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STATES IN ^{118}Sn FROM ^{117}Sn (d,p) ^{118}Sn AT 12 MeV

by

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^{118}Sn energy levels up to ≃ 5.2 MeV excitation energy are studied in the reaction ^{117}Sn (d,p) ^{118}Sn. Deuterons had a bombarding energy of 12 MeV.

The protons were analized by a magnetic spectrograph. The detector was nuclear emulsion and the resolution in energy about 10 KeV. The distorted-wave analysis was used to determine ℓ values and spectroscopic strengths. Centers of gravity and the sums of reduced spectroscopic factors are presented for the levels when it was possible to determine the S' value.

66 levels of excitation energy were found which did not appear in previous ^{117}Sn (d,p) reactions. 40 levels were not found previously in any reaction giving ^{118}Sn. The results are compared with the known ones.

INTRODUCTION

Tin is a magic number nucleus with Z = 50. This closed shell of protons reduces the effects of the neutron-proton residual interation in neutron transfer reactions and makes the theoretical calculations more reliable.

Tin has also a large number of stable isotopes. Thus we can make a systematic study using them as target to compare changes in nuclear structure using, for instance, neutron transfer reactions.

In the present paper we study the ^{117}Sn (d,p) ^{118}Sn reaction with incident 12 MeV deuterons. Our resolution, in energy, is about 12 KeV for ^{118}Sn excited states. We analise excitation energies from 0 to 5.2 MeV.

Neutron transfer reactions leading to ^{118}Sn as final nucleus were studied previously by many authors [1-6]. Inelastic scattering [7-14], Coulomb excitation[15], EC decay[18,21], β decay[15-20] and ^{116}Cd (α, 2n γ)[22-24] giving Sn^{118} were also studied.

We make a comparison of ours with other experimental and theoretical results. In the present work many new energy levels were discovered, including states of small cross section. This results from the fact that we have hight-resolution in energy, that the "sum method" (*) was used and also that unexplored regions of ^{118}Sn excitation energies were examined.

(*) We discovered this method in 1968 as referred in Thereza Borello's doctoral thesis (1971) and Maria José Bechara's Master of Science thesis (1973) - University of S. Paulo and described in other papers[25-27]. Our attention was called recently by O. Dietsch to a paper[28] where a similar energy interval and for nearby exposure angles.

EXPERIMENTAL PROCEDURE

Deuterons with 12 MeV energy accelerated in the three-stage University of Pittsburgh Van de Graaff Accelerator hitted a target enriched in ^{117}Sn. This target was 80 $\mu g/cm^2$ thick and with a carbon support 20 $\mu g/cm^2$ thick.

The target composition in Sn isotopes is given in table I.

Sn	112	114	115	116	117	118	119	120	122	124
%	0.08	0.04	0.06	2.34	89.2	4.5	1.12	2.16	0.26	0.28

Table I - Isotope composition of the target.

The scattered protons were analised in an Enge split pole magnetic spectrograph.

We used as detector nuclear emulsions of Kodak type NTB plates 50 μm thick, that were placed in the focal surface of the spectrograph.

Particles heavier than protons were absorbed by aluminum foils. Deuterons scattered elastically were continuously monitored by two NaI(T1) scintillators symmetrically located at about 39^{o} with to the incident beam direction. Relative normalization of the (d,p) cross sections was obtained from them.

The absolute normalization of cross sections was made using the 12 MeV deuterons elastic cross section on tin at the monitor angle (38.7^{o}) calculated with the code DWUCK[29] using an Saxon-Woods shape potential with the Perey-Perey[30] parameters shown in table II.

	Deuteron	Bound Neutron	Proton
V (MeV)	98.81	a	*
r_o (F)	1.15	1.25	1.25
a_o (F)	0.81	0.65	0.65
w_D (MeV)	17.3		13.5
r_D (F)	1.34		1.25
a_D (F)	0.68		0.47
r_C (F)	1.15		1.25
V_{So} (MeV)		$\lambda_{So} = 25$	7.5
r_{So} (F)			1.25
a_{So} (F)			0.47

Table II - Bound-state and Optical model parameters used in DWUCK calculation

$$* \quad V = 53.3 + \frac{27\ (N_{Sn} - Z_{Sn})}{118} + \frac{0.4 \times Z_{Sn}}{118^{1/3}} - 0.55\ E_p$$

where Sn indicates ^{118}Sn .

a - Adjusted to reproduce the neutron binding energy

The plates we obtained were exposed only at six laboratory scattering angles from 8^{o} to 45^{o}. They were scanned both at São Paulo and Rio de Janeiro in 0.2 mm intervals along the plate on Leitz-Ortholux microscopes with 1.25 x 15 x 25 magnifi-

cation. The distances were measured with an accurate AMES 3223 M clock. Fig. 1 gives a typical spectrum that corresponds to 27° in the laboratory.

The energy calibration of Moyer[31] was adopted and the relativistic computer code SPECTRE[32] was used to calculate the excitation energy of the residual nucleus. In fig. 1 the peaks in excitation energy of ^{118}Sn are numbered. Other peaks exist that are from ^{118}Sn isotopes or other contaminations. If the energy of a peak which appears in all the angles, can be accounted as an isotope already found in tin (d,p) reactions[2,25,26,27] we can test if it is only an isotope peak. If the intensity of the peak is larger than expected, using the values of S or S' given in the referred papers and the target composition, the peak is assumed to be from ^{118}Sn plus the isotope peak which is discounted.

To identify the weakly excited levels we used the "sum method". It was observed that for all tin isotopes the histograms of the proton tracks for Sn (d,p) reaction at two different angles have the peaks uniformelly displaced by a constant amount. This results essentialy from the fact that for medium (as tin) and heavy nuclei, the distances between two corresponding peaks are the same (within errors of ours measurements) at all angles if the spectrograph is linear, i.e., if the distance of the proton track from the edge of the plate is linear in its momentum.

For elements with different mass, however, the displacements are different (dependence on the recoil nucleus).

Fig. 2 shows the sum spectrum when the corresponding peaks are added together, reenforcing the tin peaks. This is noticeable, when Figs. 1 and 2 are compared.

Tables III, IV, fig. 3 and fig. 4 summarize our results and will be discussed later.

DISTORTED-WAVE BORN APPROXIMATION ANALYSIS (DWBA)

We used the DWUCK[29] code for DWBA calculations. The corrections of finite range and nonlocality effects are included in it. The correction parameters were $\beta_d = 0.54$ F, $\beta_p = 0.85$ F and R = 0.62 F.

A real potential well of Woods-Saxon shape corresponding to $r_o = 1.25$ F, $a_o = 0.65$ F, $\lambda_{So} = 25$ MeV and with the depth adjusted by the code to reproduce the neutron binding energy, was assumed to bind the captured neutrons. The optical parameters and bound-state employed are given in table II.

The reduced spectroscopic factors

$$S'_{\ell j} = \frac{(2J_f + 1)}{(2J_i + 1)} S_{\ell j}, \qquad (1)$$

were J_f is the spin of state observed in the stripping process, J_i is the spin of the target nucleus and $S_{\ell j}$ is the spectroscopic factor for the considered state in (d,p) reaction, calculated using:

$$S'_{\ell j} = \frac{(d\sigma/d\Omega)_{exp.} \ (2J_n + 1)}{1.53 \ \sigma_{\ell j}^{DWBA}} \qquad (2)$$

where J_n is the total angular momentum of the captured neutron, $(d\sigma/d\Omega)_{exp.}$ is the experimental value of the cross section in

the first maximum of the angular distribution which fits our experimental points and $\sigma_{\ell j}^{DWBA}$ is the DWBA cross-section taken at the same point. For $\ell = 0$ the second maximum in the angular distribution is used.

