Spectroscopic Study of 41,45Sc Nuclei Through (d,n) Reactions on 40,44Ca at 25 MeV

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I. 5. Spectroscopic Study of ^{41,45}Sc Nuclei through (d,n) Reactions on ^{40,44}Ca at 25 MeV

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The one-nucleon transfer reaction at a reasonably-high bombarding energy is one of the most useful proves for studying the nuclear structure. Especially, the (d,n) reaction is expected to give more reliable spectroscopic information than other one-nucleon stripping reactions, because its treatment in the distorted-wave Born-approximation (DWBA) analysis is simple and accurate. We have carried out a systematic investigation of the nuclear structure in sd-shell nuclei by means of the (d,n) reaction at $E_d = 25$ MeV. The aims of the present study are; firstly, to obtain spectroscopic factors for the states of ^{41}Sc and ^{45}Sc through the ^{40,44}Ca(d,n)^{41,45}Sc reactions, and secondly, to clarify the hole-probabilities, for the sd-proton shells in the ground states of calcium isotopes, which have been previously studied by Dehnhard and Cage 1).

The experiment was carried out by using 25-MeV deuterons from the CYRIC AVF cyclotron Tohoku University, and a TOF (time-of-flight) facility 2) with a 44-m long flight path. Angular distributions of emitted neutrons have been measured between 0° and 88° (lab.) by utilizing a beam swinger system. Overall energy resolutions for observed states were about 150 keV. Natural calcium metallic foils were prepared for the ^{40}Ca(d,n)^{41}Sc reaction by the rolling method. The thicknesses, measured by the weighing method, were 2.3 and 5.3 mg/cm^2. A self-supporting foil of isotopically enriched (98.7%) ^{44}Ca metal was prepared by the deoxidization-evaporation method in vacuum. The thickness of the ^{44}Ca target was measured by comparing the yields of elastically scattering deuterons with the cross sections predicted by the optical model. The result was 2.5 mg/cm^2 in its thickness.

Figs. 1a and 1b show typical neutron energy spectra taken for the ^{40,44}Ca(d,n)^{41,45}Sc reactions at $\theta_L = 15°$. Angular distributions of emitted neutron leading to the states in ^{41}Sc and ^{45}Sc nuclei are presented in Figs. 2a-2d and 3a-3g, respectively. Solid lines in the figures stand for the results obtained from DWBA calculations described hereafter. An uncertainty of an absolute cross section is estimated to be less than 15%.

The zero-range DWBA calculation for angular distributions has been accomplished with the code DWUCK4 revised by Comfort 3) in order to handle the form factors of transferred unbound nucleons, while finite-range and non-local corrections are contained. The method by Vincent and Fortune 4) has been applied to calculate the form factor of a proton in an unbound state. Adiabatic deuteron potentials were derived from sets of nucleon parameters at $E_p = E_n = 1/2\ E_d$; those for protons are given by Becchetti and Greenlees 5), while those for neutrons are given by Carlson et al 6).

Spectroscopic factors for ^{41}Sc and ^{45}Sc obtained by normalizing the experimental (d,n) cross sections to those predicted by the DWBA calculations are listed in Tables 1 and 2, respectively. Spectroscopic information so far reported 7,8) is also tabulated for comparison. In both cases, spectroscopic factors for lower lying states are in good agreement with the results derived from other reactions. However, there are some differences between the present results and those obtained from the (^{3}He,d) reaction at 40 MeV.9) about the spectroscopic factors for unbound states of ^{45}Sc, presumably due to the different treatment for the unbound states among these DWBA calculations. It is noteworthy to point out that the summed particle strengths for $1d_{3/2}$ and $2s_{1/2}$ stripping increase along with the increase of neutron number ^{40}Ca through ^{44}Ca, as reported previously in ref.1, suggesting the increase of degree of configuration mixing in the ground state wave functions for the calcium isotopes along with departing from the double-magic number nucleus ^{40}Ca.

In conclusion, the spectroscopic factors for a number of proton states, containing newly decided ones, have been obtained by the (d,n) reactions on the ^{40,44}Ca isotopes at $E_d = 25$ MeV. With some exceptions for the L = 4 transfer, angular distributions were well reproduced by the DWBA calculation using the adiabatic deuteron potential. Particle strengths for the $1d_{3/2}$ and $2s_{1/2}$ shells have been observed with increasing magnitudes for the ^{44}Ca(d,n)^{45}Sc reaction.

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9) Youngblood D. H. et al., Phys. Rev. C **2** (1970) 477.

