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EVALUATION OF NEUTRON NUCLEAR DATA OF B-11

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Abstract: Nuclear data of B-11 have been evaluated in the energy range from 0.01 meV to 20 MeV. The evaluated quantities are cross sections, angular distributions and energy spectra of secondary neutrons. The evaluation was performed by using the R-matrix theory below 7 MeV and multistep statistical model above 7 MeV. Below 7 MeV, R-matrix parameters of Koehler et al. were modified to fit experimental data of the total cross section. For calculation of the multistep statistical model, the optical model and the level density parameters were chosen to reproduce experimental data of charged particle emission and elastic scattering cross sections. Direct inelastic scattering processes for seven excited levels were considered with DWBA calculation. The results of present work are in good agreement with the experimental data of cross sections, angular distributions of secondary neutrons and double differential cross sections. They were compiled for JENDL-3 in the ENDF/B-V format.

(Evaluation, B-11, Neutron Nuclear Data, R-matrix, Optical Model, DWBA, JENDL-3)

Introduction

For Japanese evaluated nuclear data library version 3 (JENDL-3), evaluation, compilation and revision have been continued. The evaluated nuclear data of B-11 are not included in JENDL-2, though they are necessary to calculate neutron transport in the light water reactor (LWR), neutron multiplication or tritium breeding of fusion reactors. A lot of experimental data of total cross section have been measured by many authors, but few or no measurement for the other quantities of B-11 has been performed.

In this paper, the evaluation of nuclear data of B-11 was performed in the neutron energy range from 0.01 meV to 20 MeV. The evaluated quantities were cross sections, angular distributions and energy spectra of secondary neutrons, and summarized in Table 1 with Q-values. Direct inelastic scattering processes were calculated for seven excited levels (Q = -2.12, -4.45, -5.02, -6.74, -6.79, -9.12 and -10.6 MeV) with DWBA theory.

This paper consists of three parts;
(1) Evaluation of cross sections of total, elastic and inelastic scattering by using R-matrix theory. The energy range is below 7 MeV.
(2) Evaluation of the inelastic scattering and reaction cross sections, angular distributions and energy spectra of secondary neutron by using multistep statistical model and DWBA. The energy range is above 7 MeV.
(3) Results and discussions.

Evaluation below 7 MeV

R-matrix Calculation

Cross sections of total, elastic and inelastic scattering, and angular distributions of secondary neutron were evaluated with R-matrix theory. The evaluation has been performed by using RESCAL /1/. R-matrix parameters of Koehler et al. /2/ were chosen as the initial values for calculation of elastic scattering and the first level (Q = -2.12 MeV) inelastic scattering cross sections. Initial values for parameters of the second and third levels (Q = -4.45 and -5.02 MeV) were assumed tentatively, and the all parameters were modified to fit experimental data of the total cross section.

Capture Cross Section

Basically capture cross section was calculated from the multilevel Breit-Wigner (MLBW) formula by adopting resonance parameters recommended by

Table 1 The Evaluated Quantities. Symbol "O" means that the evaluation was performed.

Quantities	σ	dσ/dΩ	dσ/dE	Q-values [MeV]
total	O	-	-	-
elastic	O	O	-	0.0
capture	O	-	-	3.396
inelastic	O	O	O	-2.12
(n,2n)	O	O	O	-11.46
(n,p)	O	-	-	-10.73
(n,d)	O	-	-	-9.00
(n,t)	O	-	-	-9.56
(n,α)	O	-	-	-6.63
(n,np)	O	O	O	-11.23
(n,nd)	O	O	O	-15.82
(n,nt)	O	O	O	-11.22
(n,nα)	O	O	O	-8.67
(n,n2α)	O	O	O	-11.13

