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STATES IN ^{94}Zr FROM $^{94}Zr(d,d')^{94}Zr^*$ AT 15.5 MeV

by

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ABSTRACT

^{94}Zr energy levels up to ≅ 4.3 MeV excitation energy are studied in the reaction $^{94}Zr(d,d')^{94}Zr^{*}$. Deuterons had a bombarding energy of 15.5 MeV. The emergent deuterons were analysed by a magnetic spectrograph and the detector was nuclear emulsion. The resolution in energy was about 11 KeV. We used the distorted-wave analysis to determine the ℓ transferred, the β_{ℓ}^{2} and J^{π} values for some ^{94}Zr excited states. Our results are compared with previous ones. 32 levels of excitation energy in ^{94}Zr were found which did not appear in previous $^{94}Zr(d,d')$ reactions. 20 levels do not correspond to the adopted ones.

Key-words: Nuclear reactions and scattering involving few-nucleon systems.

1 - INTRODUCTION

Zirconium is a near closed shell nucleus with Z = 40 and has a large number of isotopes. Thus it is an interesting element to be studied in a systematic way. In this paper we look into ^{94}Zr levels.

With resolution in energy of about 11 KeV we study the $^{94}Zr(d,d)^{94}Zr^*$ reaction. The incident energy of the deuterons was 15.5 MeV and the excitation energies analysed vary from 0 to 4.34 MeV. Inelastic scattering, neutron transfer, Coulomb excitation and γ decay giving ^{94}Zr nucleus were studied previously(1). We compare ours with other experimental results.

Owing to our resolution in energy and to the utilization of the "sum method"(2,3) it was possible to find new results in spite of the large background in the plates and the existence of only five scattering angles in the experiment.

2 - EXPERIMENTAL PROCEDURE

Deuterons with 15.5 MeV energy accelerated in the University of São Paulo Pelletron accelerator hit a target enriched in ^{94}Zr. This target was 26μg thick and with a carbon support 10μg thick. Table I gives the target isotope composition.

The scattered deuterons were analysed in an Enge split pole spectrograph.

Table I - Isotope composition of the target

Zr	90	91	92	94	96
%	1.96	0.58	0.91	96.28	0.27

We used as detector nuclear emulsions of Kodak type NTB plates 50 μm thick, that were placed in the focal surface of the spectrograph. The total incident charge on the target in each exposition was measured to obtain the relative normalization of cross sections. The plates we obtained were exposed at 25°, 30°, 34°, 52° and 60° laboratory scattering angles.

The absolute normalization of cross sections was made using:

1) The 15.5 MeV deuteron elastic cross section on zirconium at 60° calculated with the code DWUCK[4] using a Saxon-Woods shape potencial with Perey-Perey[5] parameters shown in Table II.

2) An exposure at 60° laboratory scattering angle wich allows us to obtain the counts with the relative normalization corresponding to the elastic peak of ^{94}Zr.

The scanning was made in 0.2 mm intervals along the plate on Leitz-Ortholux microscopes with 1.25×15×25 magnification. The distances were measured with an accurate AMES 3223 M clock. Fig. 1 gives a typical spectrum that corresponds to 25° in the laboratory.

The excitation energy of the residual nucleus was calculated with the relativistic computer code SPECTRE[6] using the calibration from the magnetic spectrograph of the University of São Paulo.

Table II - Optical-model parameters used in DWUCK calculation.

V (MeV)	r_o (fm)	a_o (fm)	W_D (MeV)	r_d (fm)	a_d (fm)	V_s (MeV)	r_s (fm)	a_s (fm)	r_C (fm)
95.18	1.15	0.81	18.12	1.34	0.68	6.53	1.099	0.835	1.3

In fig. 1 the peaks in excitation energy of ^{94}Zr are numbered. Other peaks exist that are from ^{94}Zr isotopes or other contaminations. We used the "sum method"[2,3] and consequently consider only the peaks in wich the distance from the first inelastic peak of ^{94}Zr in (d,d') reaction is independent of the scattering angle. Thus it is possible to eliminate all contamination peaks from elements with mass not similar to Zr and also the peaks from Zr (d,p) and Zr (d,t) reactions when they are in our region of study. If the energy of a peak that fulfil the above condition can be accounted for as of an isotope already found in zirconium (d,d') reactions[7-10], we can check if it includes only such isotope peak. If the intensity of the peak is larger than expected, using the known informations, the peak is assumed to be from ^{94}Zr plus the known isotope peak. Such isotope peak is discounted to obtain the ^{94}Zr peak.

Fig. 2 shows the sum spectrum when the corresponding peaks are added together, re-enforcing the zirconium peaks. This is noticeable, when fig. 1 and 2 are compared. Tables III, fig. 3 and 4 summarize our results and will be discussed later.

3 - DISTORTED-WAVE BORN APPROXIMATION ANALYSIS

The angular distributions of the ^{94}Zr (d,d')$^{94}Zr^*$ reactions were compared with a distorted-wave Born approximation (DWBA)[11] by means of the so-called collective model[12], where the real and imaginary parts of the potential are assumed to be deformed equally. The calculations were carried out using the DWUCK code of Kunz[4]. The optical model parameters used are listed in Table II. The nonlocal correction was made with the parameter PNLOC of DWUCK set at 0.54. The effects of Coulomb potential were included in our calculations for $\ell > 1$. The experimental cross section was related to the cross section σ_{DWBA}, calculated by DWUCK, by

$$\sigma_{exp}(\theta) = \beta_\ell'^2 \sigma_{DWBA}(\theta)$$

for each angular momentum ℓ transferred

where $$\beta_\ell' = [(2J_f+1)]^{1/2}[(2J_i+1)(2\ell+1)]^{-1/2}\beta_\ell$$

β_ℓ is the deformation parameter for collective excitation. In our case $J_f = \ell$, $J_i = 0$ and thus

$$\beta_\ell' = \beta_\ell$$

4 - RESULTS AND DISCUSSION

The excitation energy (Ex), the total angular momentum J and the parity π of the observed states, as well as the experimental cross section and the square of the deformation parameter β_ℓ are given in Table III together with other previous results.

Excitation energies, orbital angular momentum (ℓ) transferred and final spin (J^π) — In Table III the excitation energies indicated are the average of the excitation energies at the angles 25°, 30°, 34°, 52° and 60°. They were obtained using the computer code SPECTRE[6] with the calibration of the University of São Paulo magnetic spectrograph and using the very accurate energy of the first level of ^{94}Zr (918.24±0.23)[13] as reference.

For our angles, if we have single peaks with large intensity it is easy to find an angular distribution calculated by DWUCK code that fits very well our experimental points. Thus no angular distribution was accepted when one of the experimental points fells outside the calculated curve three times the experimental error shown in fig. 3. If there are up to three curves that satisfy the three times error criterion they are drawn in fig. 3. If no $\ell \le 5$ satisfy this criterion, if more than three values of ℓ satisfy the criterion or if the experimental cross section is smaller than 0.015 mb/sr for all angles in a given peak (weak peak) then the curves are not plotted in fig. 3.

Table III - COMPARISON BETWEEN THE PRESENT RESULTS AND PREVIOUS ONES.