The values of ℓ alone are not sufficient to define the total angular momentum transferred. It depends also on the level which the neutron will occupy in the final nucleus. We used the shell model to ascribe the possible total transferred momenta. The more probable transitions are to the levels 1g 7/2, 2d 5/2, 2d 3/2, 3s 1/2 and 1h 11/2 in the neutron shell 51-82 of ^{118}Sn. We also obtained transitions associated to 83-126 neutron shell.

The best fits between the calculated angular distribution by the DWUCK and the experimental ones were found by trial and error and are shown in figs. 3a, 3b, 3c and 3d.

No DWBA angular distribution was accepted if one of the experimental points falls outside twice the experimental error from the curve. If there are two values of ℓ that satisfy this criterium both curves were drawn in fig. 3. If no $\ell \leq 5$ curve fits the data, if more than two values of ℓ fit them or if the angular average of $\frac{d\sigma}{d\Omega}$ is smaller than 0.006 mb/sr for a given peak (weak peak) the curves are not plotted in fig. 3. In these cases we put in table III as $(\frac{d\sigma}{d\Omega})_{max}$ the higher experimental value for this peak.

For $\ell = 2$ the DWBA curves correspond to J_n transferred equal $3/2^+$ or $5/2^+$. In two cases only one of the curves agrees with our data. In all other cases the data are in agreement with both curves. In these cases we obtain S' and J^π with the transferred momentum corresponding to the curve that fits better the data and is draw in fig.3. These values are indicated in table III with J^π in parenthesis.

For ℓ = 1,3 or 5 we used respectively the J_n values $3/2^-$, $7/2^-$ and $11/2^-$ which is the usual, not so convincing, assumption. In these cases we put, in table III the values of J^π in parenthesis.

RESULTS AND DISCUSSION

The results of excitation energy, orbital angular momentum transfered, total angular momentum and parity of the observed state, experimental cross-section and reduced spectroscopic factors are summarized in Table III together with Schneid et al[2], Norris et al[1], Poelggeest et al[24], Fleming[6] results and adopted levels from Nuclear Data Sheets[33].

^{117}Sn (d,p) ^{118}Sn										^{119}Sn(p,d)^{118}Sn		$^{116}Cd(\alpha,2n)$		Adopted Levels until 1976	
Results of the present experiment E_d = 12 MeV						Schneid et al[2] E_d = 15 MeV			Norris[1] et al E_d=11-12MeV	Fleming[6] E_d = 20 MeV		Poelgeest et al[24] E_d=17-33 MeV		Nuclear Data Sheets[33]	
Level Number	E_x (MeV)	ℓ	J^π	$(d\sigma/d\Omega)_{max}$ mb/sr	S'	E_x (MeV)	ℓ	S'	E_x (MeV)	E_x (MeV)	J^π	E_x (MeV)	J^π	E_x (KeV)	J^π
0	0.0	0	0^+	1.049	0.449	0.0	0	0.70	0.0	0.0	0^+	0.0	0^+	0.0	0^+
1	1.230	2	$(2^+$ or $3^+)$	0.190	0.236	1.22	2	0.39	1.220	1.23	2^+	1.2296	2^+	1 229.64 4	2^+
2	1.758	0	0^+	0.188	0.064	1.75	0	0.10	1.750	1.78	0^+			1 757.8 4	0^+
												2 0424	2^+	2 043.1 4	(2^+)
3	2.058	0	0^+	0.188	0.062	2.05	0	0.084	2.050	2.05	0^+			2 056.5 6	0^+
														2 120	
4	(2.279)			0.004								2.2803	4^+	2 280.33 4	4^+
														2 310 10	(3^-)
												2.3212	5^-	2 321.15 3	5^-
5^γ	2.329	2	$(1^+$ or $2^+)^*$	0.720	0.837	2.32	2	1.14	2.320	2.34	2^+			2 326.5 3	$(1^+, 2^+$ or $3^+)$
6^γ	(2.408))			0.008					2.380					2 402.6 4	(2^+)
														2 405 15	(4^+)
												2.4866	4^+	2 488.9 3	(4^+)
7^γ	2.500	0	0^+	0.557	0.172	2.49	0	0.51	2.490	2.53	0^+			2 496.6 5	0^+
									2.540						
												2.5749	7^-	2 574.83 4	7^-
8	(2.577)			0.006										2 576 15	(4^+)
9	2.680	2	$(2^+$ or $3^+)$	0.128	0.124				2.670					2 677.4 5	(2^+)
10	2.741	2	1^+ or 2^+	0.802	0.933	2.72	2	1.37	2.730	2.74	(2^+)			2 725	$(1^+, 2^+$ or $3^+)$
												2.7338	4^+	2 733.6 8	(4^+)
11	(2.775))			0.010										2 769 10	
12	2.817	(5)	$(5^-$ or $6^-)$	0.421	1.202				2.810					2 810	
									2.840					2 840	
									2.860					2 860	
									2.890			2.8785	(6^+)	2 892 5	
13^γ	2.908	(2)	$(1^+$ or $2^+)$	0.433	0.445				2.920	2.93	(2^+)			2 904 12	(2^+)
														2 929.3 7	(2^+)
$14^{\alpha\delta}$	2.933	0	0^+	0.064	0.018									2 930 20	$(3^+, 4^+$ or $5^+)$
$15^{\alpha\delta}$	2.961														
				0.030										2 963.6 7	(4^+)
16	2.972														
17	((2.991))			0.006								2.9994	6^+		
18	(3.020)			0.006											
												3.0521	8^+	3 0550 25	(8^+)
19	3.064	2	$(2^+$ or $3^+)$	0.049	0.043	3.06	2	0.042	3.050					3 058 10	2^+
												3.1082	10^+	3 111.5 25	(10^+)
$20^{\gamma\delta}$	3.141			0.018					3.130					3 137.2 5	(0^+)
									3.150					3 150	
														3 198 6	
														3 228 14	(8^+)

21[c]	3.237			0.035										3 240	10	
22	(3.264)			0.005										3 254	8	
23	(3.274)			0.008										3 274	14	(7^-)
24	(3.286)			0.008										3 275	7	
25	3.317	1	$(1^-$ or $2^-)$	0.027	0.007				3.300					3 320		
26	(3.344)			0.008					3.340					3 337	7	
27	3.363	0	0^+	0.020	0.006				3.360					3 369	15	
28[a]	3.383								3.380					3 380		
		(2)	$(1^+$ or $2^+)$	0.055	0.052											
29	3.389								3.390					3 393	10	
30[a]	3.409															
				0.020												
31	3.423													3 423	7	
32	((3.441))			0.006												
33[a]	3.464															
		(3)	$(3^-$ or $4^-)$	0.045	0.055				3.470					3 471	10	(4^+)
34	3.475															
35	3.543	(2)	$(2^+$ or $3^+)$	0.033	0.025				3.520					3.520	20	
									3.550					3 534	17	$(6^+$ or $7^-)$
36	3.576	3	$(3^-$ or $4^-)$	0.070	0.085				3.570					3 562	7	
37	3.597	2	$(2^+$ or $3^+)$	0.144	0.109									3 585	10	(2^+)
38	(3.635)			0.007												
39	(3.643)			0.006										3 664	14	(4^+)
40	(3.677))			0.005												
41	3.721	1	$(1^-$ or $2^-)$	0.169	0.042	3.70	2	0.12	3.700			3.6919	8^+	3 698	10	(6^+)
42	3.750	1 or 2	$(1^-, 2^-,$	0.039 or	0.010 or									3 700	20	
			2^+ or $3^+)$	0.033	0.025					3.750	(2^+)			3 722	10	
43	3.784	(0)	(0^+)	0.015	0.003	3.79	3	0.16	3.790					3 746	10	
44	3.819	2	$(1^+$ or $2^+)$	0.078	0.058									3 773	16	
45	(3.857)			0.007										3 808	6	
46	3.889	(1)	$(1^-$ or $2^-)$	0.016	0.003				3.890					3 857	10	(2^+)
														3 879	14	
47	3.916	2	$(1^+$ or $2^+)$	0.061	0.049	3.91	2	0.20	3.910					3 895	10	
48	3.937	2	$(1^+$ or $2^+)$	0.049	0.040									3 910		$1^+, 2^+$ or 3^+
49	3.995	1	$(1^-$ or $2^-)$	0.023	0.006					3.94	(2^+)			3 946	14	
														3 977	10	
50	4.046	1 or 2	$(1^-$ or 2^-,	0.173 or	0.039 or	4.04	2	0.13	4.020					4 014	12	
			2^+ or $3^+)$	0.179	0.123					4.06	(2^+)			4 055	14	$1^+, 2^+$ or 3^+
														4 107	10	
51	4.115	1	$(1^-$ or $2^-)$	0.062	0.015									4 112	6	