Table 2 The Optical Potential Parameters

neutron	V =41.8-0.005E*	r0=1.40	a0=0.35	/13/
	Ws=1.01E *	rI=1.15*	aI=0.50	
proton	V =66.1-0.273E	r0=1.15	a0=0.57	/14/
	Ws=1.50+0.581E	rI=1.15	aI=0.5	
	Vsym=5.5	r0=1.15	a0=0.57	
deuteron	V =80.0 *	r0=1.0 *	a0=1.0 *	/15/
	Wv=30.0	rI=1.0 *	aI=0.8 *	
	Vsym =6.0 *	r0=1.0 *	a0=1.0 *	
triton	V =103.0+20.0E*	r0=0.85	a0=0.70	/16/
	Wv=1.49E *	rI=2.06	aI=0.72	
	Vsym =8.55 *	r0=0.85	a0=0.70	
alpha	V =285.2-2.40E*	r0=1.61*	a0=0.55*	/17/
	Ws=16.16-0.70E*	rI=1.81	aI=0.65	

NOTE : E is incident neutron energy in LAB. system with units of MeV and fm. * means that parameter is modified from original one.

Table 3 The Level Density Parameters

	a[1/MeV]	T[MeV]	Pair.[MeV]
B-10	1.196	7.990	0.0
B-11	1.431	6.112	2.67
B-12	1.491	6.201	0.0
Be-8	1.115	9.187	2.13
Be-9	1.125	8.248	2.46
Be-10	1.088	10.029	5.13
Be-11	1.419	7.277	2.46
Li-7	1.138	7.197	2.67
Li-7	1.115	8.170	0.0

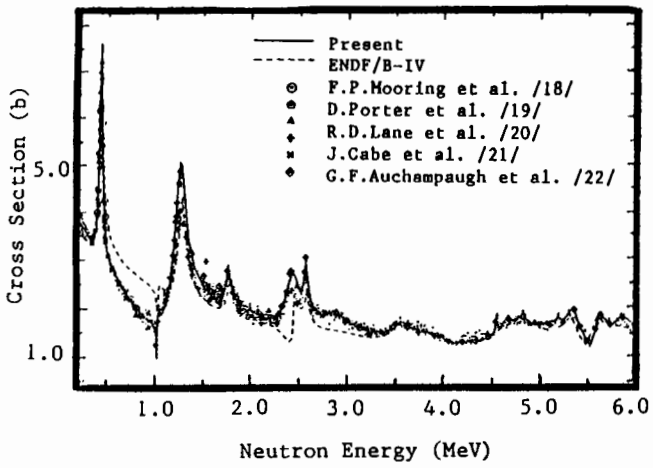

Fig. 1 Total Cross Section

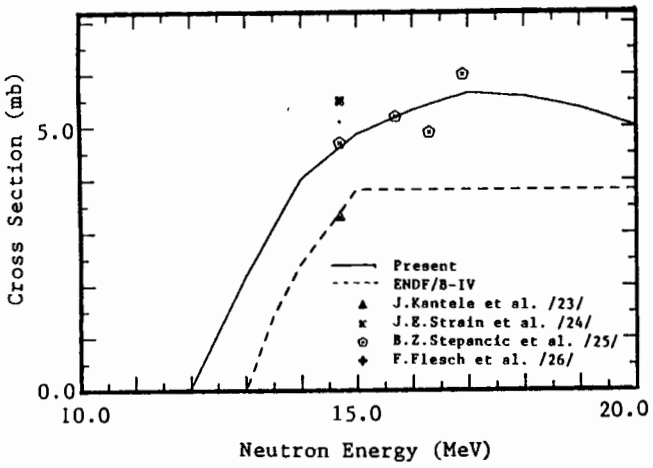

Fig. 2 (n,p) Cross Section

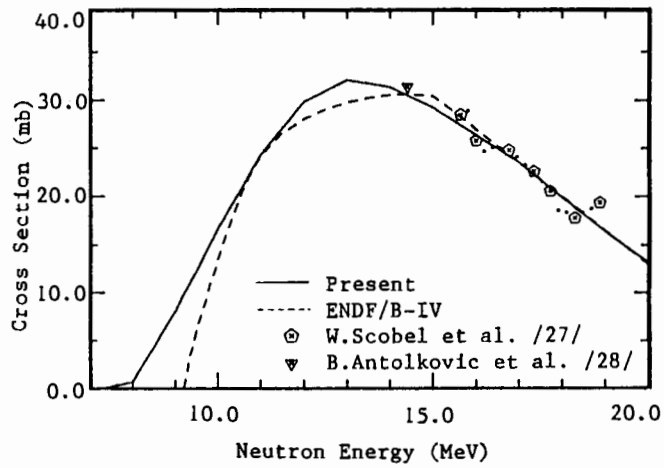

Fig. 3 (n,α) Cross Section

Mughabghab et al./3/. The direct capture cross section /3/ was added to them.