Table 1. Spectroscopic factors for ^{41}Sc obtained by the ^{40}Ca(d,n)^{41}Sc reaction at $E_d = 25$ MeV.

Ex(MeV)	*l*	J^π	C^2S	(2J+1)C^2S		
				Present	(α,t)40MeV [a]	(3He,d)40MeV [b]
0	3	7/2$^-$	1.07	8.6	8.88	8.96
1.72	1	3/2$^-$	1.01	4.0	3.66	3.4
2.09	2	3/2$^+$	0.096	0.38		0.27
2.41	1	3/2$^-$	0.11	0.43		0.36
3.47	1	1/2$^-$	0.80	1.6		1.5
3.73	1	1/2$^-$	0.24	0.47		0.16
5.04	4	9/2$^+$	0.27	2.7		1.8
5.42	2	5/2$^+$	0.27	1.6		0.19
5.71	3	5/2$^-$	0.34	2.1		0.90
5.87	3	5/2$^-$	0.15	0.92		0.36
6.47	3	5/2$^-$	0.23	1.4		(0.54)

a) D. H. Youngblood et al., Nucl. Phys. A143 (1970) 512.
b) D. H. Youngblood et al., Phys. Rev. C 2 (1970) 477.

Table 2. Spectroscopic factors for ^{45}Sc obtained by the ^{44}Ca(d,n)^{45}Sc reaction at $E_d = 25$ MeV.

E_x(MeV)	l	J^{π} [a]	C^2S	(2J+1)C^2S		
				Present	(^{3}He,d)24MeV [b]	(^{3}He,d)11MeV [c]
0	3	$7/2^-$	0.71	5.7	5.6	
0.012	2	$3/2^+$	0.49	2.0	1.9	2.12
0.376	1	$3/2^-$	0.11	0.44		0.56
0.939	0	$1/2^+$	0.09	0.18		(0.54)
1.07	1	$3/2^-$	0.17	0.67		0.56
1.56	1	$3/2^-$	0.12	0.50		0.28
2.33	1	$(3/2^-)$	0.03	0.11		0.12
2.75	3	$(5/2^-)$	0.20	1.2		
3.03	1	$(3/2^-)$	0.16	0.63		(0.64)
	3	$(7/2^-)$	0.07	0.58		
3.44	1	$(3/2^-)$	0.07	0.26		(0.28)
	3	$(7/2^-)$	0.11	0.87		
3.93	1	$(3/2^-)$	0.13	0.53		0.40
	3	$(7/2^-)$	0.04	0.33		
4.17	2	$(3/2^+)$	0.05	0.19		
	3	$(7/2^-)$	0.04	0.31		
4.51	1	$(3/2^-)$	0.04	0.14		(0.16)
	3	$(7/2^-)$	0.02	0.19		
4.70	1	$(3/2^-)$	0.03	0.12		
5.44	2	$(3/2^+)$	0.07	0.26		
5.77	1	$(3/2^-)$	0.03	0.12		
	3	$(7/2^-)$	0.03	0.26		
5.95	1	$(3/2^-)$	0.06	0.25		
6.70	3	$(7/2^-)$	0.31	2.4		
8.12	1	$3/2^-$	0.25	0.98		
8.52	1	$3/2^-$	0.10	0.39		

a) J^{π}'s in parentheses were assumed in the present work

b) A. Von der Decken et al., Phys. Lett. **41B** (1972) 477.

c) J. J. Schwartz and W. P. Alford, Phys. Rev. **149** (1966) 820. The numbers in the parentheses are those evaluated by assuming J^{π}'s in this paper.