52	4.136	2	(1^+ or 2^+)	0.044	0.036					4.12	(2^+)				
53	4.203	2	(1^+ or 2^+)	0.024	0.019										
54	4.233	(3)	(3^- or 4^-)	0.023	0.025									4 190	
55[α]	4.252			0.030											
56	4.288														
57[α]	4.313			0.025											
58	4.326														
59	(4.352)			0.008											
60	(4.365)			0.007											
61[α]	4.391			0.025											
62	4.408														
63[γ]	4.422	(0)	(0^+)	0.012	0.002										
64	4.448	(2)	(1^+ or 2^+)	0.017	0.012	4.44	2	0.082	4.400						
65[α]	4.472	(1)	(1^- or 2^-)	0.038	0.008									4 420	
66	4.484														
67	(4.507)			0.007								4.4953	10^+	4 494	7
68	(4.523)			0.008											
69	4.540	1 or 2	(1^-, 2^- or 1^+, 2^+)	0.014	0.003 or 0.010									4 540	
70	4.573	(1)	(1^- or 2^-)	0.019	0.005										
71[ε]	4.617			0.024											
72	4.637	2	(2^+ or 3^+)	0.082	0.051										
73[α]	4.696			0.043											
74	4.706														
75	4.798	(0or3)	(0^+, 3^- or 4^-)	0.016 or 0.014	0.003 or 0.012									4 757 4 800	7 (3)
76	4.832	0	0^+	0.066	0.014										
77[γ]	4.862	0	0^+	0.025	0.006										
78	4.879	0	0^+	0.040	0.008									4 895	7
79[γ]	4.940	(3)	(3^- or 4^-)	0.087	0.076										
80[β]	5.006														
81	5.014	3	(3^- or 4^-)	0.067	0.060										
82	5.025														
83[εγ]	5.043			0.020										5 040	
84	5.068	(3)	(3^- or 4^-)	0.082	0.073										
85[ε]	5.098			0.011										5 100	
86	5.116	1 or 2	(1^-, 2^-, 1^+ or 2^+)	0.019 or 0.016	0.005 or 0.010										
87[β]	5.142														
88	5.150			0.090											
89[β]	5.163														
90[β]	5.181														
91	5.193			0.034											
92	5.208														

TABLE III - Comparison of experimental results on ^{118}Sn levels.

() Excitation energy in parenthesis means weak level ($d\sigma / d\Omega$) average < 0.006. (( )) means very doubtful level.

(1^+ or 2^+) and (2^+ or 3^+) means J^π may be 1^+, 2^+ or 3^+ (see section: Distribution of Spectroscopic Strengths)

* means strong indication of $J_n = 3/2^+$.

α This level and the following one are members of an unresolved doublet.

β This level and the following two are members of an unresolved triplet.

γ Probable unresolved doublet.

δ It was not possible to fit any $\ell < 5$ curve to it.

ε More than two values of ℓ fit the data.

EXCITATION ENERGIES (EX), ORBITAL ANGULAR MOMENTUM (ℓ) TRANSFERRED AND FINAL STATE SPIN (J^{π})

In table III the excitation energies indicated are the average of the excitation energies at the angles used: 8^{o}, 12^{o}, 20^{o}, 27^{o}, 33^{o} and 45^{o}. They were obtained making use of the focal plane calibration of the spectrograph and using the well known energy of the first level of ^{118}Sn (1229.64 ± 0.04 KeV) as reference. The calibration of the spectrograph gives ≅ 0.25% uncertainity in the absolute excitation energies. The average value of the standard deviation of excitation energy measurement in one of the six angles was 3.2 KeV (actually from 1.9 KeV to 4.5 KeV) up to 3.5 MeV. From 3.5 MeV to 5.2 MeV it was 3.4 KeV (actually from 1.5 KeV to 5.5 KeV).

We have found 93 levels including all Schneid et al[2] peaks which were also found by Norris et al[1]. All 33 peaks of Norris et al[1] but 2 were also found in the present paper. However four of them corresponding to 2.540 MeV, 2.840 MeV, 2.860 MeV and 3.150 MeV indeed exist but are from isotopic contamination. The first is from ^{117}Sn (0.1586), the following two are from ^{119}Sn(G.S. and 0.024), and the last one is from ^{121}Sn(G.S.) plus ^{120}Sn(2.938) Thus we found 66 peaks which did not appear in previous ^{117}Sn(d,p) papers[1,2]. These we ones include 18 weak peaks. For the weak peaks only energies and $(d\sigma / d\Omega)_{max}$ calculated with the highest observed point in the angular distribution are indicated. We did not try to obtain the ℓ values because we have not enough confidence in the significance of errors in the cases. However among the adopted levels[33] and in a more recent paper[24] eleven of the energy values of these peaks are found.

Peaks with orbital angular momentum transfer 6 and 7 are unlikely and values larger than 7 are not expected in our case.

We did not find a number of the following known excited states (energies in MeV):

a) with ℓ = 8 or more: 3.0521, 3.1082, 3.6919 and 4.4953, all of them found in ^{116}Cd (α, 2n). Also 3.228 (J^{π} = (8^{+})) found in inelastic scattering.

b) with ℓ = 6 or 7: 2.8785 (J^{π} = (6^{+})) found in ^{116}Cd (α , 2n) and 3.534 (J^{π} =(6^{+} or 7^{-})) found in inelastic scattering. Values compatible with both 2.890 and 3.550 were found also by Norris et al[1]. The two energies 2.5748 and 3.274 that correspond to J^{π} = 7^{-} and J^{π} = (7^{-}) respectively agree however with weak levels energies we found. The energy 2.9994 (J^{π} = 6^{+})[24] is compatible with our 2.991 weak peak.

c) with ℓ = 5 we found no peak corresponding to 2.32115 found in ^{116}Cd (α , 2n), ^{118}In β decay, ^{116}Sn (t,p) and ^{118}Sb EC decay.

d) As in the previous papers on ^{117}Sn (d,p) we found no energy surely corresponding to states J^{π} = 4^{+}. The known 4^{+} states are given below, by the energy followed by the reaction leading to ^{118}Sn were they were observed:

2.28033 - Cd (α , 2n), ^{118}In β decay, ^{118}Sb EC decay and ^{116}Sn (t,p)

2.405 (J^{π} = (4^{+})) - ^{116}Sn (t,p)

2.4889 - ^{118}In β decay and Cd (α, 2n)

2.7336 - ^{116}Cd (α, 2n)

2.930 - (J^{π} = (4^{+})) ^{119}Sn (p,d)

2.9636 (J^{π} = (4^{+})) - ^{118}In β decay, ^{116}Sn (t,p)

3.471 (J^{π} = (4^{+}))-inelastic scattering.