Evaluation above 7 MeV

Elastic and Inelastic Scattering

Direct inelastic scattering processes for seven excited levels (Q = -2.12, -4.45, -5.02, -6.74 -6.79, -9.12 and -10.60 MeV) were considered. The calculation was performed with DWBA code DWUCK4 /4/. Multistep statistical model code GNASH /5/ was also used to calculate cross sections and angular distributions of the inelastic scattering.

The direct inelastic scattering cross section was added to compound one to fit experimental data of cross sections and angular distributions measured by Koehler et al. /2/, Glendinning et al. /6/, and the double differential cross section data of Takahashi et al. /7/.

Excited levels were assumed to be overlapping above 7.2 MeV. Calculation of cross section of continuum inelastic scattering was performed by means of the GNASH code.

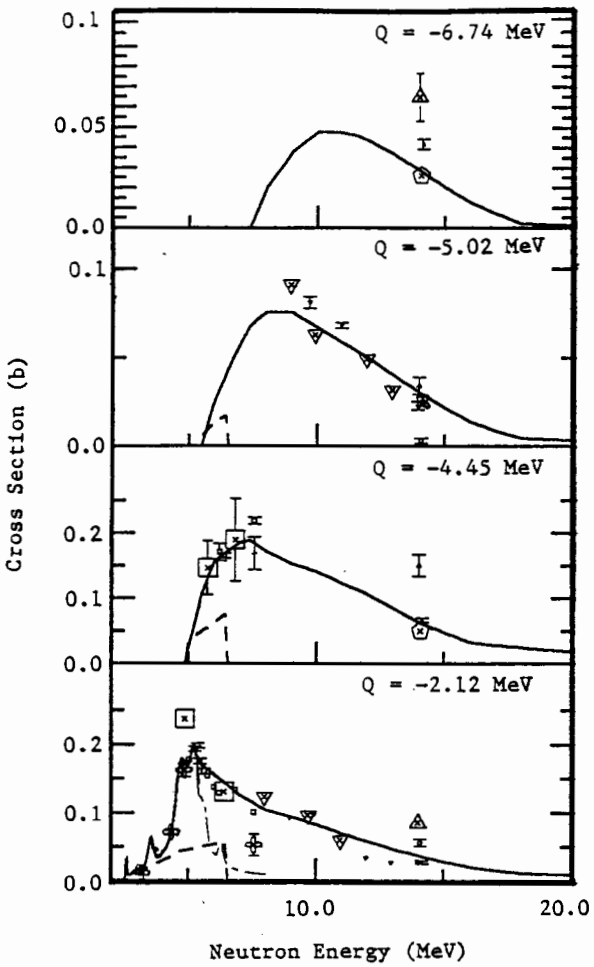

Fig. 4 Inelastic Scattering Cross Sections

Present
ENDF/B-IV
Koehler /2/
J.Roturier /29/
J.C.Alder et al. /30/
J.C.Hopkins et al. /31/
D.Porter et al. /19/
Besotosnyj et al. /32/
S.G.Glendinning et al. /13/
P.E.Koehler et al. /2/

Other Reactions

Reaction cross sections ((n,2n), (n,p), (n,d), (n,α), (n,np), (n,nd), (n,nt) and (n,nα)) and energy spectra of secondary neutrons were calculated with GNASH code. For GNASH calculation, the optical model and the level density parameters were adjusted so that the calculation could reproduce experimental data of the (n,p), (n,d), (n,t), (n,α) reaction and elastic scattering cross sections. The parameters are shown in Tables 2 and 3. Calculated cross sections of the (n,p) and (n,α) reactions were normalized to the experimental data of Stepancic et al. /8/, and the data of Antolkovic et al. /9/ and Scobel et al. /10/, respectively.