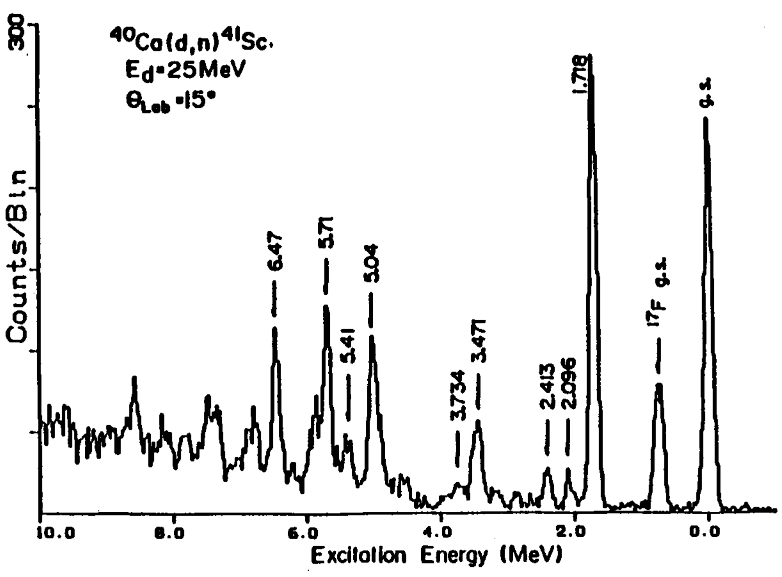


Fig. 1a. Neutron energy spectrum for the ^{40}Ca(d,n)^{41}Sc reaction.