3.664 (J^{π} = (4^{+})) - inelastic scattering.

The energies 2.28033 and 3.664 however agree with weak peaks we have. At 2.930 we found instead a 0^{+}.

The excitation energies 2.961 and 2.972 exist in the present work but it was not possible to determine the ℓ values. These energies agree with 2.9636 (J^{π} = (4^{+})) given in [33].

Other doublet 3.464 and 3.475 very near 3.471 (J^{π} = (4^{+})) given in[33] appears in the present work but with ℓ = (3).

The values ℓ = 4 for the level 2.576 from ^{116}Sn(t,p) in reference[33] page 16 may be a misprint: in pages 17 and 24 that energy is referred as ℓ = 7. Thus it should be the same level as 2.57483 ($J = 7^{-}$). We found a weak peak with excitation energie 2.577.

e) For ℓ = 3 we dont find 2.310 (J^{π} = (3^{-})) found in Coulomb excitation and ^{120}Sn (p,t) reaction.

f) For ℓ = 2 we dont find 2.0431 ($J^{\pi} = 2^{+}$) found in ^{118}In β decay, ^{118}Sb EC decay, ^{117}Sn (γ, n) and ^{116}Cd (α, 2n) as well as 2.9293 (J^{π} = (2^{+})) found in inelastic scattering and ^{118}Sb EC decay reactions.

For our energy 3.721 that corresponds to 3.70 of Schneid et al[2] we found ℓ = 1 instead of ℓ = 2.

g) Four our energy 3.784 that corresponds to 3.79 from Schneid et al[2] we found ℓ = (0) instead of ℓ = 3

h) We also do not find 2.120, 3.198, 3.722, 3.895, 4.014 and 4.757 from reference[33]

For all these energies there are not indications of J^{π}.

Among the 93 excitation energies we found, 40 were unknown in ^{118}Sn. These were the following (in MeV):

a) 8 weaks levels: 3.020, 3.441, 3.635, 3.677, 4.352, 4.365, 4.507 and 4.523. The level 4.617, the member 2.972 of the doublet (2.961, 2.972), the member 3.409 of the doublet (3.409, 3.423), the members of four doublets (4.252, 4.288), (4.313, 4.326), (4.391, 4.408) and (4.696, 4.706) and the members of two triplets (5.142, 5.150, 5.163) and (5.181, 5.193, 5.208) for which it was not possible to determine the ℓ values.

b) ℓ = 0: 4.832 and 4.862; ℓ = (0): 4.422.

c) ℓ = (1): doublet (4.472, 4.484) and one level 4.573; ℓ = 1 or 2: 5.116.

d) ℓ = 2: 4.637

e) ℓ = 3: one level 5.068 and the members of a triplet (5.006, 5.014, 5.025); ℓ = (3) one member of the doublet (3.464, 3.475), two levels 4.233 and 4.940.

Almost all of them are in the less explored region 4.0 to 5.2 MeV.

Among the 53 known levels of ^{118}Sn (below 5.2 MeV) we found there were not previous indication of ℓ in 22 cases. We found the ℓ values of 14 of them (energies in MeV):

a) ℓ = 0: 3.369 and 4.895

b) ℓ = 1: 3.320, 3.977 and 4.107; ℓ = (1): 3.879

c) ℓ = 2: 3.808 and 4.190; ℓ = (2): 3.380, 3.393 and 3.520; ℓ = 1 or 2: 4.540

d) ℓ = 3: 3.562

e) ℓ = (5): 2.810

In eight cases we also did not find the ℓ values.

In 18 of the remaining 31 cases the values of ℓ previously determined are compatible with ours but in 9 cases we could not find the ℓ values. In the last 4 cases our ℓ values are incompatible with the previous by known values 2.930 (ℓ = 4), 3.470 (ℓ=(4)), 3.700 (ℓ = 2) and 3.773 (ℓ = 3) as we found 2.933 (ℓ = 0), a doublet 3.464 and 3.475 (ℓ = 3), 3.721 (ℓ = 1) and 3.784 (ℓ = (0)).

Our excitation energies are compatible with the corresponding adopted levels but in average are about 4 KeV higher.

Our energies are $\tilde{-}$ 10 KeV larger than the energies in Schneid et al and in Norris et al. In both papers the first level is at 1.22 MeV while we take as first level the well known[33] value 1229.64 $\pm$ 0.04 KeV (1.230 MeV).

EXPERIMENTAL CROSS-SECTION $(d\sigma / d\Omega)_{max}$ AND THE REDUCED SPECTROSCOPY FACTOR

Formula 2 gives the values of S' using $(d\sigma/d\Omega)_{max}$ and the corresponding σ^{DWBA}. The error in $(d\sigma/d\Omega)_{max}$ is $\simeq$ 20% (due to uncertainty in the countings of protons and deuterons in the solid angles of spectrograph and monitor and in the elastic cross-section adopted). The same error $\simeq$ 20% is expected for σ^{DWBA} [34]. Thus the error in S' is of the order of 30%.

From the zeroth Schneid et al[2] level to the seventh one our values of S' are higher than their values, but they agree within 30% error except the fifth. For their levels eighth and ninth our values of ℓ disagree. Their tenth and twelfth levels also disagree with our in S' but they were separated in more than

one level in the present work (with higher resolution in energy). We also agree with the S' value for the Schneid et al[2] eleventh level if our ℓ is 2.

DISTRIBUTION OF SPECTROSCOPIC STRENGTHS

Using the criterions to be explained in this section for transfer values we calculated for each shell-model orbital ℓj the center of gravity $E_{\ell j}$:

$$(3) \qquad E_{\ell j} = \frac{\Sigma E^*_{\ell j} S'_{\ell j}}{\Sigma S'_{\ell j}}$$

$E^*_{\ell j}$ ($Ex_{\ell j}$) is the excitation energy corresponding to angular momentum transfer ℓ and total momentum transfer j. $S'_{\ell j}$ is the spectroscopic strengths for this energy.

Fig. 4 shows the values of $S'_{\ell j}$ as a function of $E^*_{\ell j}$ and the size of the dashed line indicated for each $E_{\ell j}$ corresponds to $\Sigma S'_{\ell j}$ found for the corresponding shell-model orbital.

Table IV give our results of $E_{\ell j}$ and $\Sigma S'_{\ell j}$ together with Schneid et al[2] values and $E_{\ell j}$ obtained by us using Fleming[6] data.

The sum-rule limit appears also in table IV.

In fig. 4 and table IV we considered all the peaks that had some indication for ℓ. In five cases we had two possible values of ℓ. In four of them ℓ may be 1 or 2 and in one ℓ may be 0 or 3 (peaks 42, 50, 69, 75 and 86).

For peak 42 we give $\ell = 2$ which is the value of Fleming[6]. For peak 50 also we give $\ell = 2$, the value obtained by Schneid et al[2] and Fleming[6]. Besides our value of S' agrees well with the value of Schneid et al[2]. For peaks 69 and 86 we give $\ell = 1$ and for peak 75 $\ell = 0$ which corresponds to the more probable curves.

The separation in J_n $3/2^+$ and $5/2^+$ was made taking into acount the following:

1) We found the more probably transferred momentum for all cases of $\ell = 2$.

2) In two peaks of large intensity (5 and 10) we obtained the value $3/2^+$ for J_n.

3) The values of the center of gravities $E_{\ell j}$ should be the same for each orbital both in (d,p) and (p,d) reactions producing ^{118}Sn.