PRESENT WORK						Jolly et al (7)		ADOPTED LEVELS (1)	
LEVEL NUMBER	Ex (MeV)	J^π	$(d\sigma/d\Omega)_{max}$ (mb/sr)	$(d\sigma/d\Omega)_{max}^{**}$ (mb/sr)	$B_\ell^2 \times 100$	Ex (MeV)	π	Ex (MeV)	J^π
1*	0.91824	2^+	3.411±0.404	3.286±0.424	1.483±0.176	0.92	+	918.75 5	2^+
2*	1.299	$(1^-,3^-,4^+)$	(0.102±0.014, 0.113±0.015, 0.110±0.015)	(0.093±0.016, 0.117±0.024, 0.093±0.016)	(0.137±0.018, 0.130±0.017, 0.157±0.021)	1.31	+	1300.19 18	0^+
3	1.468	$(3^-,4^+)$	(0.290±0.037, 0.301±0.038)	(0.292±0.044, 0.264±0.037)	(0.341±0.043, 0.430±0.055)	1.47	-	1469.62 11	4^+
4	1.670	2^+	1.262±0.152	1.364±0.214	0.631±0.076	1.68	+	1671.40 8	2^+
5	2.055	3^-	2.999±0.356	2.919±0.374	3.883±0.462	2.06	-	2057.64 10	3^-
6β	2.149			0.055±0.015				2151.31 20	2^+
7*	2.328	$(3^-,4^+)$	(0.149±0.020, 0.152±0.022)	(0.142±0.028, 0.121±0.021)	(0.201±0.027, 0.254±0.037)			2330.2 6	(4^+)
8	2.363	2+	0.249±0.031	0.222±0.033	0.148±0.019	2.35	+	2366.12 14	2^+
9	(2.401)			0.015±0.006					
10	(2.505)			0.015±0.010				2507.7 6	(3^+)
11	2.603	5^-	0.075±0.011		0.196±0.028	2.60	+	2604.5 8	5^-
12*	(2.696)			0.013±0.007				2698.5 10	(1,2,3)
13	(2.719)			0.008±0.008					
14	(2.769)			0.007±0.008					
15	2.824			0.049±0.015				2826.0 6	(2,3)
16	2.843	$(1^-,4^+)$	(0.069±0.010 0.072±0.009)	(0.086±0.015, 0.086±0.015)	(0.123±0.018, 0.131±0.016)			2846.3 3	$(1,2^+)$
								2860.6 11	(4,5)
17	2.871	4^+	0.135±0.017	0.150±0.023	0.245±0.032				
18	2.886	$(2^+,3^-,4^+)$	(0.045±0.007, 0.035±0.006, 0.039±0.006)	(0.049±0.013, 0.031±0.011, 0.036±0.009)	(0.033±0.005, 0.053±0.008 0.070±0.011)			2888.2 17	
19	2.905	$(2^+,3^-,4^+)$	(0.095±0.013, 0.066±0.009, 0.072±0.010)	(0.086±0.022, 0.061±0.015, 0.057±0.011)	(0.069±0.010, 0.102±0.014, 0.130±0.016)	2.89		2908.047 20	$(1,2^+)$
20	2.925	$(1^-,3^-,4^+)$	(0.088±0.012, 0.081±0.011, 0.095±0.013)	(0.090±0.015, 0.068±0.016, 0.090±0.015)	(0.163±0.022, 0.125±0.017, 0.176±0.024)				
								2945.0 5	
21β	3.030			0.020±0.010				3014 8	
22	(3.057)			0.010±0.011				3059.40 10	
23γ	3.137	$(3^-,4^+)$	(0.158±0.021 0.178±0.054)	(0.172±0.035, 0.170±0.029)	(0.254±0.033, 0.336±0.044)				
								3156.4 10	
24	3.217	3^-	0.200±0.025	0.198±0.034	0.322±0.041			3219.43 13	$(1^-,2,3)$
								3242 8	
25	3.281	$2^\pm$	0.077±0.012	0.089±0.021	0.065±0.010	3.28		/	
26α*	3.316								
				0.165±0.035					
27	3.331								
28	3.358	$(1^-,3^-,4^+)$	(0.105±0.014,	(0.100±0.021)	(0.211±0.029,			3361.15 18	$(2^+,3)$

			0.099±0.014,	0.091±0.022,	0.165±0.023,				
			0.076±0.011)	0.100±0.021)	0.229±0.031)				
29	3.407	$(1^-,3^-,4^+)$	(0.066±0.010,	(0.078±0.019,	(0.133±0.020,				
			0.064±0.010,	0.061±0.020,	0.108±0.016,				
			0.076±0.011)	0.078±0.019)	0.151±0.023)				
30	3.481			0.036±0.015				3482 8	
31	3.560	$(3^-,4^+)$	(0.094±0.013,	(0.109±0.025,	(0.166±0.023,				
			0.109±0.015)	0.118±0.026)	0.231±0.032)	3.61	-	3582 8	
32γ	3.598			0.065±0.020					
33β	3.686			0.040±0.015					
								3724.9 76	$(2^+,3,4^+)$
34β	3.732	$(0^+,3^-,4^+)$	(0.058±0.010,	(0.034±0.015,	(0.065±0.011,				
			0.030±0.005,	0.034±0.015,	0.057±0.010,				
			0.037±0.005)	0.053±0.013)	0.082±0.011)				
35	3.776	0^+	0.100±0.015	0.094±0.024	0.111±0.017				
36*	3.840			0.023±0.013					
37α	3.884								
				0.169±0.033		3.92	-		
38	3.897							3913 8	
								3961.8 73	(2^+)
39	3.994			0.045±0.017				4002.2 15	$(1,2^+)$
								4052.4 15	$(1,2^+)$
40*β	4.081			0.067±0.025					
								4098.5 15	$(1,2^+)$
41	4.149			0.036±0.021					
								4198.8 24	$(1,2^+)$
42β	4.225			0.054±0.022					
								4237.6 75	(1,2,3)
43	4.340			0.034±0.019					

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

β - Probable unresolved doublet

γ - Probable unresolved triplet

* - With isotope contamination correction

. - See comments in text

In our case the final spin is $J = \ell$ and parity is given by $\pi = (-)^{\ell}$.

There are two kind of errors in the energies:

a) The standard deviation of the given average energies.

b) The error resulting from spectrograph calibration.

The first kind of error, excluded the weak levels which are in parenthesis in Table III, is for energies from 1 MeV up to 3.41 MeV in average 0.6 KeV (actually the error varies from 0.3 KeV to 1.0 KeV). For higher energy levels, up to 4.34 MeV, the average error is 1.0 KeV (actually the error varies there from 0.3 KeV to 1.6 KeV). In the weak levels case the error is in average 1.4 KeV (actually they vary from 1.0 KeV to 1.9 KeV).

The second kind of error was estimated to be about 0.15% by comparing our results with the very accurate ones from refs. (14) and (15). Our results are systematically smaller than these more accurate ones. Since the error in the reference energy is pratically zero the maximum calibration error we have is about 5 KeV at 4.34 MeV.

In Table III we put all the adopted levels[1] up to 4.340 MeV and those of the present work. They are 53 in total: 20 that were not adopted levels in ref. (1), 10 that do not appear in our experiment and 23 that appear in our work and were already adopted in ref. (1).

We have found 43 excitation energies, including all Jolly et al[7] eleven ones. The Jolly et al[7] 3.28 MeV level was not adopted in ref.(1) but we have a 3.281 MeV level. Thus we found 32 levels wich did not appear previously in the ^{94}Zr (d,d') reaction. Six of them are doubtful ones in our experiment. From these 32 levels, including our doubtful levels number 10, 12 and 22 (Table III), 12 appear in other reaction and are adopted in ref. (1). Thus among the 43 excitation energies we found 20 were not adopted in ref. (1), although five of these 20 levels appear in previous works. They are:

1) Our energy level 3.281 MeV was reported[7] as 3.28 MeV in $^{94}Zr(d,d')^{94}Zr^*$ reaction.

2) The level 3330±10 KeV from ref.(16) in $^{94}Zr(p,p')^{94}Zr^*$ reaction corresponds to our doublet levels 3.316 MeV and 3.331 MeV.

3) In the $^{94}Zr(p,p')^{94}Zr^*$ reaction from ref. (17) there exists a level 3390±30 KeV that corresponds to our 3.407 MeV level.

4) The level 3833±8 KeV in $^{92}Zr(t,p)^{94}Zr^*$ reaction from ref. (18) corresponds to our 3.840 MeV level.

5) In the (p,p') reaction on ^{94}Zr from ref. (16) there is a level 3.870±10 KeV that corresponds to our 3.884 MeV level.

The 15 new levels are the following ones (in MeV):

a) 3 doubtful ones, 2.401, 2.719 and 2.769; the doublet member 3.316 and the levels 3.598, 3.686, 4.081, 4.149, 4.225 and 4.340. It was not possible to determine the J^π values for these levels.

b) 3.776, $J^\pi = 0^+$ — 3.732, $J^\pi = (0^+, 3^-, 4^+)$

c) 2.925, $J^\pi = (1^-, 3^-, 4^+)$

d) 3.137, $J^\pi = (3^-, 4^+)$

e) 2.871, $J^\pi = 4^+$

The 10 excited levels adopted in ref. (1) which we did not find are the following ones (energy in KeV):

a) The tentative levels 3724.9, 3961.8, 4198.8 and 4237.6.

b) The levels 2860.6, 2945.0, 3156.4, 3242, 4052.4 and 4098.5.

Knowing these 15 new levels and the 10 levels reported in ref. (1) which were not found by us, it is opportune to do make the following considerations.