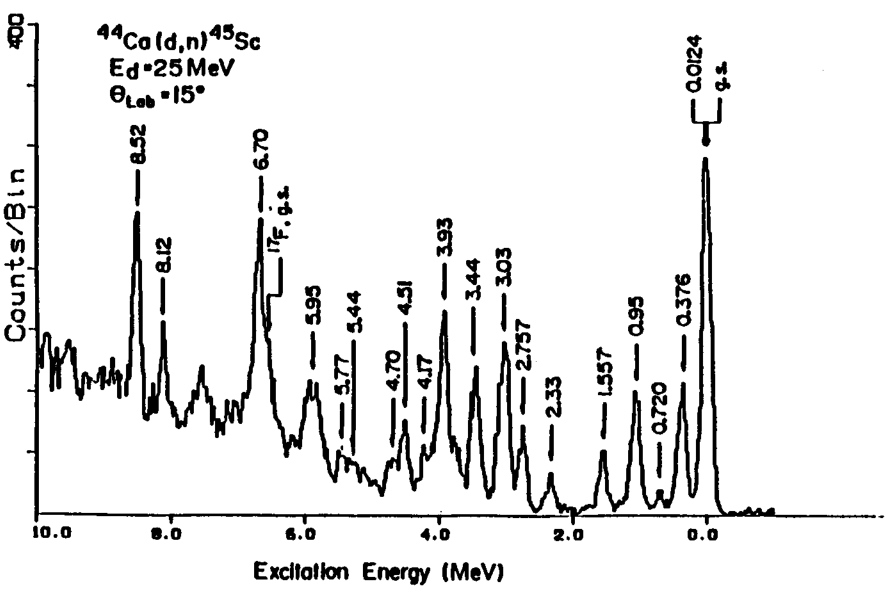
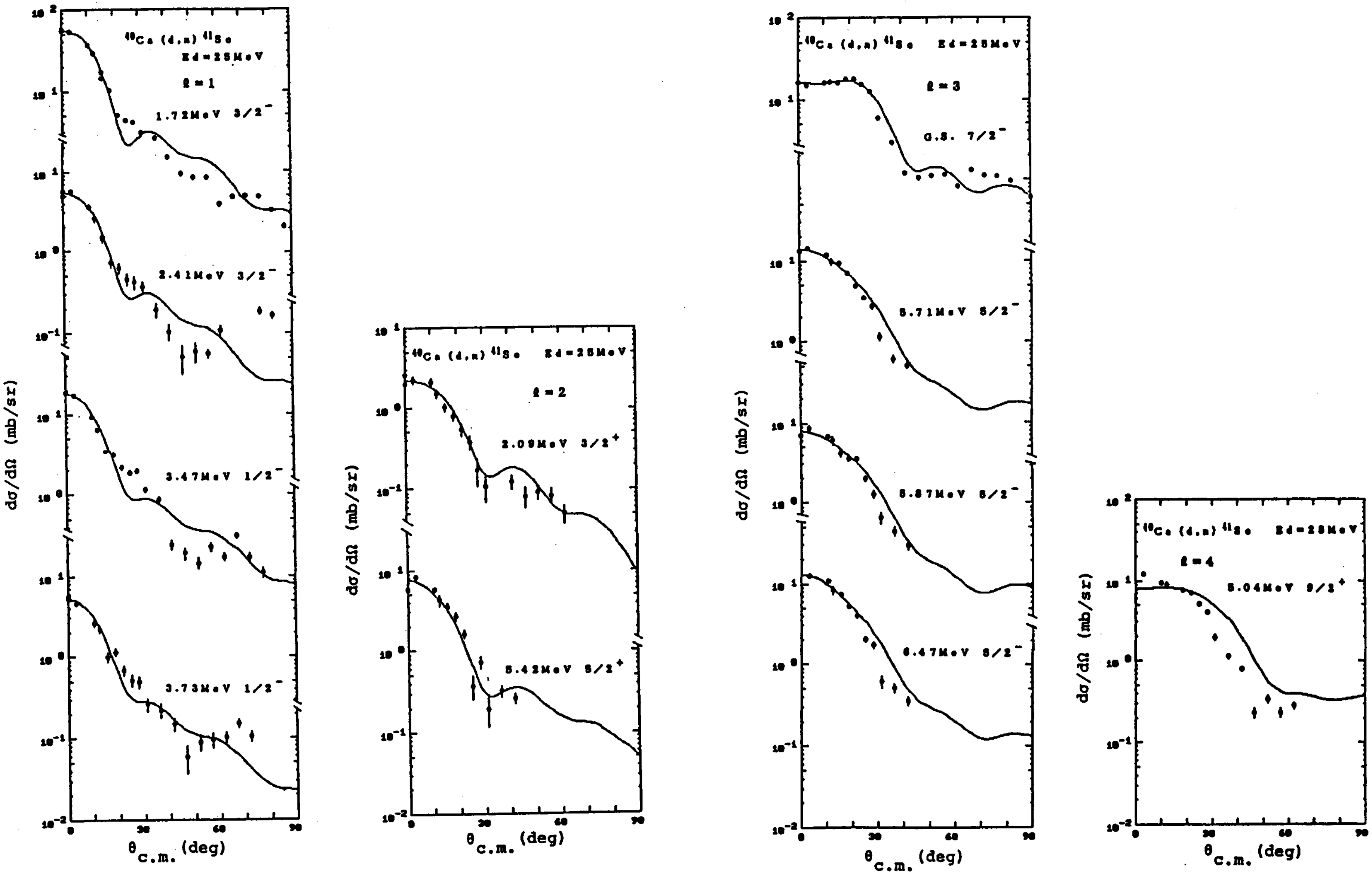
