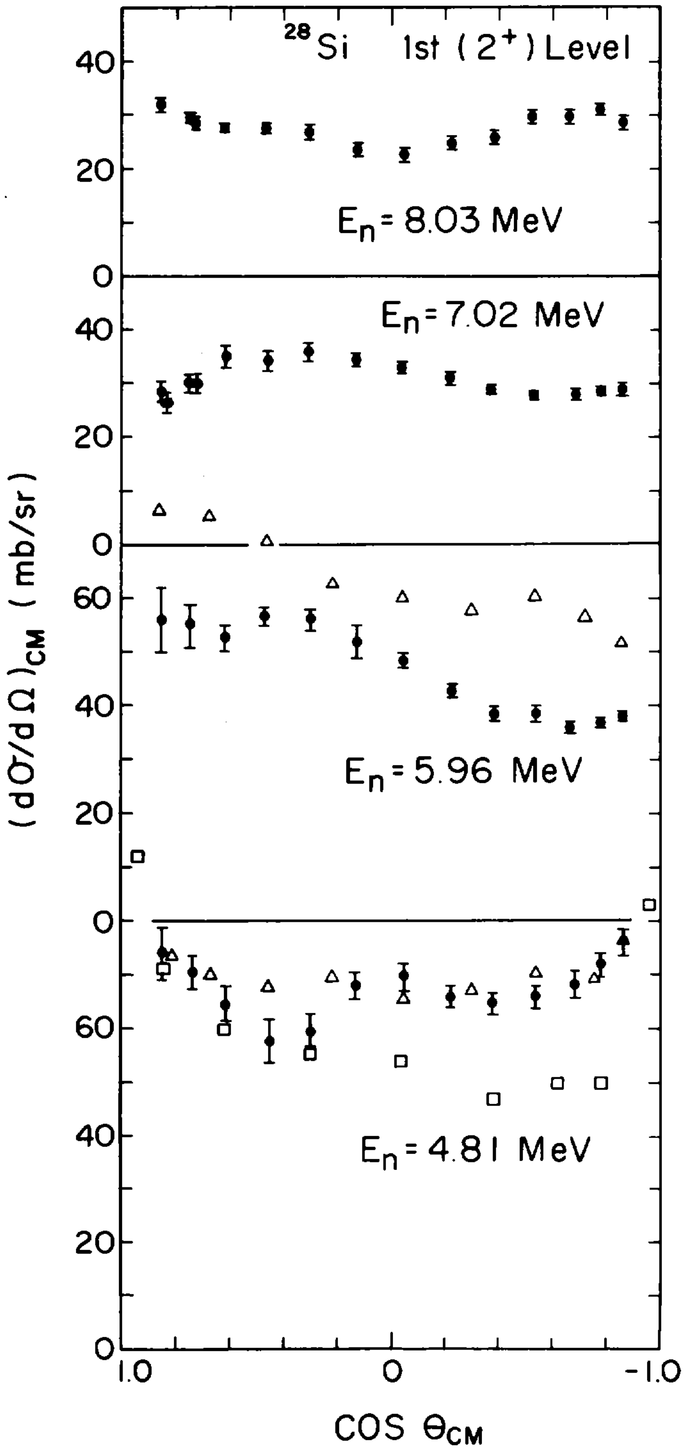

Fig. 1. Differential cross sections for inelastic scattering leading to the first excited state in ^{28}Si. Corrections for flux attenuation and multiple scattering in the sample are not yet made. Triangles are data of Petitt et al.[3] and squares data of present authors[4] reported previously.

I-C-6. A Computer Code for the Calculation of Neutron Elastic and Inelastic Scattering Cross Sections by Means of the Optical Model and the Moldauer Theory

Y. Tomita

A computer code STAX2 has been written for the analysis of the neutron elastic and inelastic scattering cross sections in FORTRAN-IV. By using this code the optical potential parameters which reproduce the experimental total cross section, elastic scattering cross section and inelastic scattering cross section leading to the first excited state can be automatically searched for. In the calculation of the compound process the Moldauer theory[1)] is used, and the Hauser-Feshbach theory is included as a special case. The resonance interference contribution is taken into account with explicit dependence of the parameter Q_c on the partial strength function $2\pi\langle\Gamma_c/D\rangle$ or with the value of Q_c which is rather arbitrarily assumed as in the conventional treatment hitherto used.

Reference:

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

I-C-7. Energy Dependence of the Nuclear Level Density

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

The energy dependence of the nuclear level density of Ni, Sr, Y, Sn and Ho in the energy range of 2 to 7.5 MeV was measured by using the inelastic neutron scattering. To examine their functional forms, the χ^2-fitting of two types of the level density forms, i.e. $E^{-2}\exp[2(aE)^{\frac{1}{2}}]$ and $\exp[E/T]$, was tried. A summary of the experimental results is shown in table 1 together with those results for seventeen elements from Cu to Bi reported previously.[1] The observed level densities for the nuclei between closed shells are well described with the Fermi gas form, $E^{-2}\exp[2(aE)^{\frac{1}{2}}]$, while those for the nuclei at the shell closure (N=82) are of the constant temperature form, $\exp[E/T]$. Complex level density forms different from either forms are observed near the shell closure (Z=50), and Concave shapes, which increases with energy more rapidly than $\exp[E/T]$, near the doubly closed shells (Z=28 N=28, Z=40 N=50, Z=82 N=126).

Countings of the nuclear levels based on the single particle levels of the shell model were performed by the use of an IBM 7044 computer and the following results were obtained.

(1) The appearance of the level density forms different from the Fermi gas form is explained with the existence of large energy gaps between the major shells in the single particle levels.

(2) There is a fairly definite correlation between the level density form and the degree of shell filling in the nuclear ground state.

This is a continuation of the previous report (EANDC (J) 8 "L" p.25). A part of this work was reported at the International Conference on Nuclear Structure (Tokyo, 1967) and the full paper will be submitted to Nuclear Physics.

Reference:

1) M. Maruyama, K. Tsukada, S. Tanaka, Y. Tomita and Y. Yamanouchi EANDC (J) 8 "L" p.25.

Table 1 Summary of the experimental results

	Element	Number of proton	Number of neutron	Functional form	T (MeV)	a (MeV^{-1})
N=28→	Co	27	32	exp		12.3-13.9
Z=28→	Ni	28	30*,32	complex(concave)		
	Cu	29	34,36	$E^{-2}\exp[2(aE)^{1/2}]$		14.1-15.4
	As	33	42	$E^{-2}\exp[2(aE)^{1/2}]$		17.2-19.2
	Br	35	44,46	$E^{-2}\exp[2(aE)^{1/2}]$		17.0-20.2
N=50→	Sr	38	48,49,50*	complex(concave)		
N=50→	Y	39	50	$E^{-2}\exp[2(aE)^{1/2}]$		(13.5-21.7)
				or $\exp[E/T]$	(0.63-0.84)	
	Nb	41	52	$E^{-2}\exp[2(aE)^{1/2}]$		(14.6-22.7)
				or $\exp[E/T]$	(0.60-0.78)	
	Ag	47	60,62	$E^{-2}\exp[2(aE)^{1/2}]$		19.3-23.7
	In	49	66	complex		
Z=50→	Sn	50	66,68,70	complex		
	Sb	51	70,72	complex		
	I	53	74	$E^{-2}\exp[2(aE)^{1/2}]$		22.2-24.8
	Cs	55	78	complex		
N=82→	Ba	56	79,80,81,82*	$\exp[E/T]$	0.55-0.61	
N=82→	La	57	82	$\exp[E/T]$	0.64-0.73	
N=82→	Ce	58	82*,84	$\exp[E/T]$	0.49-0.56	
N=82→	Pr	59	82	$\exp[E/T]$	0.48-0.55	
	Ho	67	98	$E^{-2}\exp[2(aE)^{1/2}]$		21.0-26.1
	Ta	73	108	$E^{-2}\exp[2(aE)^{1/2}]$		21.5-26.7
	Au	79	118	$E^{-2}\exp[2(aE)^{1/2}]$		19.7-26.1
Z=82→ N=126→	Bi	83	126	complex(concave)		

Asterisk (*) denotes the main isotope.
Spreads of the values of T or a for the same element are due to different choices of the inverse compound formation cross sections.