If we take into account the considerations about our errors, a correspondence, respectivelly, between the levels 2945.0±0.5, 3156.4±1.0, 3724.9±0.6, 4098.5±1.5, 4198.8±0.4 and 4237.6±0.5 and ours 2925, 3137, 3732, 4081, 4149 and 4225 is found to be most unlike.

However it is interesting to note that:

a) For three of our angles there is some indication of a level of about 2.945 MeV, where for the other two angles we could not read the plates. This very weak level might correspond to the 2.9450 MeV level from ref. (1). On the other hand the energies 2.940 ? MeV[17], 2.920±20 MeV[16] and 2.940±8 MeV[18] which were all identified to the level 2.9450 MeV in ref. (1) may correspond to our new level 2.925 MeV given above.

b) The 3.137 MeV level is a probable triplet and one of its weakly excited levels could be the level 3.1564 from ref. (1). Also in this respect the energies 3155±8 KeV[18], 3140±30 KeV[16] and 3160±30 KeV[17] which were identified to the level 3.1564 in ref. (1) are also all compatible with our new energy level 3.137 MeV. In ref. (17) the assigned J value is 4 and we have for our 3.137 MeV level J = (3,4).

c) The 3.732 MeV, 4.081 MeV and 4.225 MeV levels are all probable doublets and their corresponding weakly excited levels could be respectively the 3.7249 MeV, 4.0985 MeV and 4.2376 MeV levels assigned in the ref. (1). Our 3.732 MeV level is also in agreement with the levels 3710±10 KeV[16] and 3760±30 KeV[17] which were identified both with the level 3.7249 MeV in ref. (1). We also note that our 4.225 MeV level agrees very well with the level 4210±10 KeV from ref. (16) which was identified with the level 4.2376 MeV in ref. (1).

For the remaining 28 cases which appear both in our and in previous papers we obtain the following results:

a) For 12 of them, including 4 of the five that appear in previous works and which were not adopted in ref. 1, it was not possible for us to give any indication about the J^{π} values.

b) Among the 16 levels for which we have indication about the J^{π} values, 11 are compatible and one desagrees with J^{π} values reported in previous works. For 4 the J^{π} values were not assigned before. The

4 levels for which the J^π were completely unknown are: 2.886 MeV with $J^\pi = (2^+, 3^-, 4^+)$, 3.281 MeV with $J^\pi = 2^+$, 3.407 MeV with $J^\pi = (1^-,3^-,4^+)$ and 3.560 MeV with $J^\pi = (3^-,4^+)$. For some ambiguous J^π values, the present experiment compared with previous ones (cf. table III) gives, by exclusion, for 2.843 MeV, 2.905 MeV and 3.358 MeV respectively $J^\pi = 1^-$, $J^\pi = 2^+$ and $J^\pi = 3^-$. For 3.217 MeV we find $J^\pi = 3^-$.

The energy level 1299 KeV, in table III, has J^π values in disagreement with the adopted $J^\pi = 0^+$. However there are many experimental and theoretical reasons to assign the 0^+ value to this level. The fact that this value of J^π is excluded by our experimental results seems to indicate that the DWBA curve calculated in this case do not describe well the reaction. For this reason we think that the adjustments indicated in fig. 3 are not meaningful. The J = 0 curve is also drawn in fig. 3 for this level. A possible explanation for these discrepancies might be multiple excitation processes similarly to that of the first excited 0^+ state in ^{90}Zr where a multiple excitation throught the first 2^+ state was found to be important by Hinrinchs et al[19].

Deformation parameter β_ℓ and absolute cross section - The β_ℓ^2 given in Table III are

$$\beta_\ell^2 = C\ (N(\theta)/\sigma_{DWBA}(\theta))_{W.A.}\ ,$$

where C is the ratio between the deuteron elastic cross section at 60° and the normalized count corresponding to deuteron scattered elasticaly at 60° by ^{94}Zr. $(N(\theta)/\sigma_{DWBA}(\theta))_{W.A.}$ is the weighted average value of $N(\theta)/\sigma_{DWBA}(\theta)$. $N(\theta)$ is the normalized peak count at angle θ and $\sigma_{DWBA}(\theta)$ is the DWBA cross section for the same angle corresponding to the ℓ value obtained. The weighted average value was used because in each peak the points do not have all the same accuracy. The weights were taken as the inverse of the square of the $N(\theta)$ error.

As the spectrograph solid angle was the same independently of the exposure it does not appear in the above expression for β_ℓ^2. The curves drawn in fig. 3 correspond to this β_ℓ^2 value and the $(d\sigma/d\Omega)_{max}$ given in Table III are the cross sections at the first maximum after 20^0 in these curves. For comparison we give in Table III also the usual $(d\sigma/d\Omega)_{max}^{**} = N\ (\theta)_{max}\ C$, where $N\ (\theta)_{max}$ is the normalized count in the experimental angle nearest to the first maximum at the theoretical DWBA curve after 20^0. When we do not have any curve in fig. 3, $(d\sigma/d\Omega)_{max}^{**}$ means the maximum experimental cross section that we have for the used angles.

The error $\Delta\ (N(\theta)/\sigma(\theta))_{W.A.}$ was taken as usually as $1/\sqrt{\Sigma(\Delta N(\theta))^{-2}}$. The C error (10% attributed to the calculated elastic cross section and 5.8% to the normalized peak count at 60^0) was 11.6%. We combine the two errors in the usual way to obtain $\Delta\beta_\ell^2$.

The usually referred 20% to 30% σ_{DWBA} incertitude was not included in the β_ℓ^2 error. Since the $N(\theta)$values and the normalized peak count corresponding to deuterons scattered elasticaly at 60^0 by ^{94}Zr are measured by the same process, if a sistematic percentual error appears it will be the same for all of them and thus it will not affect the β_ℓ^2 value.

The absolute cross sections in Table III are given by

$$(d\sigma/d\Omega)_{max} = \beta_\ell^2\ (\sigma_{DWBA})_{max}\ .$$

In the incertitude in σ_{DWBA} is essentially a normalization one it will not affect the $(d\sigma/d\Omega)_{max}$ value. In fact, in this case $(\sigma_{DWBA})_{max}$ is multiplied by the same factor that divides our β_ℓ^2. This is very likely in our region of work since the theoretical angular distribution curves are fitting very well the experimental points in cases of strong excited levels (cases where the points have very small errors).

Comparison between the β_ℓ values in differents inelastic scattering reactions and β_ℓ values as a function of excitation energy.

Table IV gives the values of β_ℓ in different inelastic scattering reaction for some of the observed states of ^{94}Zr. There we compare a $(^3He,^3He')$, a (α, α') a (t,t') and two (p,p') experiments, together with our (d,d') results. These results include only experiments which made a DWBA analysis with complex coupling. The results for β_ℓ in the present work and in the two (p,p') experiments are in reasonable agreement with each other, except in the case of $J^\pi = 5^-$ where the value of β_ℓ in (p,p') is larger than in (d,d') about 70%. The β_ℓ values of (t,t'), (α, α') and $(^3He, ^3He')$ are in general smaller than ours corresponding values.

Table IV - β_ℓ values in differents inelastic scattering reactions for comparison. The incident particle energy in the lab sistem is indicated for each reaction.

Ex (KeV)	J^π	β_ℓ					
		Present work 15.5 MeV	$(p,p')^{(16)}$ 19.4 MeV	$(p,p')^{(17)}$ 12.7 MeV	$(t,t')^{(20)}$ 20 MeV	$(\alpha,\alpha')^{(21)}$ 65 MeV	$(^3He,^3He')^{(22)}$ 25 MeV
918	2^+	0.122	0.13	0.13	0.08	0.092	0.086
1468	4^+	0.066	0.077	0.065			
1670	2^+	0.079	0.075	0.065		0.050	
2055	3^-	0.197	0.20	0.18	0.15	0.154	0.18
2363	2^+	0.038		0.05			
2603	5^-	0.044	0.072	0.075			
3137	4^+	0.050		0.05*			
3560	4^+	0.048	0.061**				

* If the excitation energy 3160±30 KeV from ref. (17) corresponds to our level 3137 KeV.