4) The Clement et al(CB)[35] calculation predicts a concentration of 3/2 strength near 3.0 MeV and 5/2 near 4.0 MeV both spreading in the region between them. We have two large 3/2 peaks 5 (2.329) and 10(2.741) and the largest probable 5/2 peaks are 37(3.597) and 50(4.046).

5) We expect a gaussian like S' distribution.

6) We accept with Fleming[6] the theoretical value 4.45 of CB[35] for the excitation energy and the corresponding value S' = 3.15 as a further $\ell = 2$ level not found in Fleming's experiment (but found in ours) as one of his levels to be used in the analysis.

We thus proceed as follows: the well determined J_n equal $3/2^+$ are accepted for our peaks as well as for the corresponding peaks of Fleming[6], the same beeing done for the other $\ell = 2$ levels using at first the more probable value of J_n (Table III, in parenthesis). $E_{\ell j}$ is calculated for our J_n equal $3/2^+$ and $5/2^+$ both for our paper and for Fleming's (see item 6 above). We then improved the agreement of our $E_{\ell j}$ with the one obtained with Fleming's results by moving, by trial and error, peaks from 3/2 to 5/2 and vice versa.

The distribution of peaks is given in fig. 4.

Actually from 18 $\ell = 2$ levels 9 J_n's did not correspond, in the final classification, to the original more probable values given in Table III. These are peaks 1 (for which we had only the cur-

ve 2 d5/2 to fit our data), 9, 35, 44, 47, 48, 52, 53 and 64 (with small average cross sections $\left(\frac{d\sigma}{d\Omega}\right)_{max} \simeq 0.05$mb/sr). The S' given in the table for these peaks must be multiplied or divided by 1.2 if it changes to 3/2 or 5/2, respectively. The peaks for which J_n did not change had average cross sections $\left(\frac{d\sigma}{d\Omega}\right)_{max} \simeq 0.30$ mb/sr.

The resulting separation of $3/2^+$ and $5/2^+$ corresponds almost to attribute $J_n = 3/2^+$ for peaks below 3.0 MeV and $J_n = 5/2^+$ for those above 3.0 MeV.

$n_{\ell j}$	Present Paper E_d = 12 MeV Ex. up to 5.208 MeV		Sum-rule limit = $2j + 1$	Schneid et al[1] E_d=15 MeV Ex.up to 4.44 MeV		$E_{\ell j}$ ^{118}Sn fro Fleming[6] data
	$E_{\ell j}$ (MeV)	$\Sigma S'_{\ell j}$		$E_{\ell j}$ (MeV)	$\Sigma S'_{\ell j}$	$E_{\ell j}$ (MeV)
1g 7/2	-	0	8	-	0	-
2d (5/2)	3.897	0.529±0.062	6	3.96	0.45±0.08	4.20
2d (3/2)	2.503	2.729±0.408	4	2.36	2.90±0.55	2.42
3s 1/2	1.132	0.807±0.147	2	1.16	1.39±0.26	1.04
1h(11/2)	> 2.817	1.202	12	> 0	0	-
2f (7/2)	> 4.404	0.374	8	> 3.79	0.16	-
3p (3/2)	> 3.987	0.094	4	> 3.70	0.06	-

TABLE IV - Values of $E_{\ell j}$ and $\Sigma S'_{\ell j}$

If $\ell = 2$ in both papers we atribute our j transferred to Schneid et al[2] results. For the Schneid et al[2] level with $\ell = 2$ which disagrees with our $\ell = 1$ we take our $\ell = 1$ (Ex. 3.70 MeV).

In the shell model the valence neutrons in the target, ^{117}Sn, are 17. We expect them to occur in the orbital shell from 50 to 82 and more probably in the 1g 7/2, 2d 5/2, 2d 3/2 and 3s 1/2 orbitals.

We had excitation energies up to 5.208 MeV. With our work conditions we expected to find pratically all spectroscopic strengths corresponding to 1g 7/2, 2d 5/2, 2d 3/2 and 3s 1/2. If we assume that the maximum number of neutrons in each orbitals is given by the sum--rule limit, $\Sigma S'_{\ell j}$ divided by $(2j + 1)$, (table IV) gives us the non occupation probability in each of these shell-model orbital for ^{117}Sn ground state.

Ours results agree very well with Fleming[6] in ^{117}Sn (p,d) ^{116}Sn reaction. From their data we obtained the occupation probabi_ty in each of the referred shell-model orbital (Table V). The exci_tation energies $\lesssim$ 3.01 with ℓ = 2 were taken as $3/2^+$ transferred momentum and the other as $5/2^+$ in ^{116}Sn correspondingly to our sepa_ration in ^{118}Sn. The results for the non occupation probability of of Schneid et al[2] are in table V. For ℓ = 0 Schneid et al[2] results do not agree very well with ours and Fleming[6]. Actually the occupa_tion and non accupation probabilities should add up to one for each orbital when all corresponding reactions are exhausted.

ORBITAL	SCHNEID ET AL[2]	PRESENT WORK	FLEMING[6]
	Non occupation probability		Occupation probability
1g 7/2	0.0	$\simeq$ 0.0	0.700 ± 0.179
2 d 5/2	0.075 ± 0.013	0.088 ± 0.060	0.833 ± 0.066
2 d 3/2	0.725 ± 0.138	0.682 ± 0.102	0.340 ± 0.023
3 s 1/2	0.695 ± 0.131	0.404 ± 0.074	0.615 ± 0.044

TABLE V - Non occupation probability (Schneid et al[2] and present work) and occupation probability (Fleming[6])

In reference 2 they study excited states of ^{118}Sn until $\simeq$ 4.5 MeV . In reference 6 they have excited states of ^{118}Sn until $\simeq$ 4 MeV. At these energies we expect that in both cases practically all reaction involving the 1g 7/2, 2d 5/2, 2d 3/2 and 3s 1/2 orbitals were exhausted. This agrees with the fact that we have few and very small values of S' above 4 MeV for these orbitals (fig.4) and with the results in table V.

The sum of $\Sigma S'_{\ell j}$ for the considered orbitals in Schneid et al[2] is 4.74 $\pm$ 0.61, in the present work is 4.065 $\pm$ 0.438 and in Fleming[6] is 13.19 $\pm$ 1.49.

These results agree with the existence of four holes and sixteen valence neutrons in the referred orbitals for ^{117}Sn ground state.

CONCLUSIONS

We found 93 levels in the reaction ^{117}Sn (d,p) with 12 MeV deuterons, the excitation energies going from 0 to 5.2 MeV. 66 of these levels have not been found before in (d,p) reactions. 40 levels were unknown in any reaction leading to ^{118}Sn (8 of them are weak levels). For 15 of the 32 non weak levels we found the ℓ value. In 53 known excitation energies of ^{118}Sn (including 11 weak levels) that we found, there was no indication of ℓ value for 22 cases.

In 14 of these cases we determined ℓ.

By a joint analysis of ours and Fleming's[6] ^{117}Sn (p,d) results we showed that we have located practically all transitions associated to the orbitals 1g7/2, 3d5/2, 2d3/2 and 3S1/2.