I-C-8. Excited Levels of ^{133}Cs by Neutron Inelastic Scattering

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

Excitation cross sections of the $^{133}Cs(n,n'\gamma)$ reaction have been measured in the energy range 0.5 ~ 1.0 MeV with a Ge(Li) detector associated with a pulsed-beam time-of-flight system. The electronic system used was the same, except slight modifications, as that shown in fig. 1 in the previous report.[1)]

Since the excited levels of ^{133}Cs above 0.5 MeV are not known yet, a purpose of the present investigation is to examine energies of those levels by observing the threshold neutron energies necessary for the production of specific gamma rays.

Analysis of the data is now in progress.

Reference:

1) S. Kikuchi, Y. Yamanouti, M. Maruyama, and K. Nishimura, EANDC (J) 8 'L' 21.

I-C-9. 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

A full paper on this subject was published: Nuclear Physics A115 (1968) 17 - 32.

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D. Others

I-D-1. Decay Properties of the Fission Product ^{134}I

H. Umezawa, T. Suzuki, Y. Tsukihashi, and E. Takekoshi

A fine structure of the mass yield curve of the thermal neutron fission of ^{235}U is indicated at mass 134 and interpreted as the nuclear shell effect. It is interesting to study the independent fission yields of the nuclides of the mass chain. The decay properties of ^{134}I [1] and ^{134}Te [2], however, have not yet been known in detail enough to determine the fission yields by a radiochemical method. On the other hand, the level structure in ^{134}Xe from the decay of ^{134}I is of great interest among even-even Xe isotopes, $^{126-136}Xe$, which exhibit "vibrational" character, since ^{134}Xe is in near neighbor of the closed shell nuclide, ^{136}Xe.

In the present work, the decay properties of 52-minute ^{134}I have been investigated by the NaI(Tl) and Ge(Li) detector techniques; singles spectrum with Ge(Li) detector of true coaxial type, $\gamma-\gamma$ coincidences with NaI(Tl) and Ge(Li) detector, sum spectrum with well type NaI(Tl) detector, and anisotropy measurement for some cascade transitions with NaI(Tl) and Ge(Li) detector.

The ^{134}I source for this study was prepared by irradiating a uranyl acetate sample in the JRR-1 reactor. The fission product tellurium was separated from the sample by the spontaneous deposition technique with a copper foil.[3] Iodine-134 was separated from the tellurium by the solvent extraction method with carbon tetrachloride, after completing the growth from the parent nuclide, ^{134}Te.

Energies (and intesities) of the gamma rays determined in the experiments are 136(5.0), 236(weak), 405(8.4), 433(4.2), 488(weak), 514(4.1), 529(1.3), 541(9.8), 596(11.6), 622(10.3), 633(3.1), 644(weak), 677(7.7), 733(weak), 768(3.9), 848(100.0), 859(6.1), 873(weak), 885(69.1), 905(weak), 923(weak), 948(6.4), 976(5.4), 1041(3.2), 1073(17.1), 1103(2.3), 1138(11.8), 1458(4.3), 1615(4.7), 1743(3.0), and 1810(6.2) KeV. Decay scheme is being composed.

References:

1) N. R. Johnson et al., Phys. Rev., 122, 1546 (1961).

2) J. M. Ferguson et al., J. Inorg. Nucl. Chem., 24, 1(1962).

3) H. Umezawa and H. Okashita, French patent 1496047(1966).

I-D-2. Thermal Neutron Scattering from Light Water Ice

Y. Nakahara

The phonon spectrum of light water ice at $0^{\circ}C$ was computed by means of the root sampling method for a sampling of 1,050 points in an irreducible sampling region of the first Brillouin zone[1]. The force model we used in our computation is a non-central force model formulated by Forslind[2]. We assume that point molecules with mass of H_2O molecule are arranged at positions of oxygen atoms. The phonon spectrum obtained by the root sampling method, therefore, does not contain those modes corresponding to molecular rotations and vibrations.

The characteristic frequencies for molecular rotations and vibrations of H_2O molecule in ice are known from the infrared and Raman spectroscopic investigations[3]:

$$\text{rotation} \qquad \omega_r = 0.0756 \text{ eV},$$

$$\text{vibrations} \qquad \begin{cases} \omega_v^1 = 0.2033 \text{ eV}, \\ \omega_v^2 = 0.3896 \text{ eV}, \\ \omega_v^3 = 0.4030 \text{ eV}. \end{cases}$$

Although intensities of these discrete modes may be somewhat different from the values for liquid water, we used the same values as those obtained by Nelkin for liquid water[4].

The full frequency distribution for ice is given by

$$f(\omega) = f_1(\omega) + f_2(\omega),$$

where $f_1(\omega)$ = the continuous spectrum of lattice vibrations,

$f_2(\omega)$ = the discrete spectrum of molecular rotations and vibrations.

We used the GASKET code written by Koppel et. al. to evaluate scattering law for light water ice[5]. The total scattering law is obtained by convolving the scattering laws calculated from the continuous and discrete spectra. The double differential scattering cross section and the scattering law for thermal neutron scattering from light water ice at 268°K have been measured extensively by Harling.[6] Our calculation resulted in good agreement with the neutron scattering measurements.[1]

The details of the present work will be published in the Journal of Nuclear Science and Technology (Tokyo).

References:

1) Y. Nakahara, "Phonon Spectrum and Thermal Neutron Scattering in Light Water Ice", JAERI-memo 3108 (unpublished) (1968), to be published in J. Nucl. Sci. Tech.

2) E. Forslind, Proc. No. 21, Swedish Cement and Concrete Res. Inst. at Royal Inst. of Technology, Stockholm (1954).

3) S. Seki, Bussei Butsurigaku Koza (Series in Solid State Physics, written in Japanese), Vol. 11, Chapt. 6, ed. K. Ariyama et. al., Kyoritsu Pub. Co. Ltd., Tokyo (1954).

4) M. Nelkin, Phys. Rev., 119 (1960) 741.

5) J.U. Koppel, J.R. Triplett and Y.D. Naliboff, "GASKET: A Unified Code for Thermal Neutron Scattering", GA-7417 (Rev.) (1967).

6) O.K. Harling, "Compilation of Doubly Differential Cross Section and the Scattering Law for H_2O and D_2O at 299°K and H_2O at 268°K", BNWL-436 (1967).

E. Japanese Nuclear Data Committee

I-E-1. Evaluation of Carbon Total Neutron Cross Section up to 2 MeV

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

Evaluation of carbon total neutron cross section $\sigma_{nT}(E)$ up to 2 MeV is carried out by analysing the numerical data in SCISRS and some other reports. The numerical data which are informed to be preliminary or obsolete ones by authors, are not adopted in the present work. All the numerical data adopted are equally handled and no special weight is given to any of the data. An empirical formula for the $\sigma_{nT}(E)$ has been obtained by the least-squares method and is expressed as follows:

$$\sigma_{nT}(E) = 4.729 - 2.968E + 0.551E^2 + 0.413E^3 - 0.166E^4,$$

where $\sigma_{nT}(E)$ is in barns and E in MeV.

A brief report of this work will soon be submitted for publication in "Newsletter" of the ENEA Neutron Data Compilation Centre.

I-E-2. On the Evaluation of ^{239}Pu Data in the keV and Resolved Resonance Region

C. Durston*, and S. Katsuragi

This work, which was made at the U.K. Atomic Energy Establishment, Winfrith when S. Katsuragi was there on attachment from JAERI, was published in JAERI-1162 with the following summary:

*FRPD, A.E.E., Winfrith, Dorchester, Dorset, England

The new evaluation for ^{239}Pu cross-sections in the keV region is described. The present evaluation gives a better interpretation to both the α-value and fission cross-section. This evaluation confirms the applicability of the channel theory of fission. In the resolved resonance regions a fit to the cross-section is obtained suitable for use with the GENEX code. For users' convenience the resonance parameters are listed.

I-E-3. Bibliography for Thermal Neutron Scattering

The Thermalization Group, JNDC

The present note is the summary of JAERI Report 4043 which was published in October 1967.

The Thermalization Group of the Japanese Nuclear Data Committee has collected literatures on measurements and calculations of thermal neutron scattering cross sections and basic studies of lattice dynamics, liquid and molecular dynamics. These references are needed for the data evaluation which is one of the main activities of the Committee. This report is a list of the references classified by kinds of material, which are collected by group members up to now.