** This corresponds to a excitation energy 3570±10 with J = (4,5) in ref. (16).

Fig. 4 gives the $\beta_\ell^2 \times 100$ values versus excitation energy in MeV. In cases where it was not possible to determine univocally the ℓ value (even comparing our results with other) we used the ℓ that corresponds to the curve that fits better our experimental points. In this cases in fig. 4 the corresponding lines are dashed.

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FIGURE CAPTIONS

Fig. 1 - The deuteron spectrum from the $^{94}Zr(d,d')^{94}Zr$ reaction at $\theta_{lab}=25^0$.

Fig. 2 - Sum spectrum of $^{94}Zr(d,d')^{94}Zr^*$ for $\theta = 25^0, 30^0, 34^0, 52^0, 60^0$.

Fig. 2 - (continued)

Sum spectrum of $^{94}Zr(d,d')^{94}Zr^*$ for $\theta = 25^0$, $30^0, 34^0$, 60^0. The 52^0 left plate, which corresponds to higher values of Ex, has the position of the peaks shifted in relation to the others then was not included neither in the sum spectrum nor in the Ex calculations.

Fig. 3 - Angular distributions. The lines are DWBA curves fitted to the experimental data, except for Ex = 1.299 MeV and $\ell = 0$. The error corresponds to statistics and background subtraction.

Fig. 4 - The $\beta_\ell^2 \times 100$ values versus excitation energy.

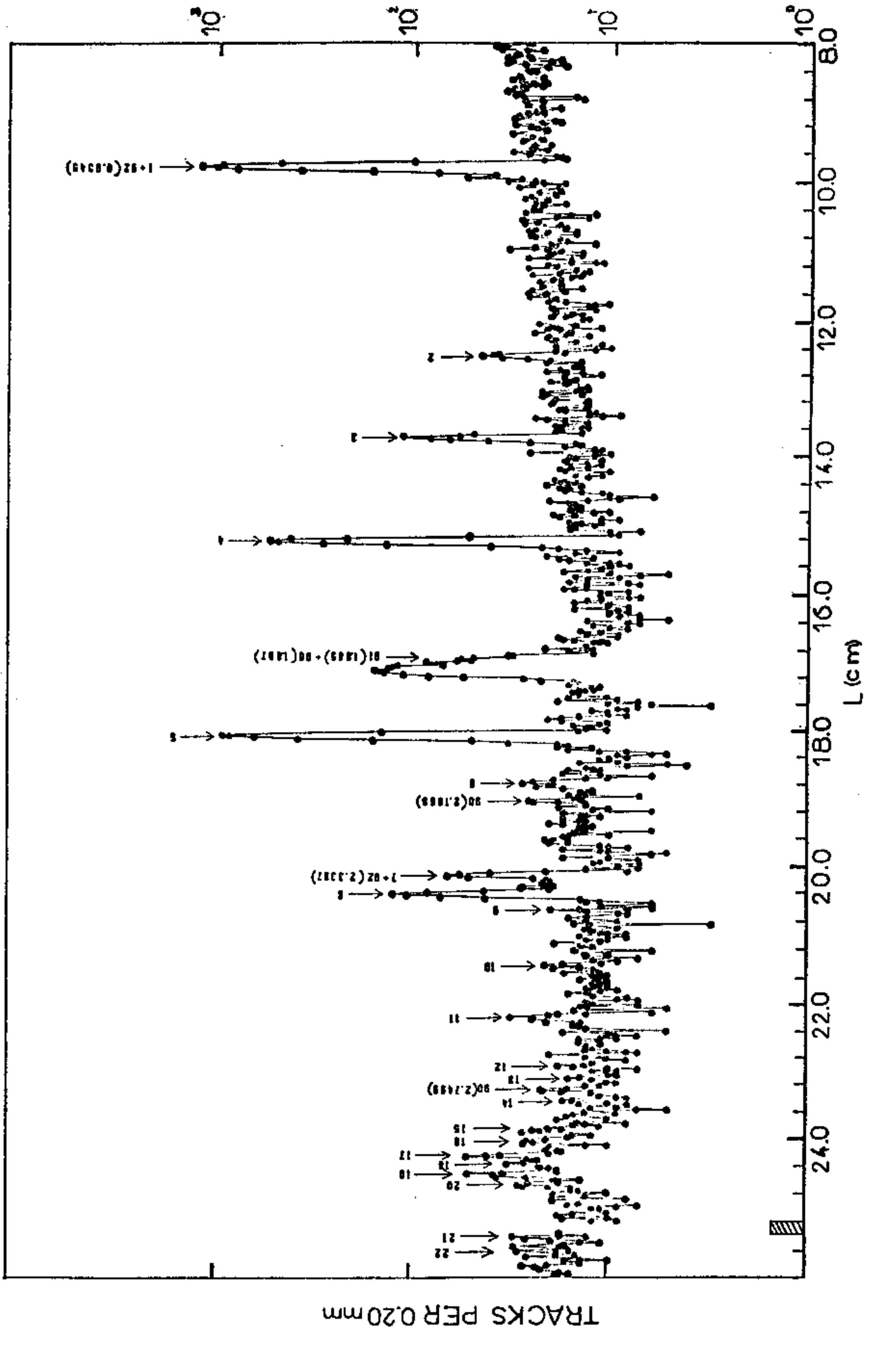

Fig. 1

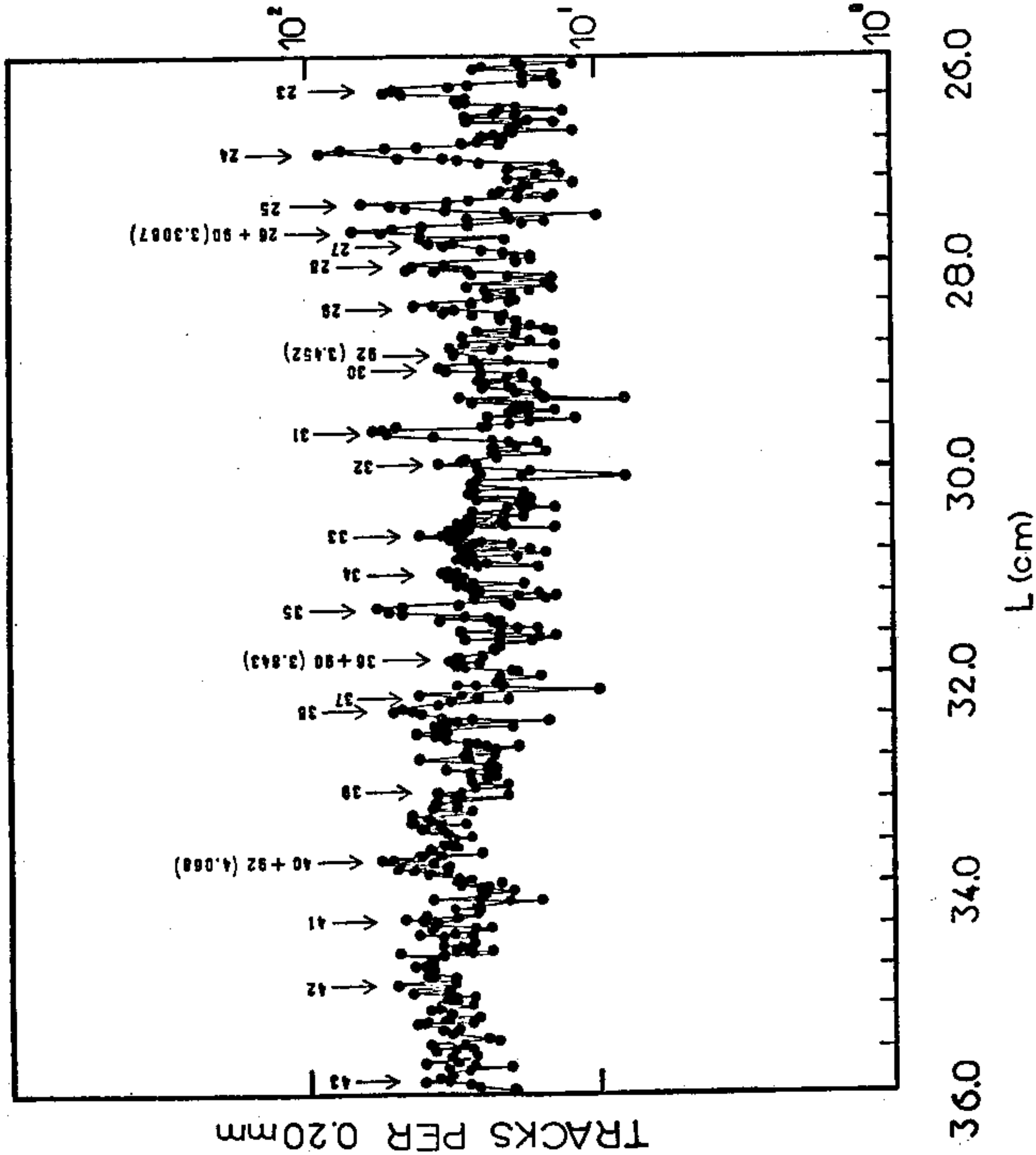

Fig. 1 - (continued).

