States at $E_x = 6$–13 MeV in ^{23}Na from ^{19}F(^{6}Li,d) at $E(^6$Li$)= 16$ MeV

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A total of 38 angular distributions have been measured for the ^{19}F(^{6}Li,d)^{23}Na reaction leading to states in the excitation energy region 6.3–13.25 MeV. For many of them, L values have been assigned and spectroscopic factors extracted, using standard distorted-wave techniques.

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I. INTRODUCTION

The nucleus ^{23}Na has been the object of many reaction studies including proton stripping [1] and pickup [2,3], two-nucleon transfer [4], and alpha-particle transfer [5–7]. Other reactions used to study ^{23}Na include ^{25}Mg(d,α) [8], ^{20}Ne(^{7}Li,α) [9], ^{12}C(^{12}C,p) [10], and ^{12}C(^{12}C,$p\gamma$) [11]. Many levels of ^{23}Na have been observed as resonances in (p,p) [12] and (p,γ) [13–15]. Its level structure is well understood up to quite high excitation energies [16]. Even so, above about 7 MeV in E_x, many levels have not had their J^π assigned. In some cases, little or no J information is available; in others J^π's have been restricted to a small range of values. In the latest compilation [16], unique J^π values are known for only 44 of the 134–141 states from $E_x = 6.0$ to 10.7 MeV. For J^π and E_x information from the above references, we refer throughout to the latest compilation [16].

For states below $E_x = 6$ MeV, two reports of the ^{19}F(^{6}Li,d) reaction have appeared — at $E(^6$Li$)$=16.0 [5] and 36.0 MeV [6]. Despite the higher energy of the latter, spectroscopic information was not improved — small cross sections, poor fits to angular distributions, and large uncertainties in spectroscopic factors were observed.

States above 6 MeV have been investigated in ^{19}F(^{6}Li,d) at 34 MeV [7]. Those authors present 27 angular distributions over the laboratory angular range 4°–45°. Eight of them cover most of that range, with an average of 10 points each. The other 19 have from 2–7 points (average is 5) within that range. Reference [7] assigns 12 L values, and presents distorted-wave Born-approximation (DWBA) calculations for these and 15 other levels — using for the latter the L's deduced from J^π values that were known at the time. In that work, peaks from a carbon target backing are about 100 times as strong as the peaks from ^{19}F. However, the ^{12}C peaks were a problem only for states in ^{23}Na from 4 to 6 and 9 to 12 MeV. The authors do not mention or identify any peaks from the known ^{16}O contaminant in the target. We return to this point below.

For states below $E_x = 5$ MeV, the earlier 16- and 36-MeV studies indicated that DWBA calculations gave a much better description of the data at the lower energy. Without a doubt, compound-nuclear (CN) cross sections leading to a specific final state are larger at $E(^6$Li$)$=16 MeV than at 34 MeV. However, for the excitation energy range of interest, the angular momentum (L) matching is better at 16 MeV.

One additional factor is the *shape* of the compound angular distributions. Even though the *angle-integrated* compound cross sections are smaller at 34 MeV, the compound angular distributions are more forward peaked there. Thus, at the forward angles — where L's and spectroscopic factors are determined — the influence of compound processes may not be dramatically different at the two energies.

In [7], the authors show statistical CN calculations for two $\frac{5}{2}^+$ states at 5.38 and 5.74 MeV. They conclude that CN processes dominate the former but are negligible for the latter. The 5.74-MeV comparison is misleading, because they compare the calculated CN cross section for a single state with the experimental cross section for an unresolved triplet of states. The other two members may have little or no direct component, but the CN mechanism is highly *unselective*; and, hence, all three will undoubtedly have a CN contribution. If the CN cross sections at 34 MeV are as large as depicted in Fig. 4 of [7], then CN processes would be expected to dominate many of their other peaks — most of which contain 2–5 states.

In the present paper, we report 16-MeV results of ^{19}F(^{6}Li,d) for states at 6–13 MeV in ^{23}Na. Detailed comparisons are made with results of the 34-MeV experiment.