II. Kyushu University
Department of Nuclear Engineering

II-1. (n, p) and (n, np) Reactions Induced by 14 MeV Neutrons

Analysis of the data for ^{40}Ca discussed in the previous reports has now been published in Nuclear Physics A111 (1968) 184.

Similar analysis for ^{64}Zn and ^{66}Zn have been completed and a full report has been published in Journal of the Physical Society of Japan 25 (1968) 964.

II-2. (n, n') Reactions in Medium-Weight Nuclei

No new progress has been made after the report of 1967, because two research workers who engaged in this study moved out from our department.

II-3. (n, n) and (n, n') Reactions of ^{32}S, ^{40}Ca and ^{59}Co

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

No new progress has been made. A new code for corrections such as MAGGIE is now under study.

II-4. (n, n) and (n, n') Reactions of ^{6}Li and ^{7}Li Induced by 14 MeV Neutrons

M. Hyakutake, M. Sonoda, A. Katase, Y. Wakuta,
H. Tawara, M. Chijiya and H. Hasuyama

Elastic and inelastic scattering cross sections of 14.1 MeV neutrons have been measured for ^{6}Li and ^{7}Li by associated-particle time-of-flight technique at laboratory angles between 20^o and 160^o. Over-all time resolution (FWHM) was about 2.0 nsec at a bias corresponding to 2.5 MeV neutron. Neutrons inelastically scattered from 2.18 MeV state of ^{6}Li and 4.63 MeV state of ^{7}Li were well resolved from elastically scattered neutrons. However, 0.478 MeV state ^{7}Li was not resolved from the ground state.

The differential elastic and inelastic scattering cross sections are shown in Fig. 1 through 4 in comparison with those found by other investigators.[1-3] The errors indicated in our data are those due to statistical fluctuation and uncertainty of neutron detector efficiency.

Corrections for multiple scattering, flux attenuation and angular resolution are now in progress. Analyses of the data are to be carried out by optical model and DWBA method.

References:

1) C. Wong, J.D. Anderson and J.W. McClure: Nuclear Physics 33 (1962) 680.

2) A.H. Armstrong, J. Gammel, L. Rosen and G.M. Frye, Jr.: Nuclear Physics 52 (1964) 505 .

3) F. Merchez, N.V. Sen, V. Regis and R. Bouchez: Comptes Rendus 260 (1965) 3922.

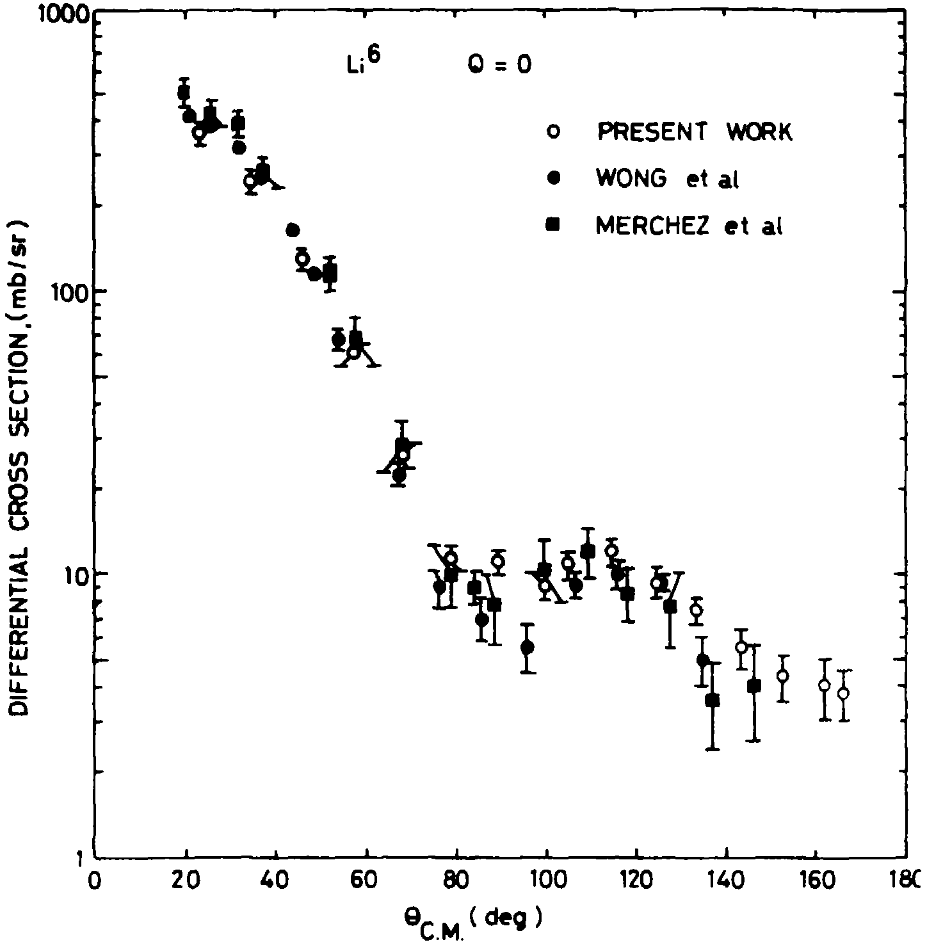
Li6
Q = 0
PRESENT WORK
WONG et al
MERCHEZ et al
DIFFERENTIAL CROSS SECTION, (mb/sr)
1000
100
10
1
0
20
40
60
80
100
120
140
160
180
θC.M. (deg)

Fig. 1

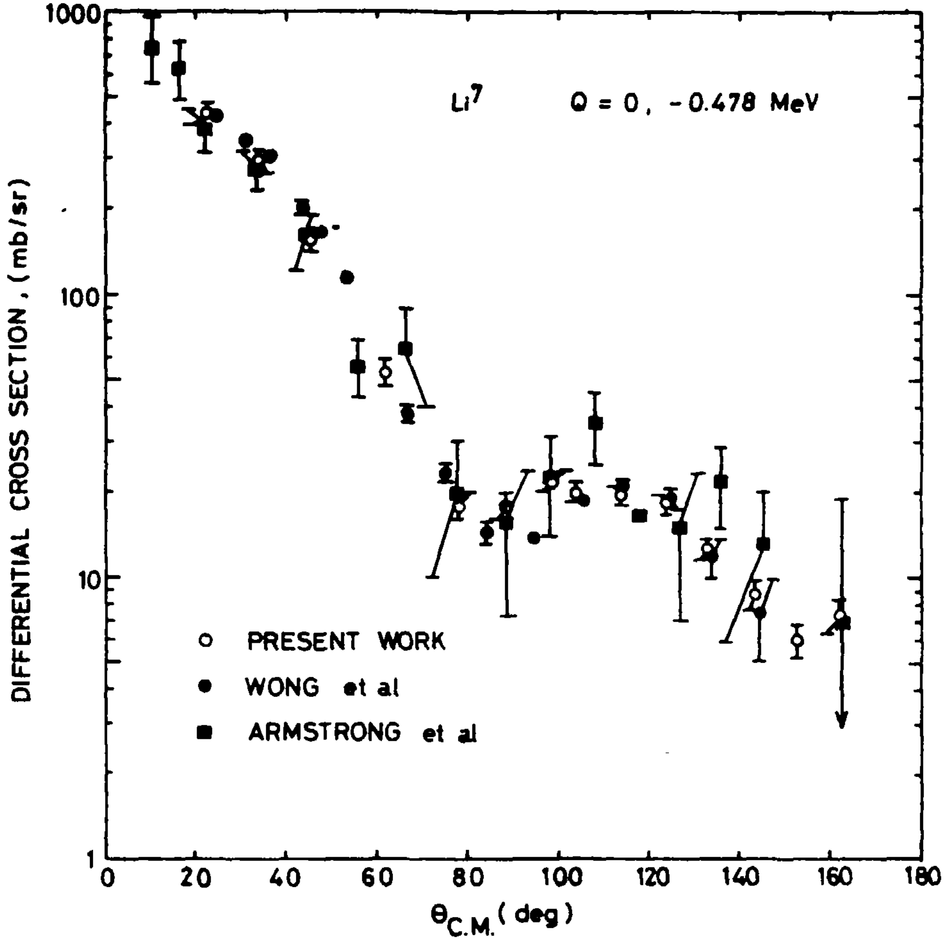
Li7
Q = 0, -0.478 MeV
PRESENT WORK
WONG et al
ARMSTRONG et al
DIFFERENTIAL CROSS SECTION, (mb/sr)
1000
100
10
1
0
20
40
60
80
100
120
140
160
180
θC.M. (deg)