Cross section and energy spectrum of the (n,n2α) reaction were evaluated by adopting those shapes of (n,nt) reaction and normalizing to the He production data of Kneff et al. /11/.

Total and Elastic Scattering Cross Sections

The total cross section was obtained by fitting to the experimental data of Auchampaugh et al./12/. The elastic scattering cross section above 7 MeV was obtained by subtracting the reaction cross sections from the total cross section.

Results and Discussions

Cross Sections

The total cross section calculated with R-matrix in the energy range from 0.2 to 6.0 MeV is shown in Fig.1. The solid and dashed lines mean the present work and ENDF/B-IV, respectively. The present result is in good agreement with the experimental data.

Figures 2 and 3 show the examples of the (n,p) and (n,α) cross sections calculated by using GNASH code. As an example of calculation with statistical model and DWBA, the inelastic scattering cross sections of first four excited levels are illustrated in Fig.4. The solid, dashed, and dash-dotted lines mean the present work, ENDF/B-IV, and the calculation with the R-matrix parameters of Koehler et al., respectively. The ratio of compound process to direct process was assumed to be 0.8 in whole energy range. The present results reproduce the experimental data.

Angular Distributions

The angular distributions of elastically scattered neutrons at the incident neutron energies of 4.00, 7.98 and 13.94 MeV are shown in Fig.5. The present result at En = 4.00 MeV was calculated with R-matrix and calculations at 7.98 and 13.94 MeV were performed with DWUCK4 and GNASH. Figure 6 shows the inelastic angular distributions of the first three levels. Calculation was carried out with R-matrix for the first level and with DWUCK4 and GNASH for second and third levels. The present work agrees with the experimental data.

Double Differential Cross Section

The double differential cross section at En = 14.2 MeV and θ = 45.0 deg. is shown in Fig.7 compared with the experimental data measured at Tohoku university. The peaks of elastic and