II. EXPERIMENTAL DETAILS AND DATA

The experimental details are as in [5]: SF_6 gas target, multiangle spectrograph, and nuclear emulsion plates. Excitation energy range covered in the present experiment is 6–13.5 MeV. Spectra obtained at 15° are displayed in Figs. 1 and 2. Resolution is 25 keV (FWHM). No impurity peaks are present in the spectrum, despite the one part in seven presence of S in the target. Presumably, cross sections on S are somewhat smaller than

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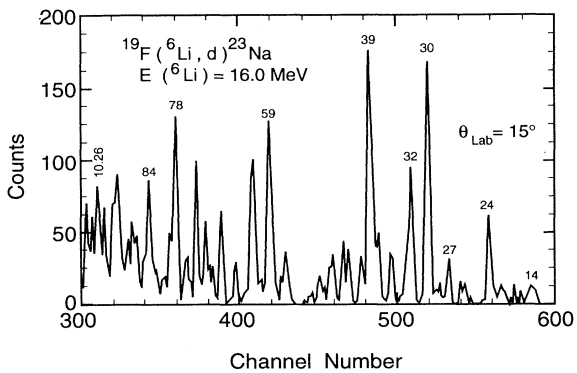

FIG. 1. Spectrum of deuterons from the reaction ^{16}F(^{16}Li,d)^{23}Na, at a bombarding energy of 16.0 MeV and a laboratory angle of 15°. Excitation energy range covered is 5.6–10.3 MeV. Level numbers correspond to those in Table I.

on ^{19}F. Data were recorded at seven angles from 7.5° to 52.5° in 7.5° steps.

Excitation energies (accurate to ±10 keV) and angular distributions have been extracted for 38 peaks. Several of them clearly consist of more than one state. In many

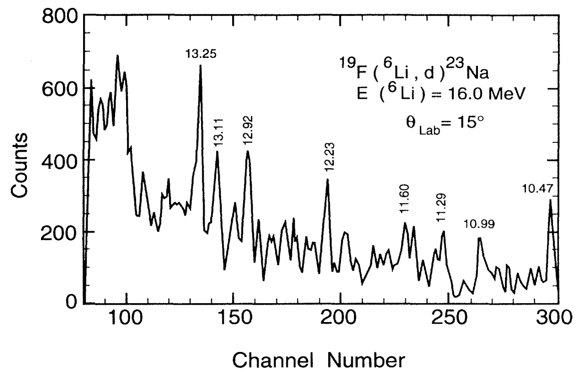

FIG. 2. As Fig. 1, but for E_x = 10.3–13.5 MeV.

cases, the peak is broad enough to imply more than one state; in others, the angular dependence of the excitation energy suggests two or more states with different angular distribution shapes. In other cases, even though several levels [16] are known within our resolution, our results are consistent with virtually all our cross section arising from a single state.

Our excitation energies are compared with those from the latest complication in Table I. We also give there

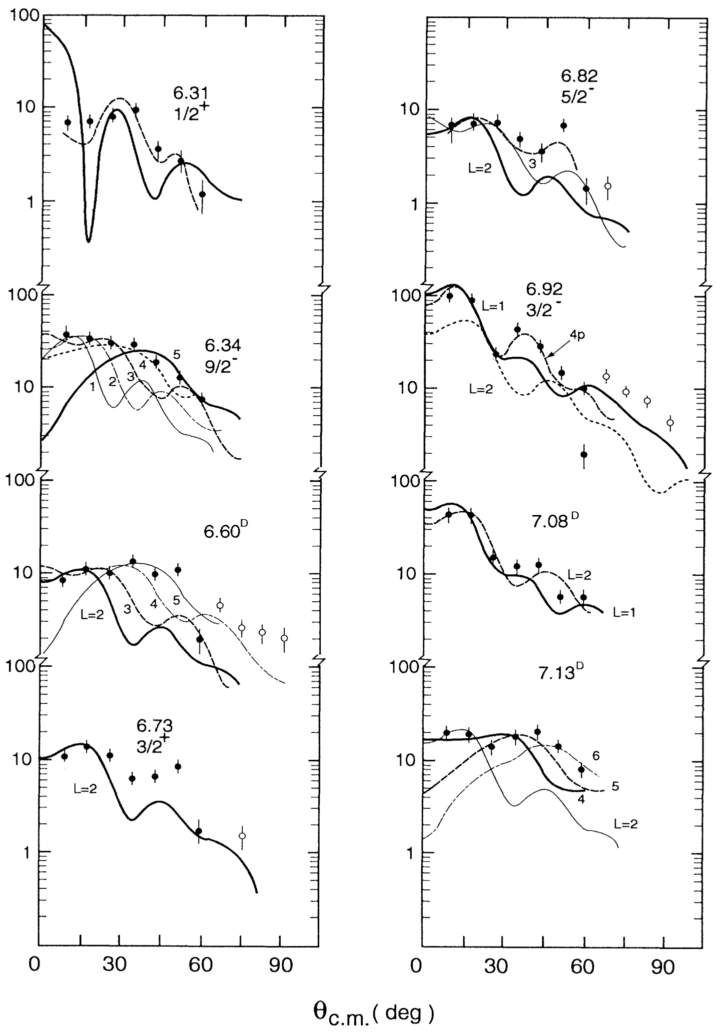

FIG. 3. Angular distributions for the reaction ^{19}F(^{6}Li,d) leading to the states indicated. Curves are from DWBA calculations discussed in the text.