Fig. 2

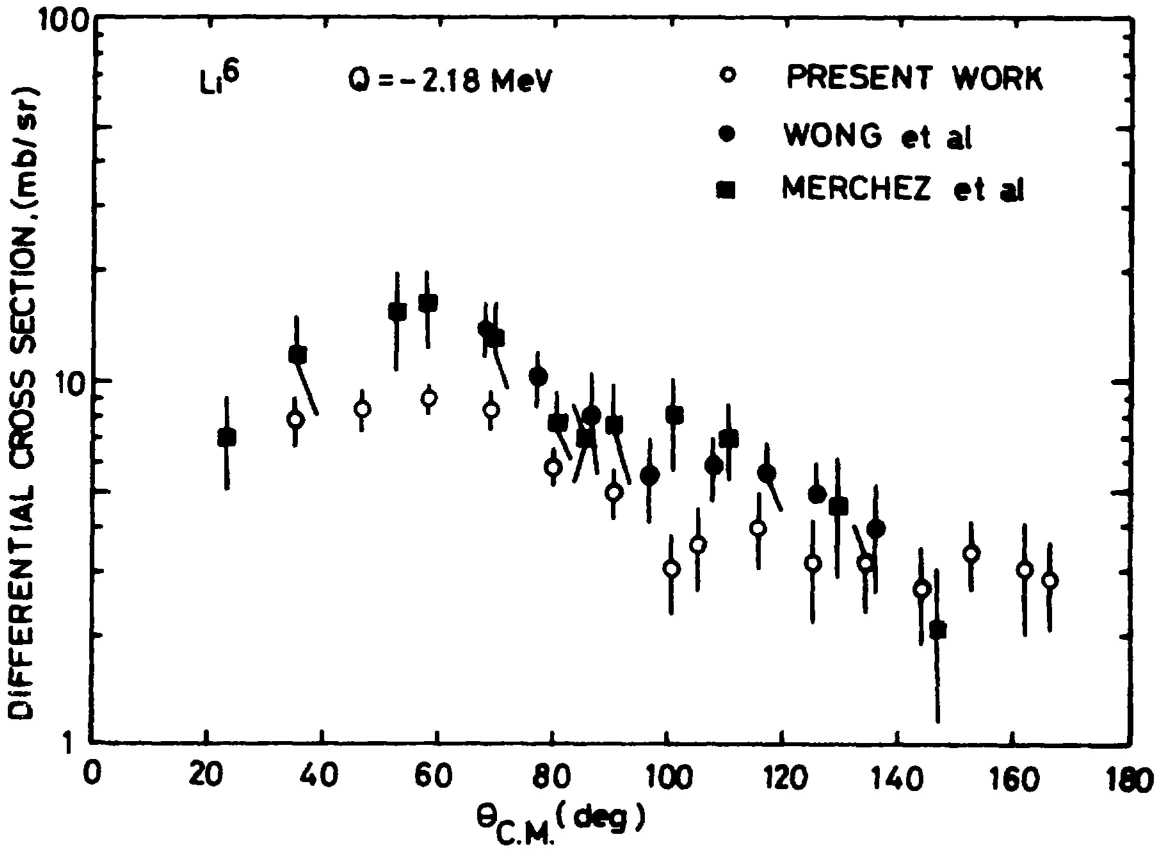
100
10
1
DIFFERENTIAL CROSS SECTION, (mb/sr)
Li6
Q = -2.18 MeV
PRESENT WORK
WONG et al
MERCHEZ et al
0 20 40 60 80 100 120 140 160 180
θC.M.(deg)

Fig. 3

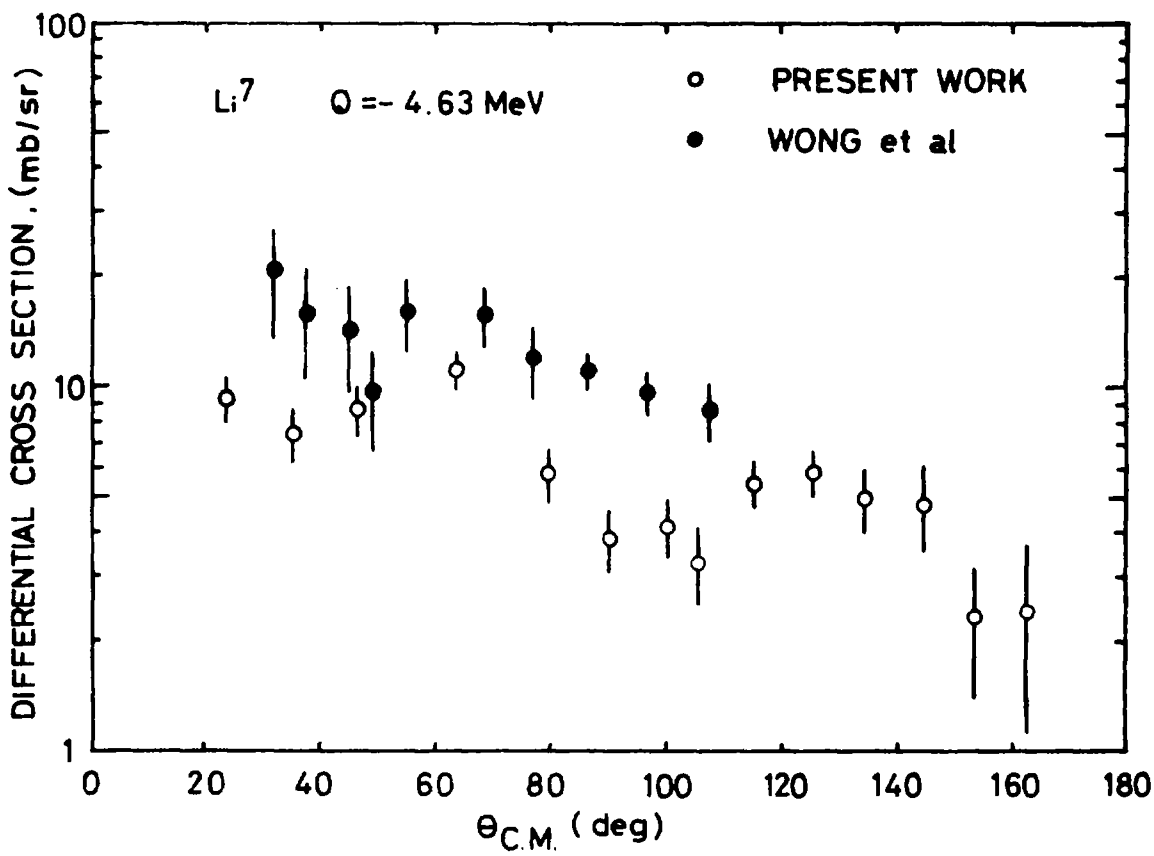
100
10
1
DIFFERENTIAL CROSS SECTION, (mb/sr)
Li7
Q = - 4.63 MeV
PRESENT WORK
WONG et al
0 20 40 60 80 100 120 140 160 180
θC.M. (deg)

Fig. 4

II-5. Improved Fast Neutron Time-of-Flight Spectrometer with Pulse Shape Discrimination

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

A neutron time-of-flight spectrometer has been constructed for 14 MeV neutron scattering experiments. The pulse shape discrimination method proposed by Alexander and Goulding[1] was employed. The block diagram is shown in Fig. 1. The neutron detector is a liquid scintillator NE213 (5"ϕ x 2") viewed by a photomultiplier XP1040. Output pulses from XP1040 are used both for pulse shape discrimination and energy measurement. An overall time resolution of less than 2.0 nsec was achieved at such high counting rate as about 10^4 cps. A typical example of time-of-flight spectra with and without pulse shape discrimination is shown in Fig. 2 for ^{12}C. The resolution has been greatly improved. This spectrometer was used for the study of neutron scattering from ^6Li and ^7Li and found to be quite satisfactory. A complete description is to be published.

Reference:

1) T.K. Alexander and F.S. Goulding: Nucl. Inst. Methods, 13 (1961) 244.