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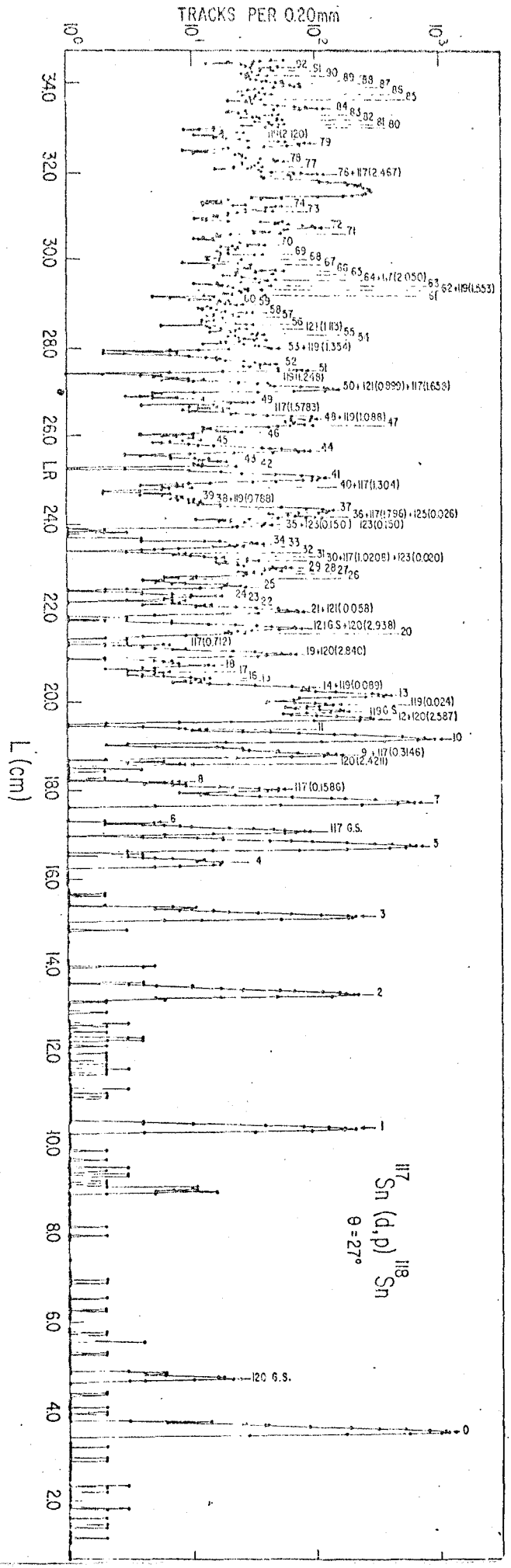

Fig. 1 - The proton spectrum from ^{117}Sn (d,p) ^{118}Sn reaction at $\theta_{Lab} = 27^{0}$.