TABLE I. Results of the reaction $^{19}F(^{6}Li,d)^{23}Na$, at $E(^{6}Li,d)$=16.0 MeV, compared with information from the latest compilation (where n.s. represents nonstripping).

Compilation[a]			Present		
E_x (keV)	$2J^{\pi}$	No.	E_x (MeV)[b]	$\sigma_{max}(\mu b/sr)$	L
6308	1^+	23	6.31	9.7	0
6354	9^-	24	6.34	37	(5) or n.s.
6578	$(5,9)^+$	25	6.6[D]	14	(4) or n.s.
6618	$(5,7)^+$	26			
6735	3^+	27	6.73	15	2
6820	5^-	28	6.82	8	3 or 3(+2)
6868	$(3,5)^+$	29			
6921	3^-	30	6.92	103	1
6947	$3^{(+)}$	31			
7071	$(3-7^+)$	32			
7082	3^-	32′	7.08	44	1(+2)
7122	$(1-7)^+$	33			
7133	$(3,5)^+$	33′	7.13	22	2(+4 or 5)
7154	–				
7185	–	34	7.18	5.5	n.s.
7267	—	35	7.27	17	3
7277	$(5^-,7)$				
7390	$(1-7^+)$	36	7.39	25	4 or n.s.
7412	$(5-9^+)$	37			
7452	$(3,5)^+$	38	7.48[D]	123	1+2
7488	$(1,3)^-$	39			
7566	$(5,7^+)$	40	7.56	16	2
7682	–	41	7.68	20	n.s.

TABLE I. (*Continued*).

Compilation[a] E_x (keV)	Compilation[a] $2J^\pi$	No.	Present E_x (MeV)[b]	Present σ_{max}(μb/sr)	Present L
7724	(1-5)	42	7.73[D]	25	0(+3,4)
7750	$(5,7^+)$	43			
7834	$(5^+,7)$	44	7.84	19	(5) or n.s.
7873	$3,5^+$	45a			
7876	5	45	7.89	21	1 or n.s.
[7891	5^+; T=3/2]				
7965	—				
7980	—	47	7.98[D]	11	2+5 or n.s.
7991	$(1\text{-}7^+)$				
8061	—				
8106	—				
8128	—				
8155	—				
8178	—				
8226	—				
8261	—				
8302	—				
8329	—				
8360	$(3^+ - 7^+)$	56	8.36	17	2(+5 or 6)
8417	3				
8475	$(3,5)^+$	58	8.47[D]	83	4
8505	—	59			
8560	—				
8611	—				
8631	$(3,5^+,7^+)$				
8646	$(1\text{-}7^+)$	62	8.65	65	4 or n.s.
8664	1^+; T=(3/2)				
8721	$(1\text{-}7^+)$				
8799	–				

TABLE I. *(Continued).*

Compilation[a] E_x (keV)	$2J^\pi$	No.	Present E_x (MeV)[b]	$\sigma_{\max}(\mu b/sr)$	L
8822	–	66a	8.82	13	5
8830	1^+				
(8862)	–				
(8894)	–				
8945	7^-	67	8.94	27	(4) or n.s.
8972	–				
(9000)	–				
9041	–				
9072	–				
9103	–	71	9.11	28	2(+6)
9143	–				
9147	$(1-7^+)$				
9171	–				
9211	3^-	73	9.21	40	(4)
9253	1^+				
9287	–				
9322	–				
9396	7^-				
9401	–				
9405	1				
9426	$(1-5^+)$	78	9.43	59	2(+5)
9652	$(3,5)^+$				
9656	1^+				
9674	$(3^+,5)$				
9683	3^+				
9701	3^+	84	9.70	33	3,(4)

TABLE I. *(Continued).*

Compilation[a] E_x (keV)	$2J^\pi$	No.	Present E_x (MeV)[b]	$\sigma_{max}(\mu b/sr)$	L
9732	7				
9742	–				
. . . c)					
9988	–				
10003	1^-				
10016	5^+				
		92/93	10.03[D]	43	3 or 4 or n.s.
10040	–				
10049	–				
10070	(5,7)				
10076	5				
. . .					
(10214)	–				
10221	–				
10231	5^+				
10243	1^+				
(10253)	–		10.26	41	6 + (2 or 3 or 4) or n.s.
10281	3^+				
10304	–				
10318	3^-				
. . .					
10409	–				
10440	5^+				
10448	$(5^+,7)$				
10478	3^+		10.47	126	2(+4)
10501	3^-				
10507	1^+				
10519	5^+				

TABLE I. (*Continued*).