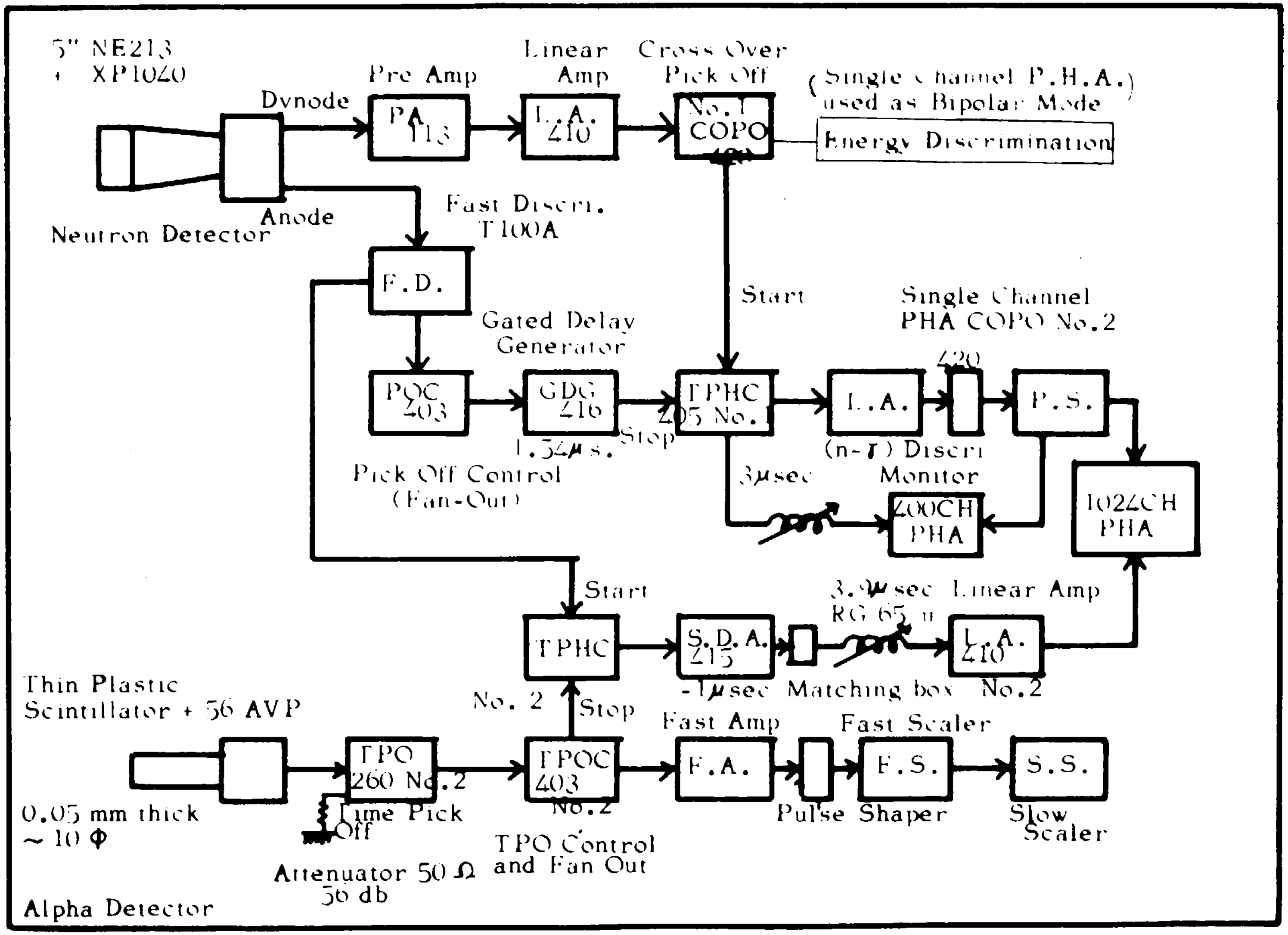

Fig. 1 Block diagram of the time-of-flight spectrometer with (n-γ) pulse shape discrimination.

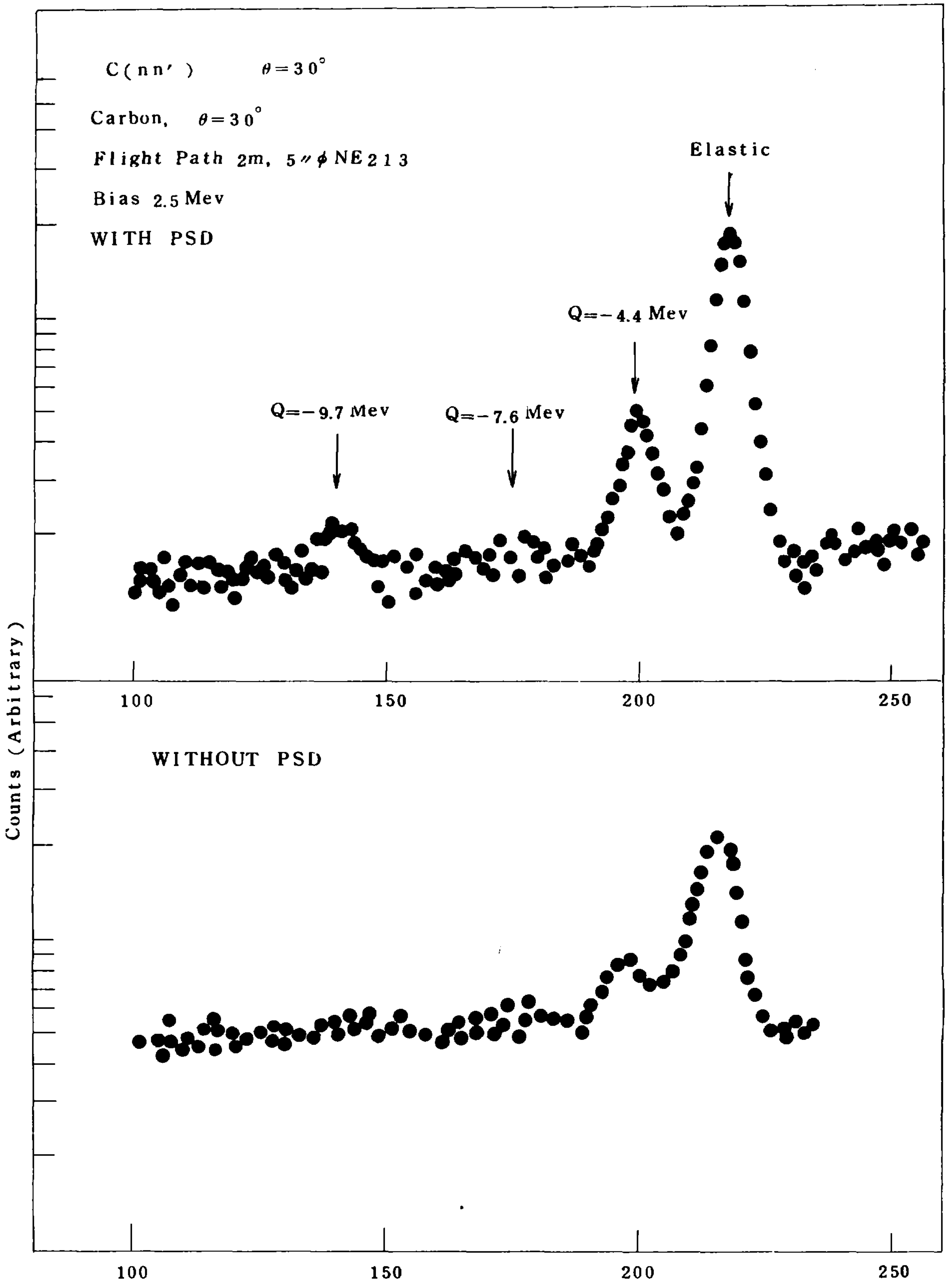

Fig. 2 CHANNEL NUMBER

II-6. Three-Point-Charge Model for Ternary Fission

Akira Katase

This work was completed and a full paper has been published in Journal of The Physical Society of Japan 25 (1968) 933.

II-7. Fission Reactions Induced by High-Energy Gamma Quanta

Y. Wakuta, A. Katase, M. Sonoda and M. Hyakutake

Analysis of the data for U and Th obtained with a system of solid state detectors is still underway.

The fission cross sections were also measured for the nuclei of lower mass number, using solid state track detectors. Rescanning is now in progress.