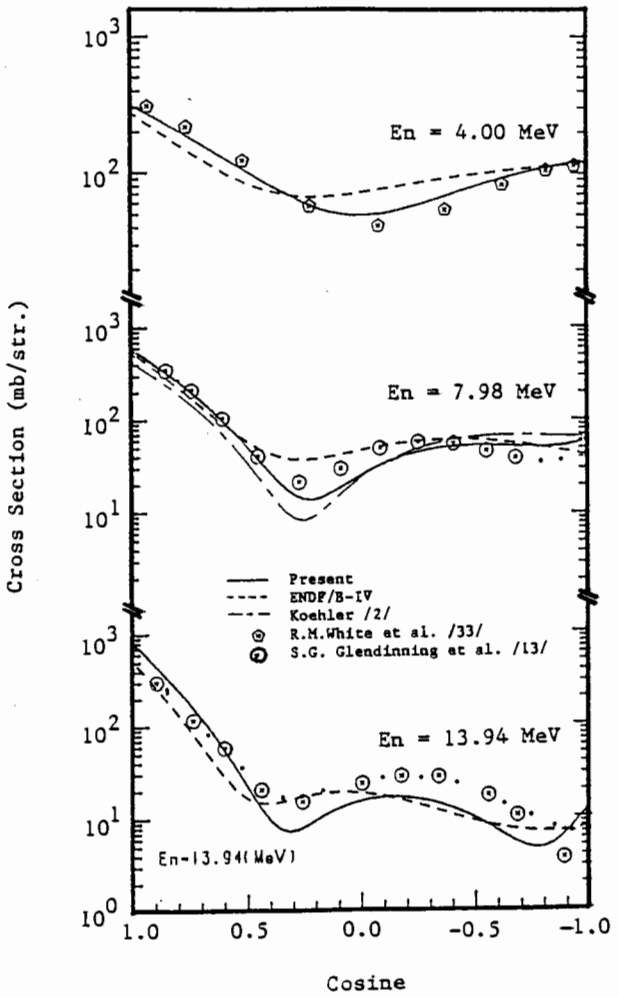

Fig. 5 Angular Distributions of Elestic Scattering

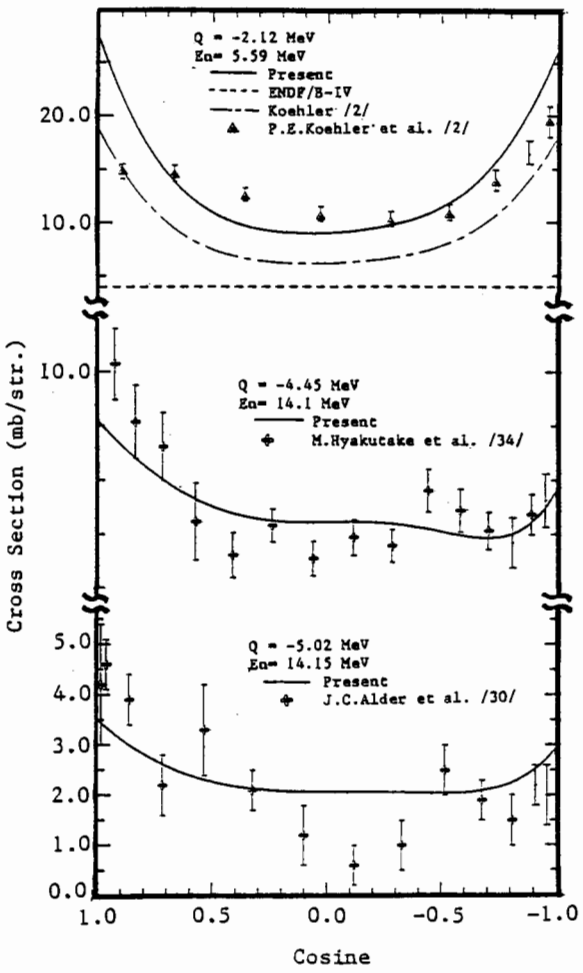

Fig. 6 Angular Distributions of Inelastic Scattering

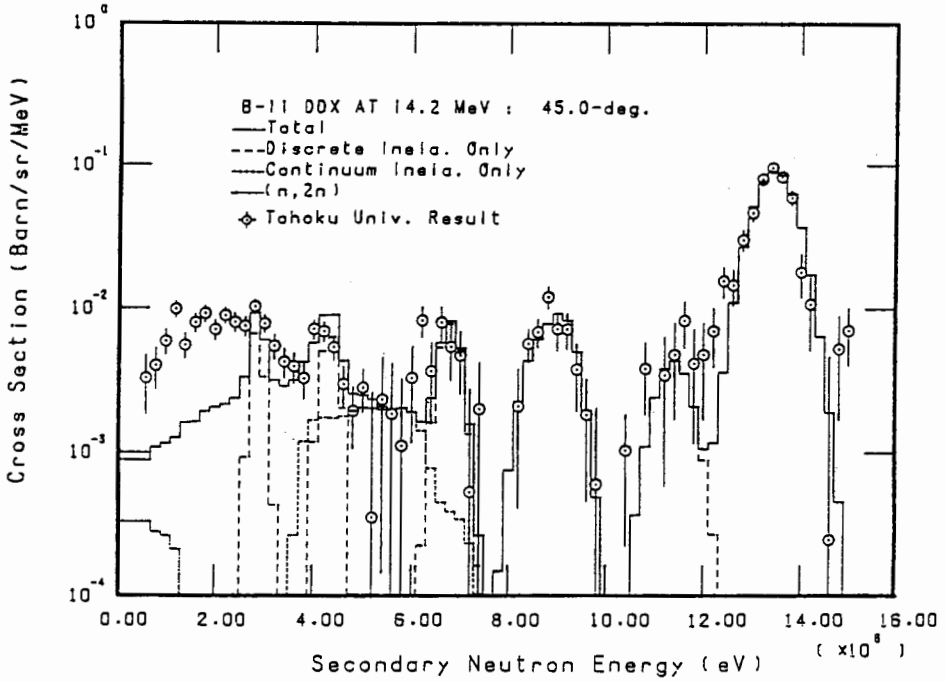

Fig. 7 Double Differntial Cross Section

inelastic scattering are in good agreement with the experimental data. In the lower energy region of secondary neutrons, the present result is much smaller than that of Tohoku university, because the (n,nd), (n,nt) and (n,n2α) reactions are not included in the calculation.

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