Compilation[a]			Present		
E_x (keV)	$2J^\pi$	No.	E_x (MeV)[b]	σ_{max} (μb/sr)	L
			10.99	39	3 or 4
			11.29	78	4 or n.s.
			11.52	86	(0)
			11.60	58	(4)
			12.23	110	2 (or 3)
			12.92	66	2 or 3 or n.s.
			13.11	68	(4) or n.s.
			13.25	156	3

[a]Reference [16].
[b]Uncertainty ±10 keV. [D] denotes at least two states are observed.
[c]Above this energy, we list states from the compilation only if they are near our energy.

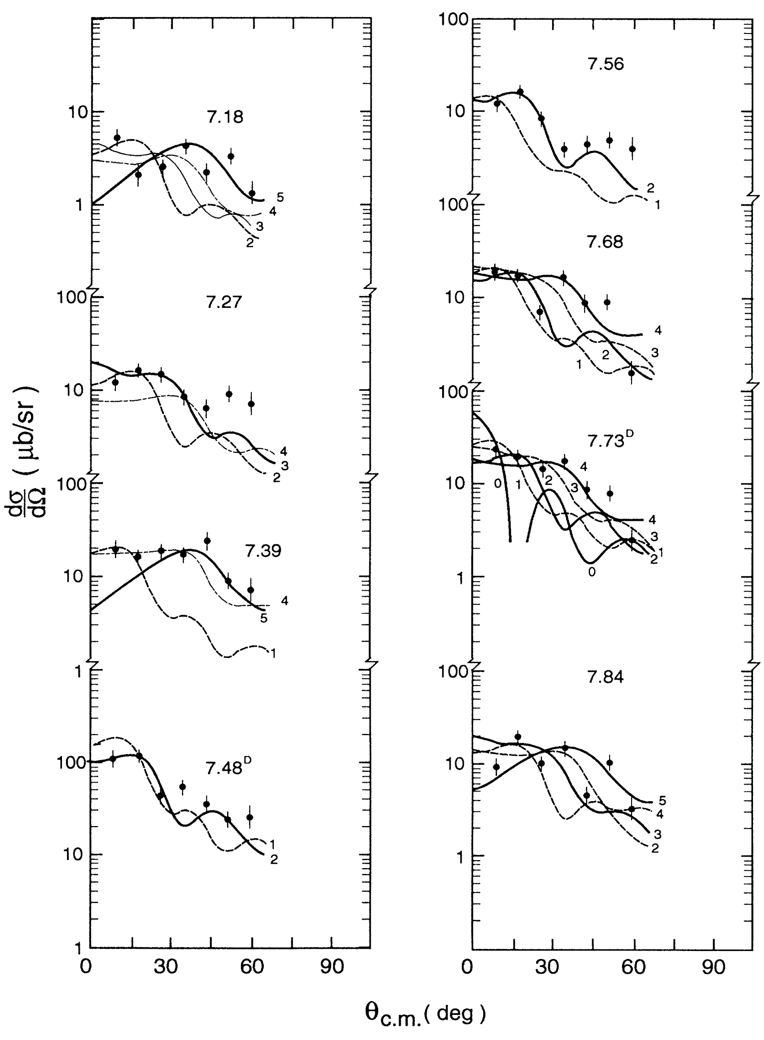

FIG. 4. As Fig. 3, but for the next set of states.