In order to obtain the velocity distribution of fission fragments, time-of-flight measurements has been carried out, using a PDP5 computer on line. The system is found to operate satisfactorily, if background problems are solved. The preliminary result is shown in Fig. 1.[1)]

Reference:

1) Genshikaku-Kenkyu. (Studies of Nucleus) 13 (1968) 1. (in Japanese).

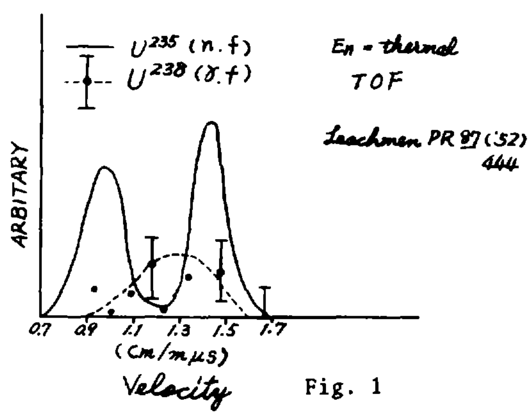

Fig. 1

III. Osaka University

III-1. Vib-Rot Frequency Distribution in Organic Molecular Crystal and Comparison with Neutron Scattering*

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

The neutron scattering laws of several organic moderator molecules were experimentally investigated by Brugger[1] and Gläser[2]. The differential cross sections were also measured by several authors[3),4),5]. Though Gläser gave a generalized frequency distribution function $\rho(\beta)$ for solid biphenyl, liquid benzene and liquid biphenyl, the peaks appeared there were rather broad. On the other hand, Tarina suggested the similarity of the fine structure of frequency distributions in solid and liquid benzene.

We also found many correspondences among neutron scattering, infrared, Raman and NMR data[6),7),8]. Recently, by using X-ray scattering, Narten stressed the close relation about molecular arrays in solid and liquid benzene. To obtain clear understandings of these many informations from different fields, we need to confirm the basic models of these molecules. So the aim of this study is to establish the dynamical models for benzene and biphenyl crystals and to get any suggestions for structure variations through transition points. With the progress of neutron scattering experiments the fine structures of scattering become available. To get the physical meanings of these fine structures rather orthodox treatment

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

** Department of Nuclear Engineering, Faculty of Engineering.

of frequency spectra must be made. In the light of this situation we will propose a matrix method to treat molecular vib-rot motion with lattice vibration.

When we treat all the freedoms of a crystal in parallel, the potential will be written in the following form:

$$V = \sum_{j} V_j + \sum_{i \neq j} V_{ij} + V_L + V_{L,\ intra} ,$$

where the 1st term is the sum of intra-molecular potentials,

the 2nd term is the sum of interaction potentials of all the possible pairs of molecules,

the 3rd term is the lattice vibrational potential and the last term is the interaction potential between lattice vibration and intra-molecular motion.

The 1st term is easily represented by the inner coordinate vector $\vec{R}$ of the molecule and the 3rd term by the crystal-fixed cartesian coordinate vector $\vec{Y}$. By neglecting the 2nd and last terms, Schimanouchi and Harada[10] solved the eigen-value problem. Their work was, however, limited to the case of in-phase lattice vibration and we are now planning to generalize their theory by including both the out-of-phase effect and the effect coming from the 2nd and last terms in the potential.

References:

1) R. M. Brugger, Phys. Rev., 126 (1962) 29.

2) W. Gläser, Nucleonik, 7 (1965) 64.

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

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

5) D. K. Ross, F. P. Szabo and Y. Sanalan, Symposium on Neutron Thermalization and Reactor Spectra SM 96/1 (1967).

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

7) T. Sekiya, K. Sakamoto, C. Nishida and Y. Watari, Tech. Repts. Osaka Univ., 17 (1967) 229.

8) JAERI-Memo (to be published) (1968).

9) A. H. Narten, J. Chem. Phys., 48 (1968) 1630.

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III-2. Theory of Multiple Scattering of Slow Neutron

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

A paper on this subject was published in Prog. Theor. Phys. 39 (1968), 37 with the following abstract.

In the previous paper[1], the Van Hove formula[2] for the single scattering cross section is generalized to include the effect of multiple scattering. The aim of the present paper is to improve the formula derived in 1) so as to satisfy the condition of detailed balance. The cross section is expressed in terms of the time-dependent propagators of the neutron and the many-particle space-time correlation functions for the target system.

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A well-defined classical approximation for the multiple scattering process is also studied along the line of reasoning of the previous paper[3].

References:

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

2) L. Van Hove, Phys. Rev., 95 (1954), 246.

3) S. Sunakawa, S. Yamasaki and T. Nishigori, Prog. Theor. Phys., 37 (1967), 1051.

III-3. Quasi-classical Theory of Slow Neutron Scattering

T. Nishigori* and S. Sunakawa**

A paper on this subject was submitted to Prog. Theor. Phys.

The Vineyard classical approximation[1] of the scattering cross section of a slow neutron violates the condition of detailed balance, because of the obvious defect that the recoil effect of the scattered neutron is completely discarded. In order to remedy this defect, great effects have been made by many authors[2)-4)], but these results still have some unsatisfactory features. In the previous paper[5], a new method for obtaining a classical approximation of the scattering cross section was proposed. In this treatment, the recoil effect of

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the scattered neutron is fully taken into consideration. The condition of detailed balance is, however, not satisfied rigorously, since the effect of the quantum mechanical thermal average is discarded. The aim of the present note is to remedy this defect and to obtain a well-defined classical formula which satisfies the condition of detailed balance rigorously.

The classical expression for the scattering cross section depends on which quantum mechanical formula we prefer. We reformulate, therefore, the quantum mechanical formula for the scattering cross section so as to be quite adequate to get a well-defined classical expression. By making use of the generalized cumulant expansion method[6], and with the aid of the fluctuation-dissipation theorem for the cumulant function $K_{\alpha\beta}(p,t)$ defined below, we can transform the scattering cross section derived in 5) into the following form

$$\frac{d^2\sigma}{d\Omega d\epsilon_f}=\left(\frac{m}{2\pi\hbar^2}\right)^2 |\langle p_f|t(\epsilon_i)|\vec{p}_i\rangle|^2 \frac{p_f}{p_i} e^{-\beta\epsilon/2} \sum_{\alpha,\beta} \frac{1}{2\pi\hbar}\int_{-\infty}^{\infty} e^{i\epsilon t/\hbar} \Lambda_{\alpha\beta}(p,t)dt, \qquad (1)$$

where the scattering function $\Lambda_{\alpha\beta}(p,t)$ is given by

$$\Lambda_{\alpha\beta}(p,t)=\exp\left[-\left\{\operatorname{cosec}\left(\frac{\beta\hbar}{2}\frac{d}{dt}\right) Im K_{\alpha\beta}(p,t) - C(p)\right\}\right] \qquad (2)$$

The cumulant function $K_{\alpha\beta}(p,t)$ in (2) is defined by

$$K_{\alpha\beta}(p,t)=\left\langle \exp_s\left[\frac{i}{\hbar}\left(pA_{1\alpha\beta}(t)+p^2A_{2\alpha\beta}(t)+p^3A_{3\alpha\beta}(t)+\dots\right)\right]-1\right\rangle_{cum}, \qquad (3)$$

where

$$A_{1\alpha\beta}(t) = r_{\alpha p}(0) - r_{\beta p}(t) \quad ,$$

$$A_{2\alpha\beta}(t) = \frac{1}{2i\hbar} [r_{\alpha p}(0), r_{\beta p}(t)] \quad , \tag{4}$$

$$A_{3\alpha\beta}(t) = \frac{1}{12}\left(\frac{1}{i\hbar}\right)^2 \{ [[r_{\alpha p}(0), r_{\beta p}(t)], r_{\beta p}(t)] - [[r_{\beta p}(t), r_{\alpha p}(0)], r_{\alpha p}(0)] \}$$

The bracket $< \ldots >_{cum}$ designates a cumulant average and $\exp_s$ indicates the symmetrized exponential. The operator $r_{\alpha p}$ in (4) refers to the component of $\mathbf{r}_\alpha$ in the direction of the momentum transfer p. The constant of integration $C(p)$ in (2) is determined by the initial condition

$$C(p) = Re\, K_{\alpha\beta}(p, 0) + [\cot(\frac{\beta\hbar}{2}\frac{d}{dt})\, Im\, K_{\alpha\beta}(\vec{p}, t)]_{t=0} \quad . \tag{5}$$

The point of the expression (1) of the scattering cross section is that the recoil effect of the scattered neutron is involved explicitly in the commutators $p^2A_{2\alpha\beta}(t)$, $p^3A_{3\alpha\beta}(t)$, ... , and that the condition of detailed balance is assured owing to the extra factor $\exp(-\beta\varepsilon/2)$ and to the property

$$A_{\alpha\beta}(p, t) = A_{\alpha\beta}(-p, -t) \quad , \tag{6}$$

which is valid under the condition that the Hamiltonian of the target system is invariant under space-reflection and time-reversal operation. Hence, we can see that the quantum mechanical expression (1) is quite convenient to obtain a well-defined classical formula.