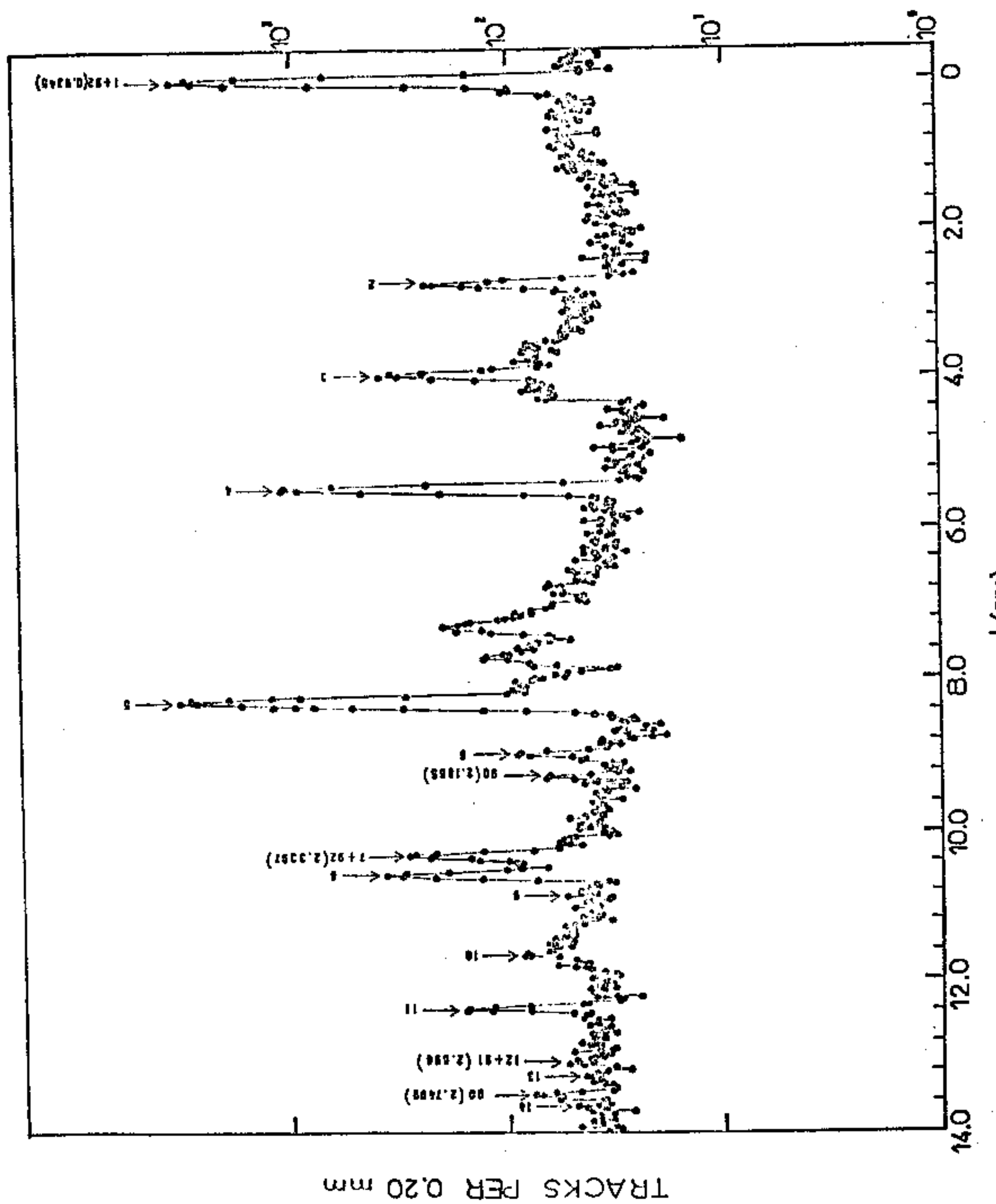

Fig. 2

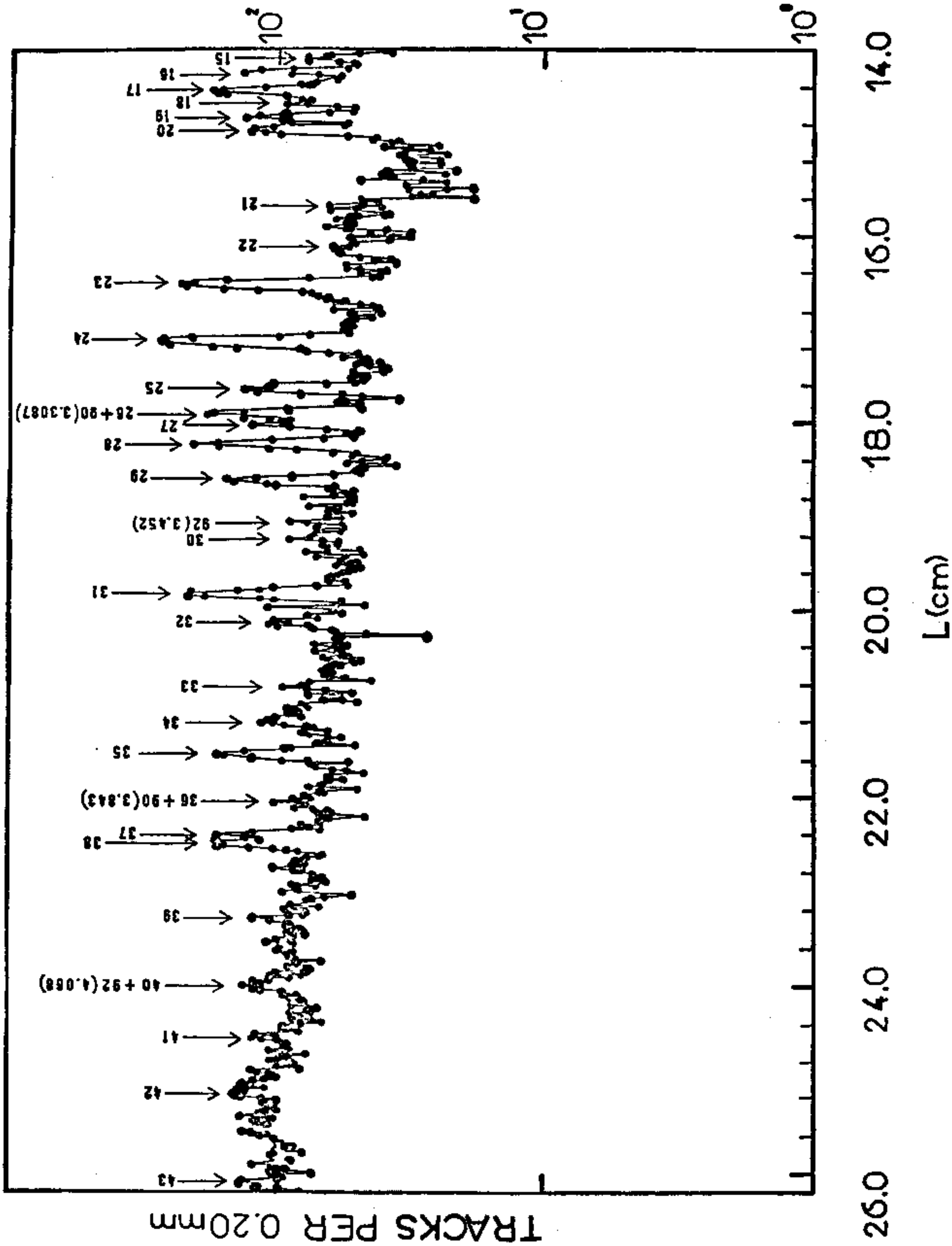

Fig. 2 - (continued).