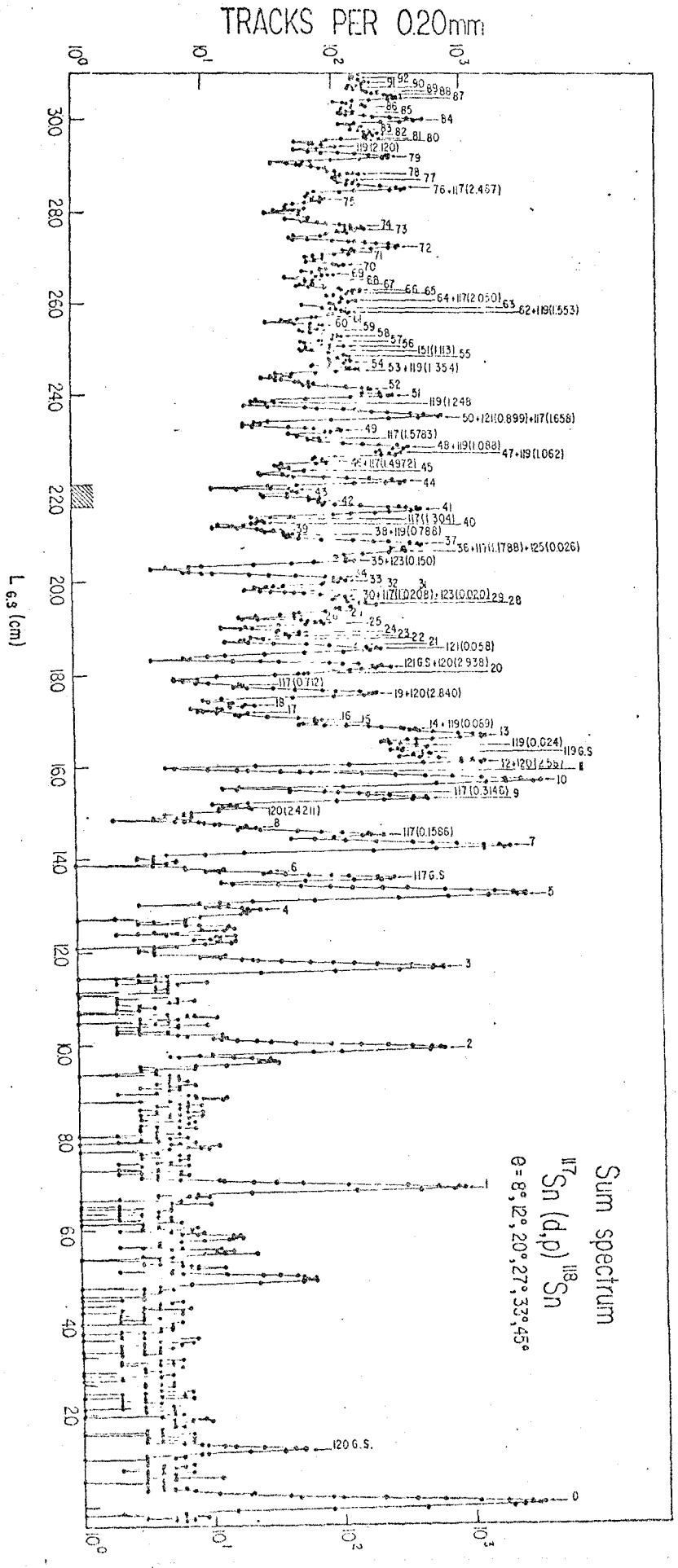

Fig. 2 - Sum Spectrum

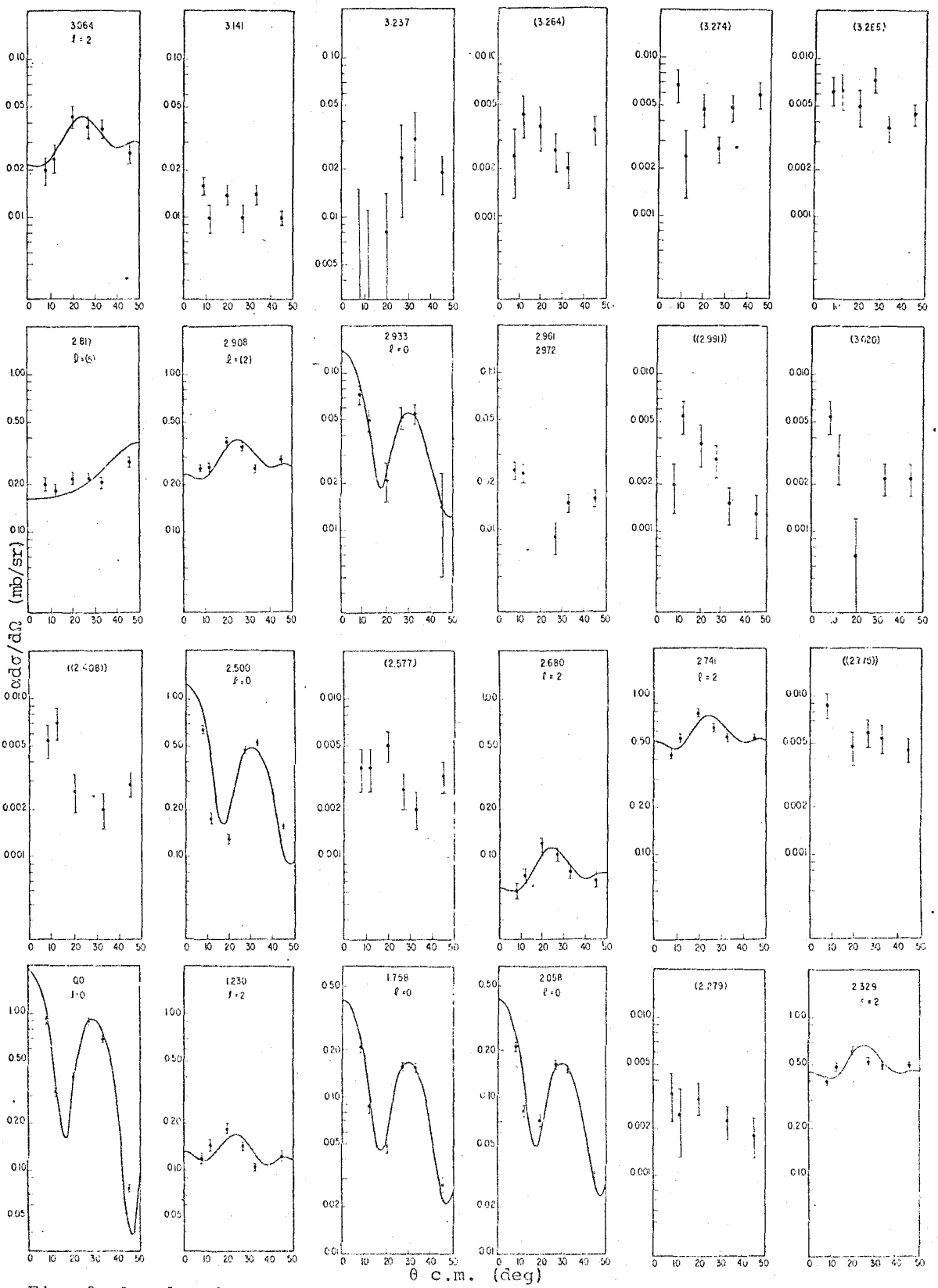

Fig. 3a Angular distributions. The lines are DWBA curves fitted to the experimental data. The error corresponds to statistics and background subtraction. The value of excitation energies of ^{118}Sn (in MeV) and the value of ℓ are given. $\alpha = 0.89$, target composition correction.

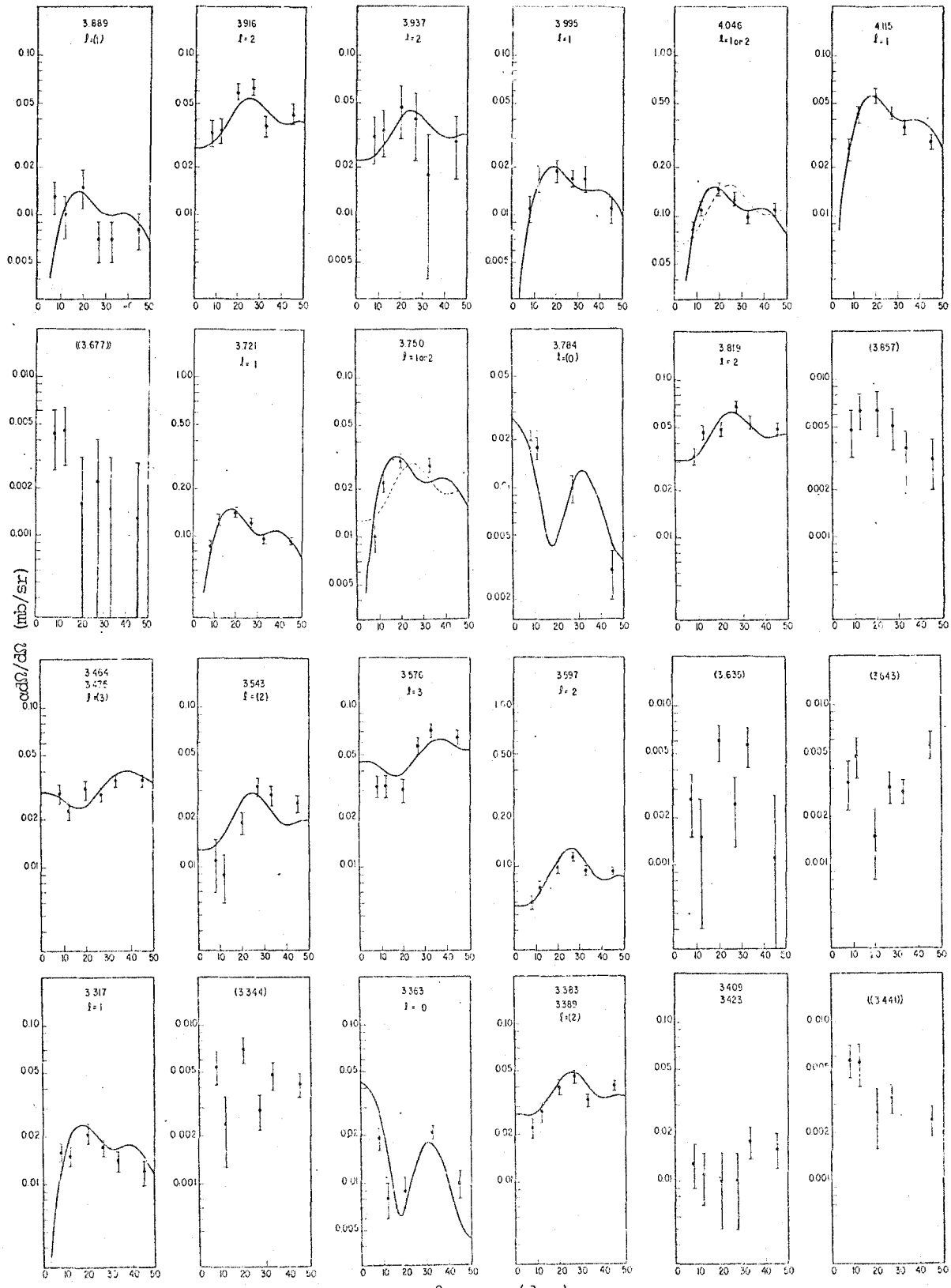

Fig. 3b Angular distributions (continued)

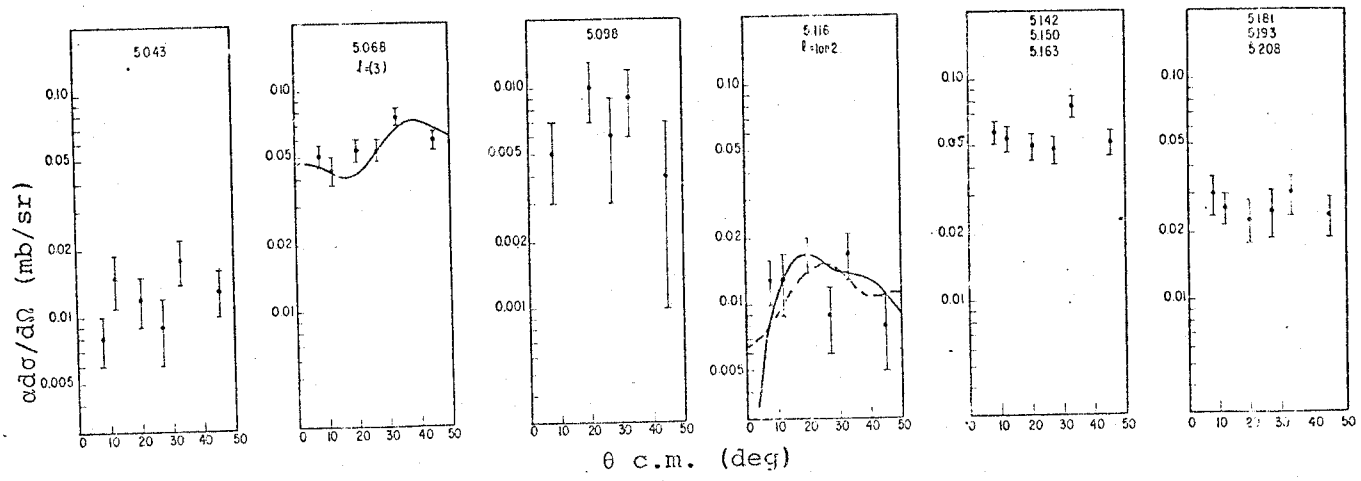

Fig. 3d Angular distributions (continued)