The quasi-classical expression of the scattering cross section is obtained by taking in (1) the following classical limit

$$\mathbf{r}_\alpha(t) \rightarrow r_\alpha^{\,c}(t) \;,\; \frac{1}{i\hbar}[\cdot\cdot,\cdot\cdot] \rightarrow \{\cdot\cdot,\cdot\cdot\}_c \text{ and } <S\cdots>_{cum} \rightarrow \ll\cdots\gg_{cum} \,, \tag{7}$$

where $r_{\alpha}^{c}(t)$ is a solution of the classical equations of motion of the target atoms, the bracket $\{\cdot\cdot,\cdot\cdot\}_c$ denotes the classical Poisson bracket and $\ll\cdots\gg_{cum}$ designates the classical cumulant average.

It can be shown classicaly that the classical scattering function $A_{\alpha\beta}^{c}(p,t)$ has the similar symmetric property

$$A_{\alpha\beta}^{c}(p,t) = A_{\alpha\beta}^{c}(-p,-t) \tag{8}$$

as (6). The classical expression of the scattering cross section, therefore, satisfies the condition of detailed balance, and furthermore the recoil effect is taken into consideration by the classical Poisson brackets.

When the equations of motion of target atoms are described by linear equations, the expression for the scattering cross section has a simple form. In this case the Poisson bracket $A_{2\alpha\beta}^{c}(t) = \{r_{\alpha p}^{c}(o), r_{\beta p}^{c}(t)\}_c/2$ becomes independent of the statistical average and the Poisson brackets $A_{3\alpha\beta}^{c}(t), A_{4\alpha\beta}^{c}(t)$, ... vanish. The self-part ($\alpha=\beta$) of the scattering function $A_{s}^{c}(p,t)$ has the Gaussian form, and the incoherent part of the scattering cross section is given by

$$\frac{d^2\sigma_{inc}^{c}}{d\Omega d\epsilon_f} = A_{inc}^{2}\frac{p_f}{p_i}e^{-\beta\epsilon/2}\frac{1}{2\pi\hbar}\int dt\, e^{i\epsilon t/\hbar}$$

$$\times\exp[-\frac{p^2}{2\hbar}\{\mathrm{cosec}\,(\frac{\beta\hbar}{2}\frac{d}{dt})\{r_{\alpha p}^{c}(o), r_{\alpha p}^{c}(t)\}_c - [\cot(\frac{\beta\hbar}{2}\frac{d}{dt})\{r_{\alpha p}^{c}(o), r_{\alpha p}^{c}(t)\}_c]_{t=0}\}] \tag{9}$$

In this simple case, the cross section based on (9) does coincide with that of the exact quantum theory. This is due to the fact that the classical Poisson bracket $\{r_{\alpha p}^{c}(o), r_{\alpha p}^{c}(t)\}_c$ gives the same c-number as the corresponding quantum-mechanical commutator $[r_{\alpha p}(0), r_{\alpha p}(t)]/i\hbar$, and moreover that the c-number is independent of the target variables. In non-linear cases, however, the commutator $[r_{\alpha p}(0), r_{\alpha p}(t)]$ does not become a c-number but it still depends on the target variables. In this case, the classical result does not coincide with that calculated in quantum-mechanical way, because of the difference between the quantum statistical average and the classical one. Even in this complicated case, the present method of a classical approximation will give a reasonable result, since it satisfies the condition of detailed balance and takes the recoil effect fully into account.

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1) G. H. Vineyard, Phys. Rev., 110 (1958), 999.

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3) A. Rahman, Phys. Rev., 130 (1963), 1334.

4) M. Rosenbaum and P. F. Zweifel, Phys. Rev., 137 (1965), B271.

5) S. Sunakawa, S. Yamasaki and T. Nishigori, Prog. Theor. Phys., 37 (1967), 1051.

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IV. Radiation Center of Osaka Prefecture

IV-1. Photoneutron Cross Section of ^{13}C from Threshold to 15 MeV

K. Fukuda, S. Okabe and Y. Sato

The photoneutron excitation curve of ^{13}C was observed at incident bremsstrahlung energies up to 15 MeV by the method of direct neutron detection using a 15 MeV linear electron accelerator. Gross feature of the cross sections as a function of photon energy showed two broad peaks at about 9 and 13 MeV in accordance with results of other experiments[1]. Detailed structures were also found in these peaks: the cross section curve showed several peaks at 6.2, 7.4, 8.2, 9.1 and 13 MeV, and broad resonances appeared in the energy region of 11 MeV. These resonances well correspond to well known levels of ^{13}C [2]. The angular distributions of emitted neutrons corresponding to these resonances were nearly 90° symmetric.

Theoretical analyses on the $^{13}C(\gamma,n)^{12}C$ reaction, which had been done by several authors[3,4,5], were compared with the present results. Neutrons from the 13 MeV peak had a $1 + (0.5 \pm 0.2)\sin^2 \theta$ distribution. This value of anisotropy coefficient was much smaller than the predicted value of 3/2 by assuming that the resonance at 13 MeV in $^{13}C(\gamma,n)^{12}C$ is mainly due to the excitation of a single neutron[3]. The total integrated cross section under the resonances from threshold to 10 MeV was 2 MeV-mb, which was smaller by a factor of 5 or more than the value predicted from a single particle model with a Saxon potential[4]. Pronounced peak could not be found in the cross section curve immediately above threshold because of poor statistical accuracy. An integrated cross section from threshold to 6 MeV was about 10^{-2} MeV-mb. It should be noted that the states involved do not correspond exactly to the type assumed by the single particle model, except near the threshold region. Integrated cross sections under the resonances at 7.4, 8.2 and 13 MeV were 0.3, 0.6 and 16 MeV-mb, respectively. Good agreement was found between measured values and predicted one from an intermediate coupling model[5].

The analysis of the data is now in progress, and the present study is to be published.

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V. Rikkyo (St. Paul's) University

V-1. Gamma-rays from $^{107}Ag(n,\gamma)^{108}Ag$*

M. Hattori, T. Nagahara, and K. Kitao**

The energy and intensity of gamma rays following thermal neutron capture by ^{107}Ag were measured in a range of gamma ray energy from 40 keV to 650 keV with an 8 cm^3 planar Ge(Li) detector. The energy resolution of the detector was 2.5 keV (FWHM) at 122 keV. A 200 mg metallic silver target, which fully enriched in ^{107}Ag, was placed in a thermal neutron beam from the Rikkyo University TRIGA-II reactor. The beam flux was about 10^6 n/cm^2.sec at target position.

These results are shown in table and figure, in which the intensities have been normalized at 207.6 keV for comparison with the work of Estulin et al.[1]

The detailed analysis and further measurements are in progress.

Reference:

1) Estulin et al., Soviet Phys.--JETP 16 (1963) 978; Soviet Jour. Nucl. Phys. 4 (1967) 16.