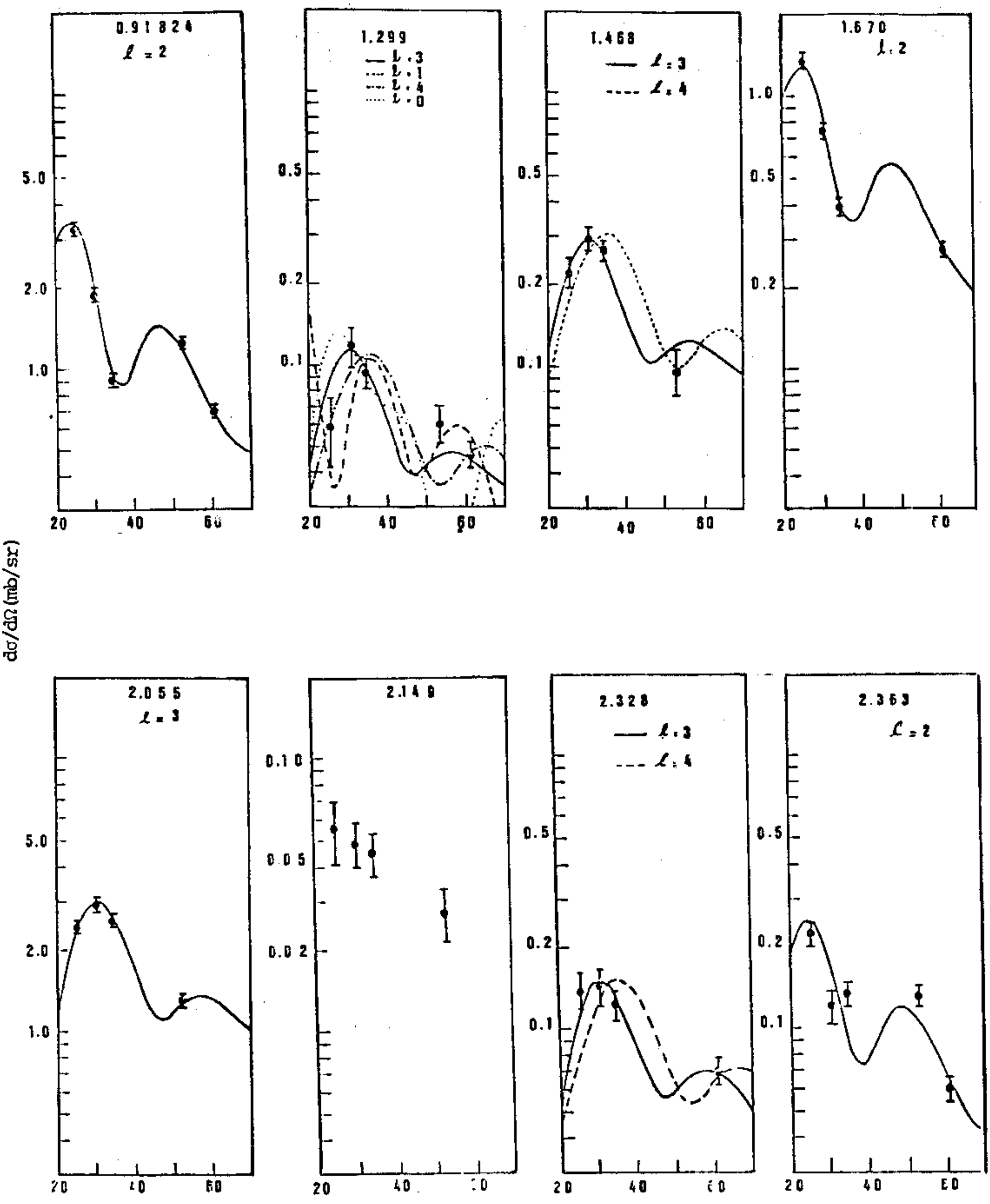

Fig. 3

θ$_{c.m.}$ (Degrees)

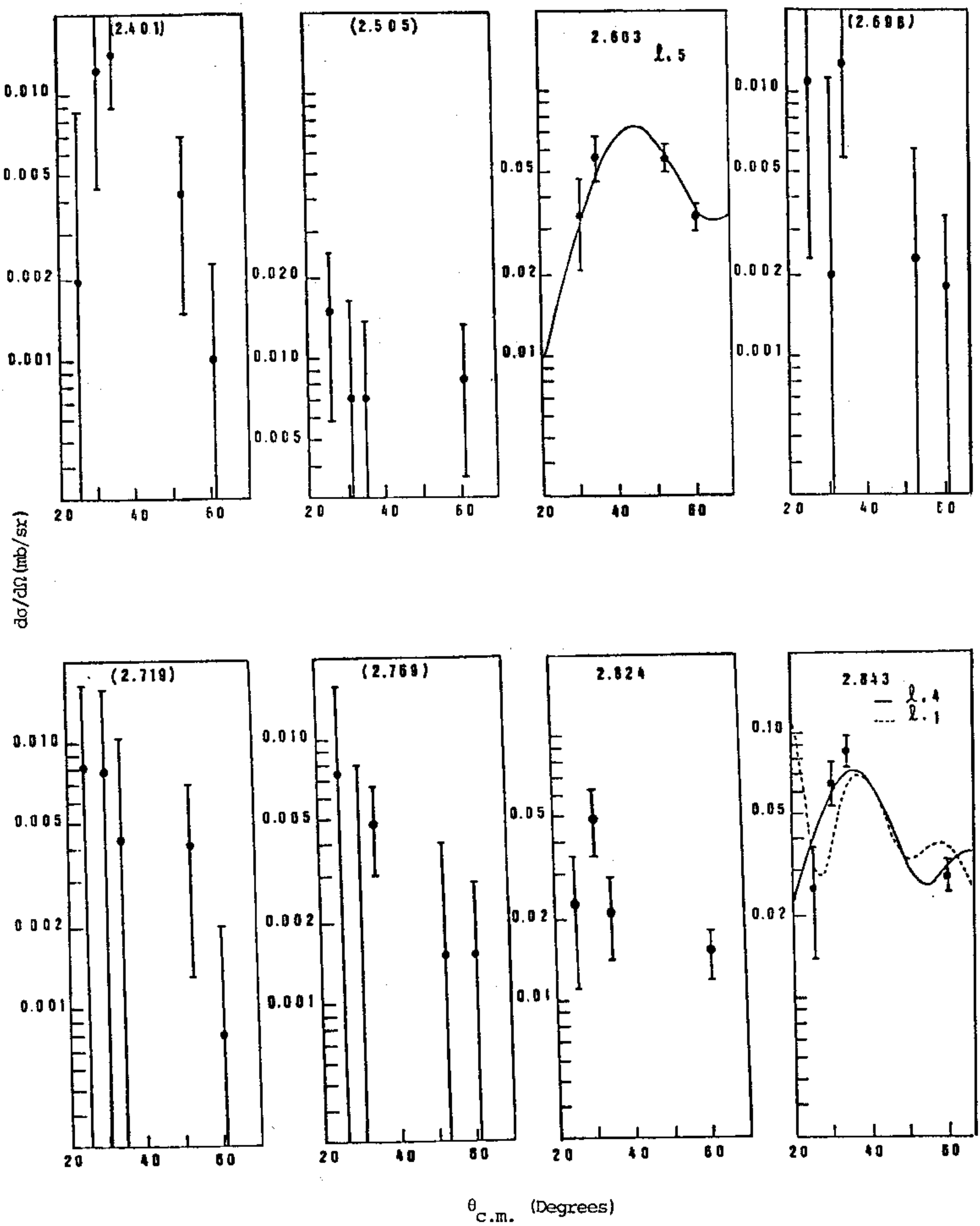

Fig. 3 (continued)