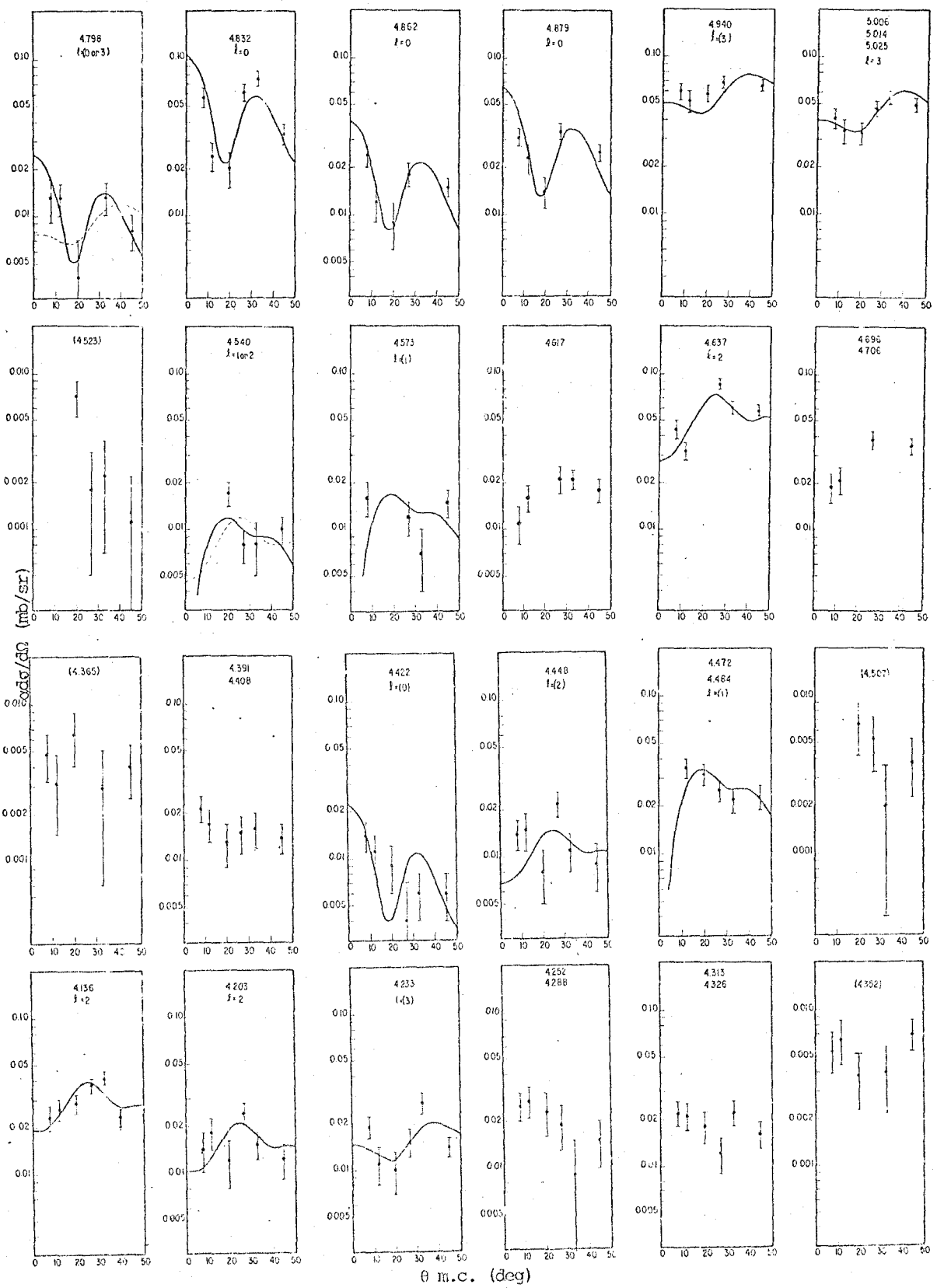

Fig. 3c Angular distributions (continued)

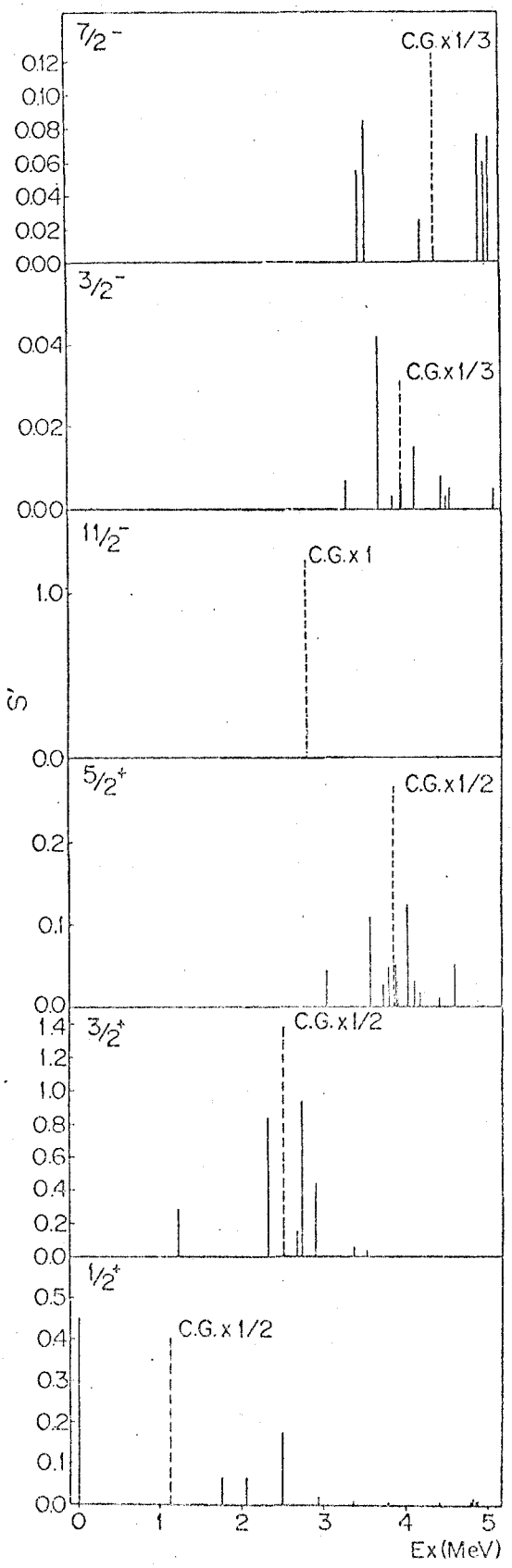

Fig. 4 - S' as a function of $E^*_{\ell j}$. The height of the dashed lines indicated for $E_{\ell j}$ corresponds to $\Sigma S'_{\ell j}$ for each shell-model orbital.