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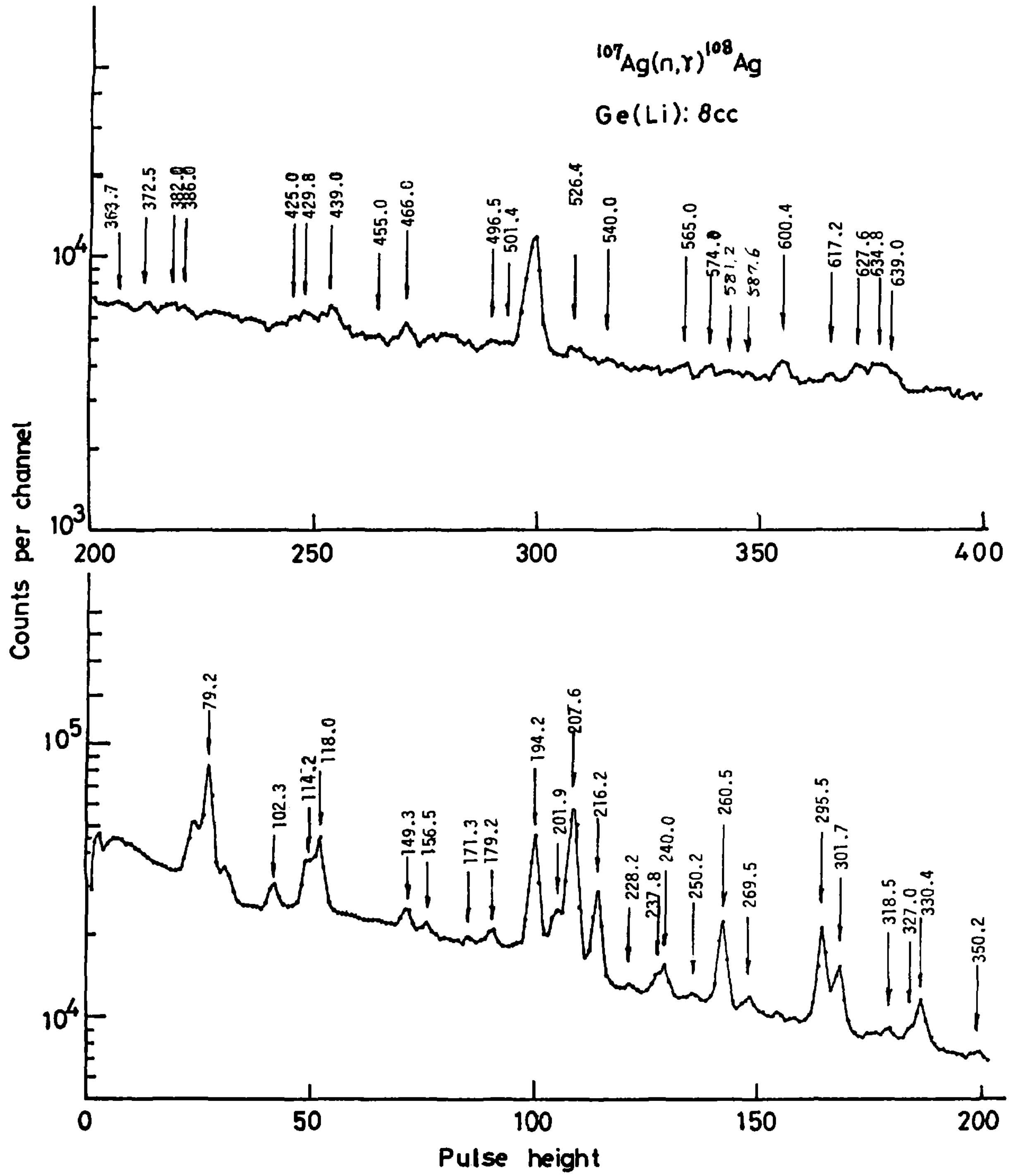
* This work was presented at the 1968 Autumn meeting of Japan Physical Society.

** National Institute of Radiological Sciences.

$^{107}Ag\ (n,\gamma)\ ^{108}Ag$

Gamma ray energies (keV)	Intensities (photons per 100 neutron captures)	Gamma ray energies (keV)	Intensities (photons per 100 neutron captures)
79.2	20.0	372.5	0.2
102.3	1.1	382.0	0.4
114.2	2.2	386.0	0.4
118.0	3.5	425.0	0.4
149.3	0.8	429.8	0.8
156.5	0.4	439.0	1.2
171.3	0.1	455.0	0.2
179.2	0.2	466.0	0.7
194.2	6.6	496.5	0.5
201.9	3.0	501.4	0.4
207.6	10.0	526.4	0.5
216.2	4.0	540.0	0.3
228.2	0.2	553.8	0.4
237.8	0.8	565.0	0.7
240.0	0.9	574.0	0.5
250.2	0.2	581.2	0.4
260.5	4.0	587.6	0.4
269.5	0.5	600.4	1.1
295.5	5.9	617.2	1.2
301.7	3.0	627.6	1.2
318.5	0.3	634.8	1.2
327.0	0.9	639.0	0.6
330.4	1.7		
350.2	0.4		
363.7	0.1		



$^{107}Ag(n,\gamma)^{108}Ag$
Ge(Li): 8cc
363.7
372.5
382.0
386.0
425.0
429.8
439.0
455.0
466.0
496.5
501.4
526.4
540.0
565.0
574.0
581.2
587.6
600.4
617.2
627.6
634.8
639.0
79.2
102.3
114.2
118.0
149.3
156.5
171.3
179.2
194.2
201.9
207.6
216.2
228.2
237.8
240.0
250.2
260.5
269.5
295.5
301.7
318.5
327.0
330.4
350.2
Counts per channel
Pulse height

VI. Tokyo Institute of Technology

VI-1. Photo-Disintegration of ^6Li

H. Hirabayasi, K. Kusuhara, and Y. Oda

In the photonuclear reactions of ^6Li, nearly equal number of proton and neutron are expected to be produced in the corresponding reaction processes charge symmetrically. In the previous work on the ^6Li irradiated with the Bremsstrahlung of 15.7 MeV maximum γ-ray energy, we observed an eminent proton group of E_p=1.90 MeV. Although the existence of this proton groups have been several times reported in the literature, the origin of this proton group does not seem to have been clarified. We have studied the energy spectrum of the photo protons from ^6Li with Bremsstrahlung of 8.8 MeV maximum energy. The D(γ,p)n reaction has been also studied as a supplementary work. The 1.90 MeV proton group has been observed again in the nuclear emulsion. This fact excludes the $^6Li(\gamma,pn)^4He$ process through the Ex=9.3 MeV state of ^6Li, formerly proposed as the main origin. The $^6Li(\gamma,n)^5Li(p)^4He$ (Q=-5.662 MeV) processes might be considered to be the origin of the present proton group. However, protons through the 7.94 MeV state of ^6Li which are emitted from the recoiling ^5Li nuclei would show the kinematical broadening in energy, ranging from 0.96 to 2.3 MeV, in contrast to the observed sharpness. The $^6Li(\gamma,p)^5He$ process through the 6.83 MeV (Q=-4.655 MeV) state of ^6Li can be taken for an adequate candidate for the origin of the present proton group.

Among some features concerning to the reactions at this state, it is worthwhile to note the following rather peculiar accidental coincidence. Of course through this state, the $^6Li(\gamma,n)^5Li(p)^4He$ process would occur. The energy spread of the protons is however estimated to be from 1.10 to 2.10 MeV. Thus this kind of protons produced in a ^6Li target of 800 KeV thickness would not be well discriminated from the primary (γ,p) protons. Further experiments are now in progress.

VII. University of Tokyo Department of Physics

VII-1. Search for an Exothermic (n,n') Process

K. Miyano and H. Morinaga

We have looked for an exothermic (n,n') process in the case of ^{148}Pm isomer[1]. In this case the pile neutron cross section of ^{148m}Pm has been obtained at 29,000±5,000 barns.[1] However, the cross section of ^{148m}Pm from the rate of buildup of ^{148m}Pm was about two times larger than that from buildup of ^{149}Pm[2]. This discrepancy has been inferred as due to an extremely large ^{149}Pm(n,γ) cross section. But it is also possible that this is due to the ^{148m}Pm(n,n') reaction.

We have tried to obtain the ^{148m}Pm(n,n') reaction by measuring the additional buildup of ^{148g}Pm under its exposure to the slow neutron.

From the decay of ^{148m}Pm during the irradiation, the destruction cross section of ^{148m}Pm was found to be 27,000±2,000 barns. The ^{148m}(n,n')^{148g}Pm cross section is estimated to be less than 10^2 barns.

A full paper on this subject was submitted for publication in the Journal of Physical Society of Japan.

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1) Nuclear Data, Section B, edited by K. Way et al. 2 (1967) no.4.

2) R. P. Schuman and J. R. Berreth, Nucl. Sci. and Eng. 12 (1962) 519.