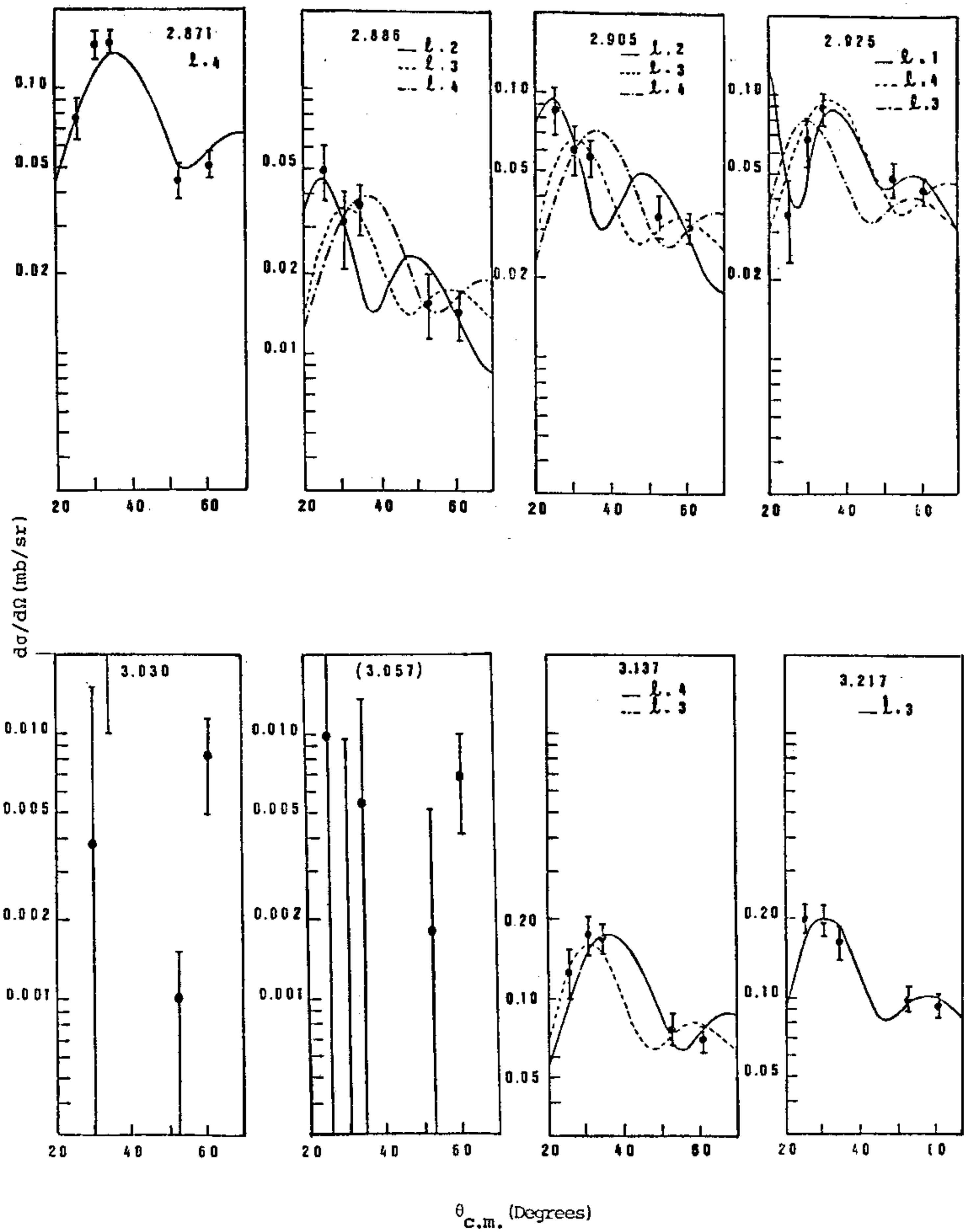

Fig. 3 (continued)

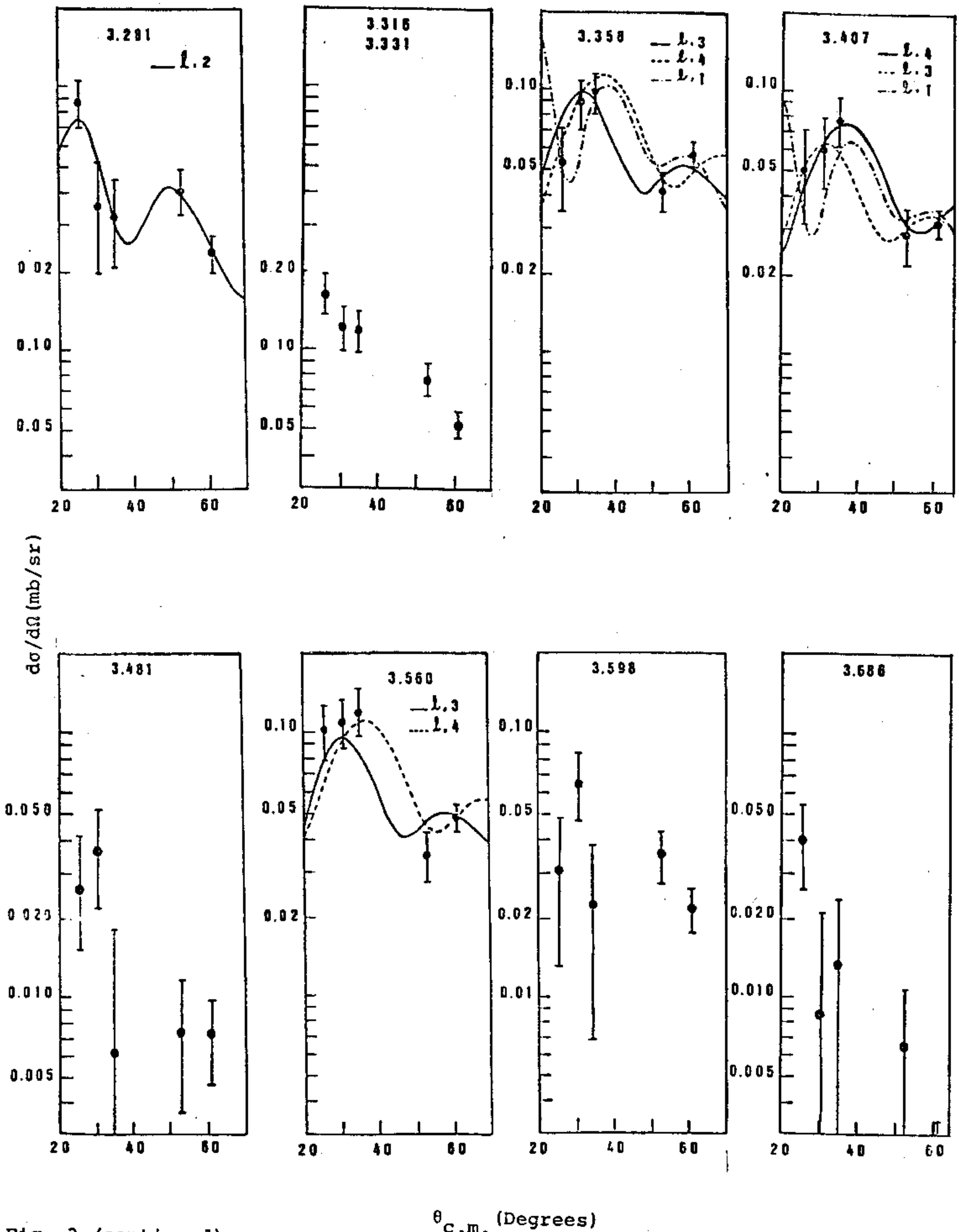

Fig. 3 (continued).