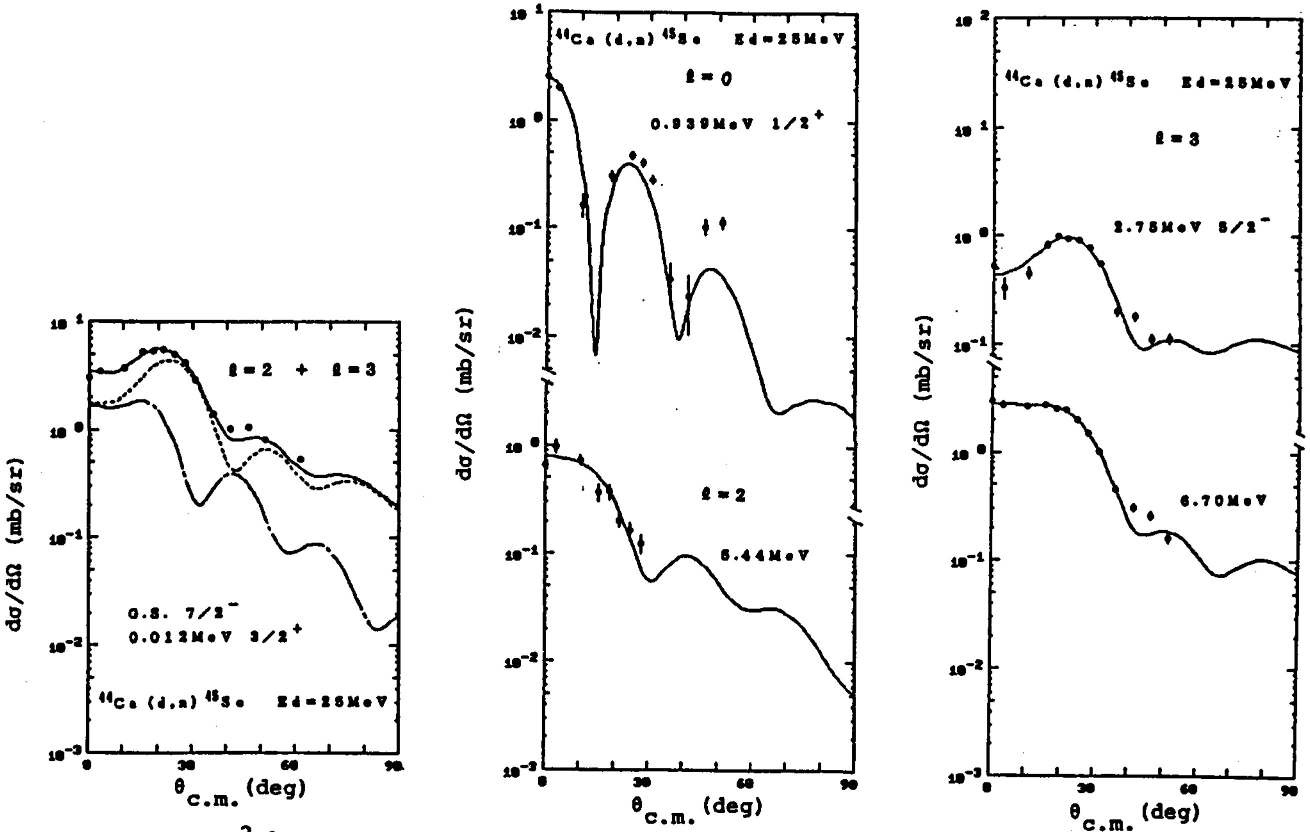