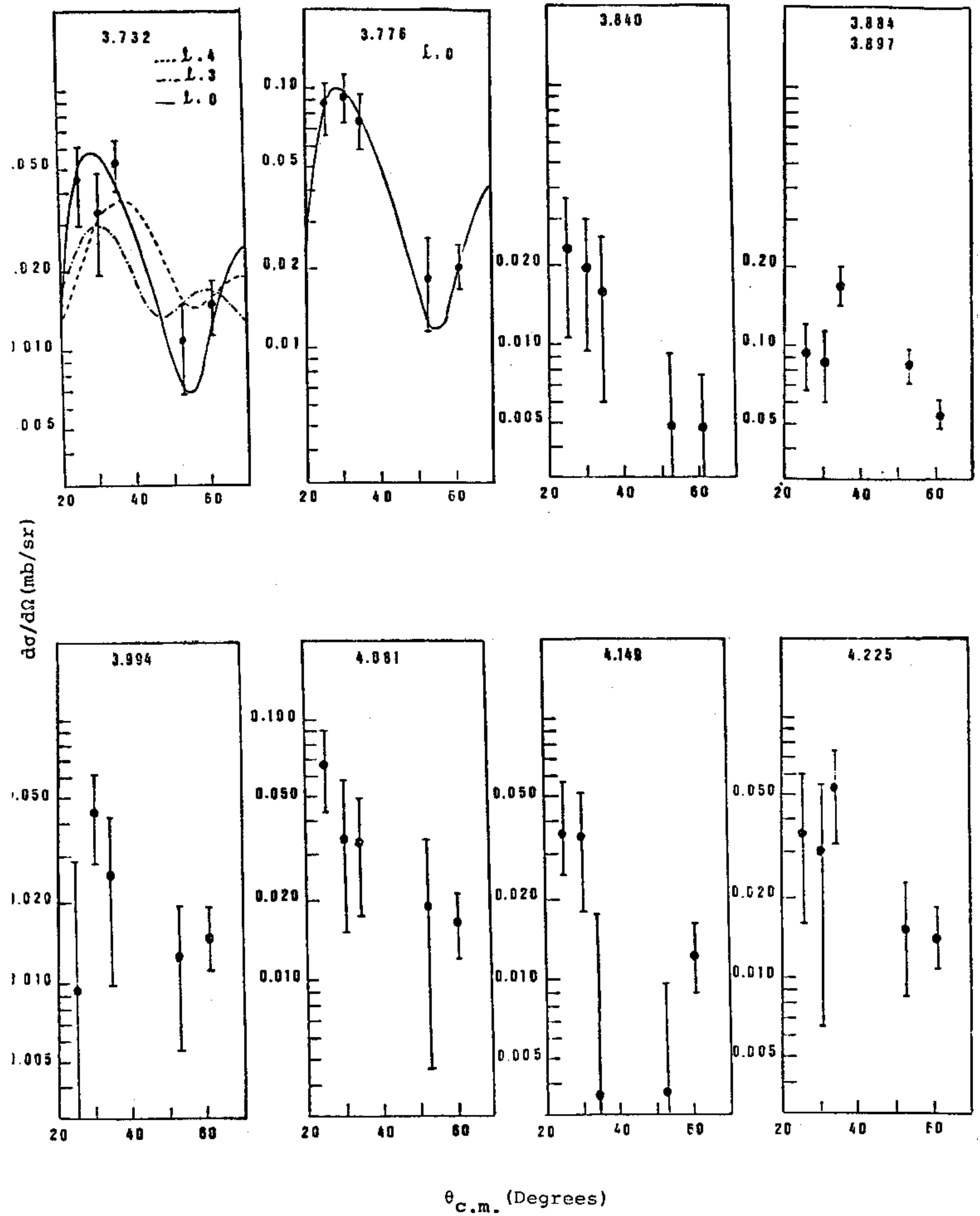

Fig. 3 (continued)

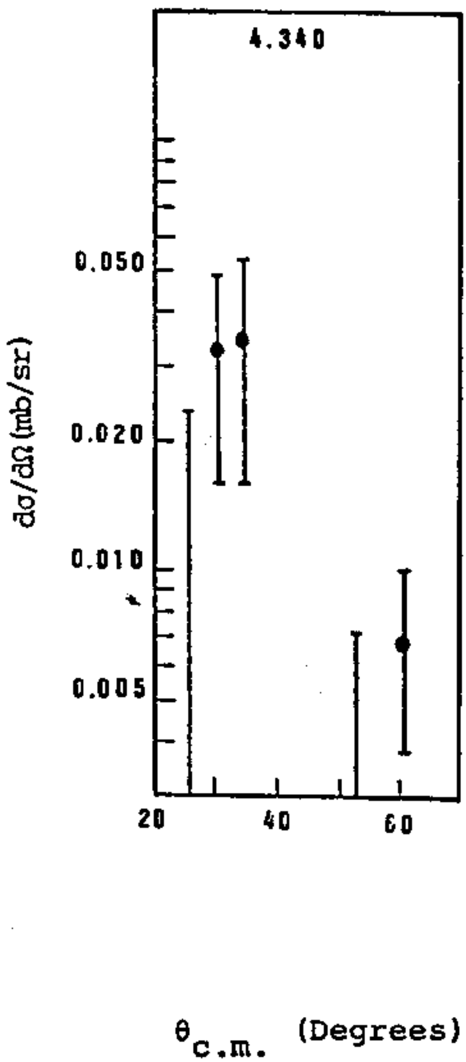

Fig. 3 - (continued).

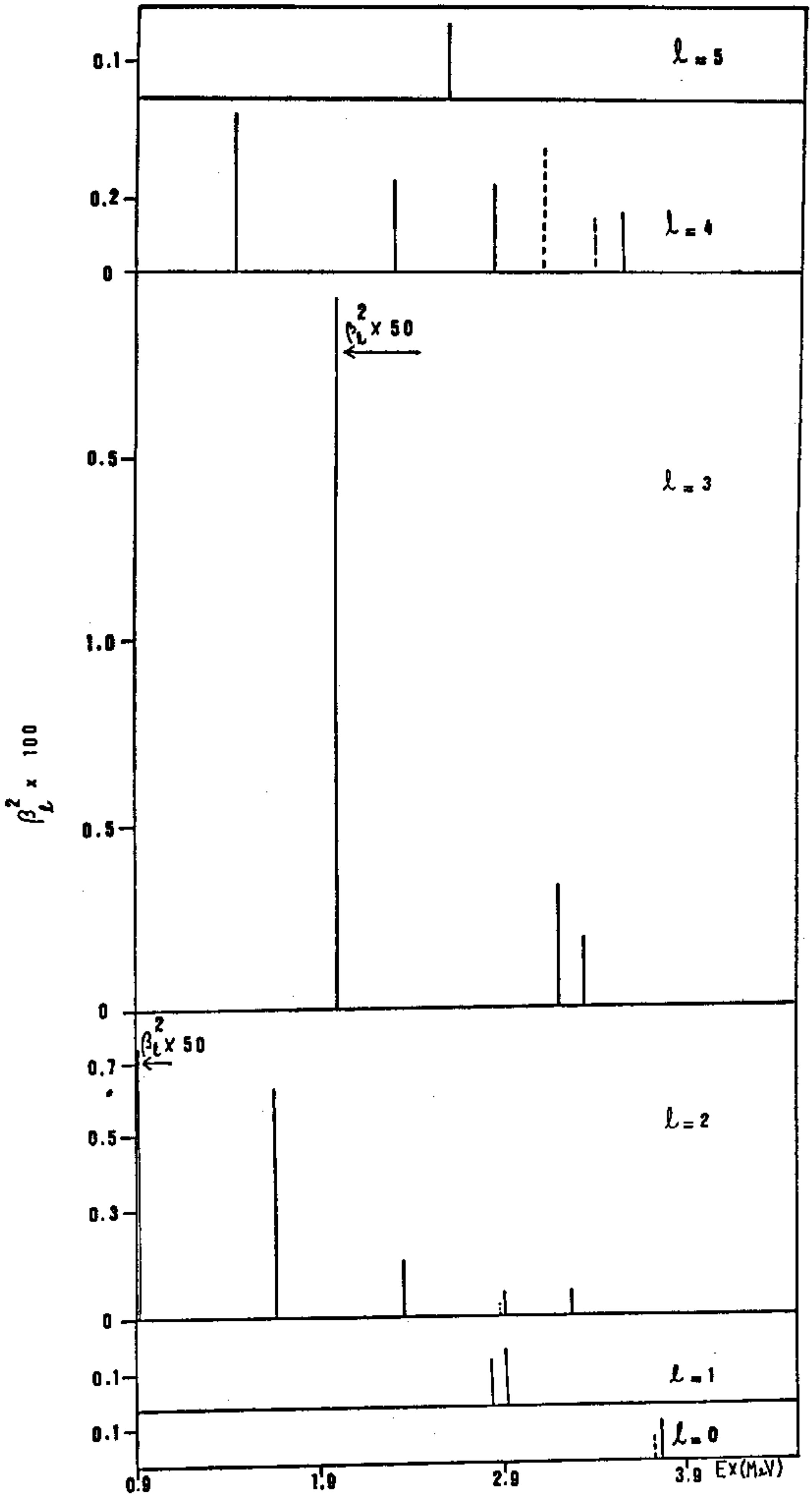
l = 5
l = 4
l = 3
l = 2
l = 1
l = 0
0.1
0.2
0
0.5
1.0
0.5
0
0.7
0.5
0.3
0
0.1
0.1
β²ℓ x 100
β²ℓ x 50
β²ℓ x 50
0.9
1.9
2.9
3.9
Ex(MeV)

Fig. 4

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