Fig. 1b. Neutron energy spectrum for the ^{44}Ca(d,n)^{45}Sc reaction.



2-a 2-b 2-c 2-d

Fig. 2a-2d. Angular distributions of emitted neutrons in the ^{40}Ca(d,n)^{41}Sc reaction. Solid curves represent the results of the DWBA calculation mentioned in text.

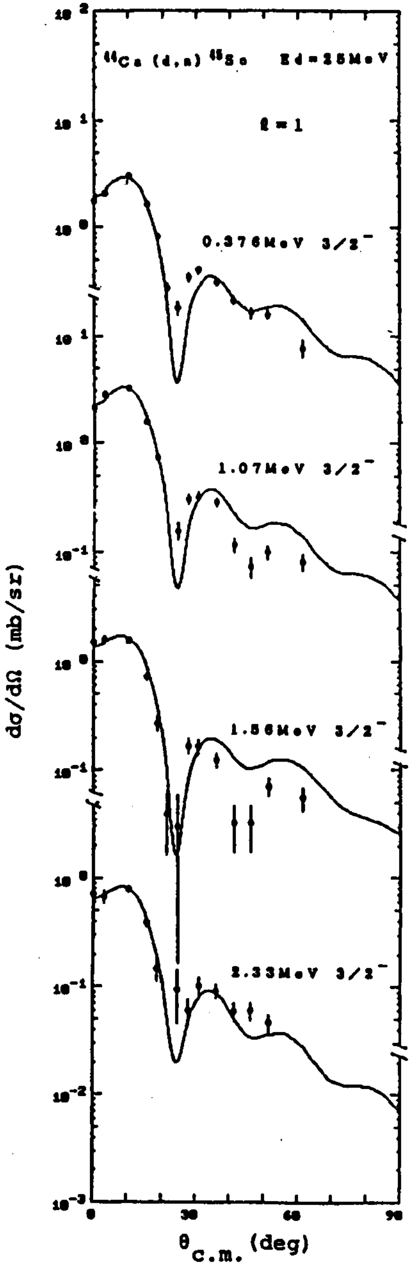


3-a

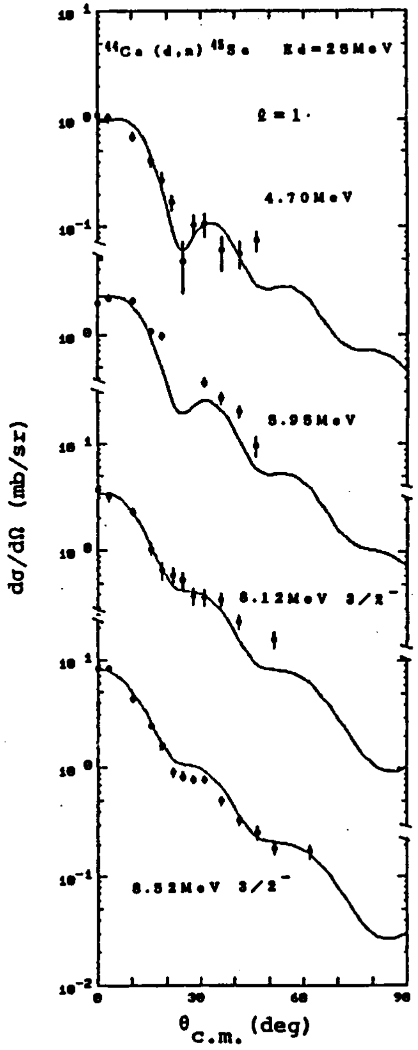
3-b

3-c

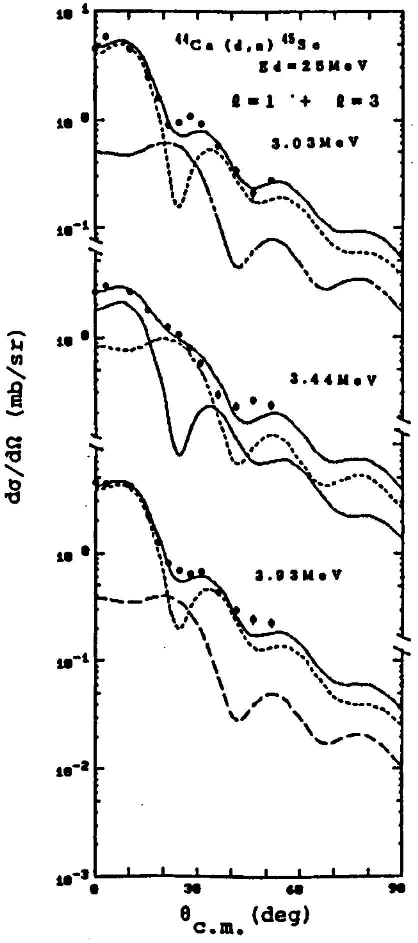
Fig. 3a-3g. Angular distributions of emitted neutrons in the ^{44}Ca(d,n)^{45}Sc reaction. Solid curves show the DWBA predictions. The observed differential cross sections summed up for the unresolved ground and 0.012 MeV states are shown. Angular distributions for other unresolved peaks are also presented by decomposing into two assumed transfer-L components by least-square fitting.


^{44}Ca (d,n) ^{45}Sc Ed=25MeV
ℓ=1
0.376MeV 3/2$^-$
1.07MeV 3/2$^-$
1.56MeV 3/2$^-$
2.33MeV 3/2$^-$
dσ/dΩ (mb/sr)
$\theta_{c.m.}$ (deg)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
30
60
90

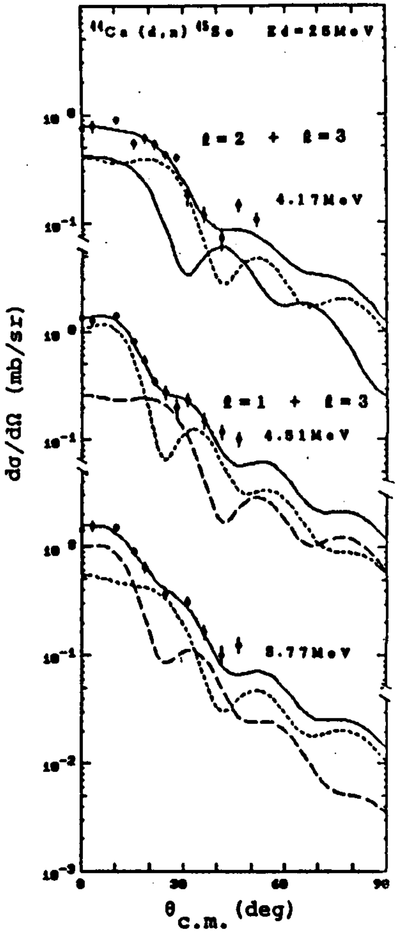
3-d


^{44}Ca (d,n) ^{45}Sc Ed=25MeV
ℓ=1
4.70MeV
5.95MeV
6.12MeV 3/2$^-$
6.52MeV 3/2$^-$
dσ/dΩ (mb/sr)
$\theta_{c.m.}$ (deg)
10^1
10^0
10^{-1}
10^{-2}
0
30
60
90

3-e


^{44}Ca (d,n) ^{45}Sc
Ed=25MeV
ℓ=1 + ℓ=3
3.03MeV
3.44MeV
3.93MeV
dσ/dΩ (mb/sr)
$\theta_{c.m.}$ (deg)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
30
60
90

3-f


^{44}Ca (d,n) ^{45}Sc Ed=25MeV
ℓ=2 + ℓ=3
4.17MeV
ℓ=1 + ℓ=3
4.81MeV
5.77MeV
dσ/dΩ (mb/sr)
$\theta_{c.m.}$ (deg)
10^0
10^{-1}
10^{-2}
10^{-3}
0
30
60
90

3-g