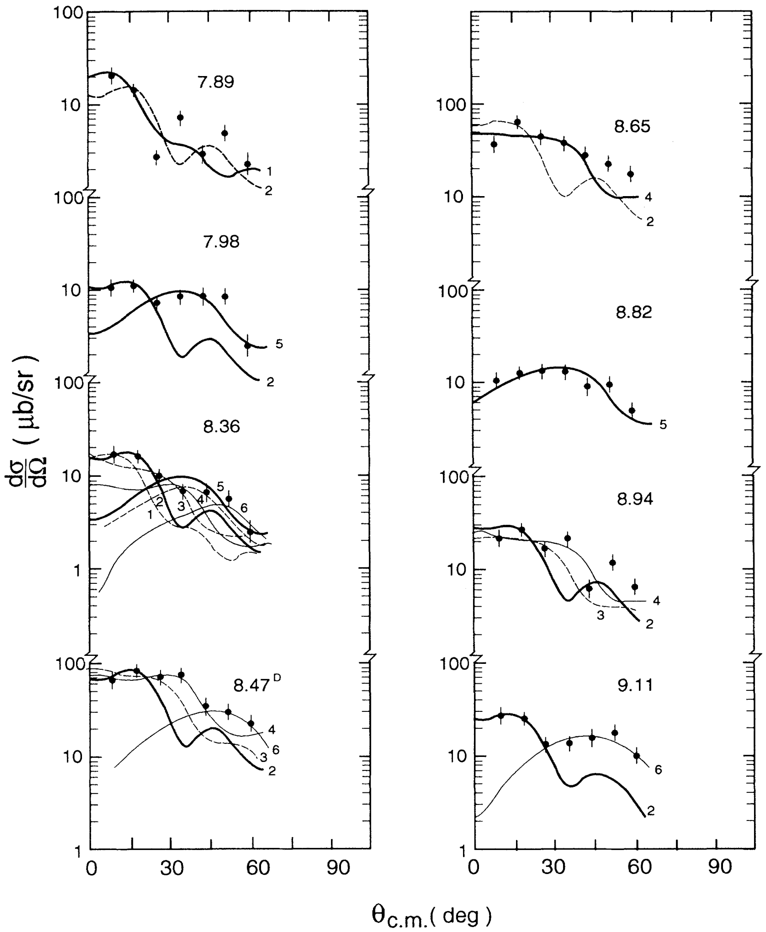

FIG. 5. As Fig. 3, but for higher-lying states.

the existing J^π information from [16] and our maximum measured cross section. We indicate with spacings in Table I the known levels that could contribute to a given peak. With our 25-keV resolution — compared to 70 keV in [7] — it is very likely that their peaks contain more unresolved states than ours. The general trend of measured peak cross sections at the two ^{6}Li energies indicates little change. Ratios of our σ_{max} to those of [7] (read off their angular distribution plots) vary from 0.5 to 2.0, but all cluster around 1.6 for most states. [One exception is the 5.97-MeV state, which we refer to later, and which has a ratio of σ(16 MeV)/σ(34 MeV)=0.16.]

Angular distributions are displayed in Figs. 3–7. (Curves are results of DWBA calculations discussed below.)

III. ANALYSIS AND DISCUSSION

Distorted-wave calculations were performed, using the code DWUCK [17] and the optical-model parameters of [5]. Results are compared with the data in Figs. 3–7. In some cases we show DWBA curves for only one or two L values; in others we compare several curves. If J^π (or a set of J^π's) is known for a peak, we always compare the data with that (those) L value(s). [As $J^\pi(^{19}\mathrm{F(g.s.)})$ is $\frac{1}{2}^+$, L is unique for a fixed final J^π.] If Ref. [7] assigned an L value, we also compare our data with a DWBA curve for that L. In several cases, these L's do not fit the data, or no definite J^π information is available, or our angular distribution is not characteristic of a single L. Then we display curves for many L's.

It is clear from the figures that many of the levels are reached via direct α transfer, and that for those states the angular distribution determines the L value. We have extracted spectroscopic strengths by normalizing DWBA curves to the data near angles at which the cross section is a maximum. The relation is

$$\sigma_{\mathrm{exp}} = NS\frac{(2J_f+1)\sigma_{\mathrm{DW}}}{(2J_i+1)(2L+1)} . \quad (1)$$

As J_f is not known for the majority of these states, we have extracted $(2J_f+1)S$. The value of the overall normalization factor, N, is chosen as in [5], by making $S=1$ for the g.s. Throughout this paper, S will denote the relative spectroscopic factor and $\mathcal{G}$ the relative spectroscopic strength $\mathcal{G}=(2J_f+1)S$. Unprimed quantities S and $\mathcal{G}$ will have the normalization of [5] [viz. S(g.s.)=1], while primed quantities S' and $\mathcal{G}'$ are normalized as in [7] [viz. S'(4.78 MeV)=1].

Our L and $\mathcal{G}$ values are compared in Table II with those from [7]. We converted their S' values back into $\mathcal{G}$'s by making use of the information in their Table II.

Many of our results agree with those of [7], but several do not. We mention briefly a few problems with [7]. For

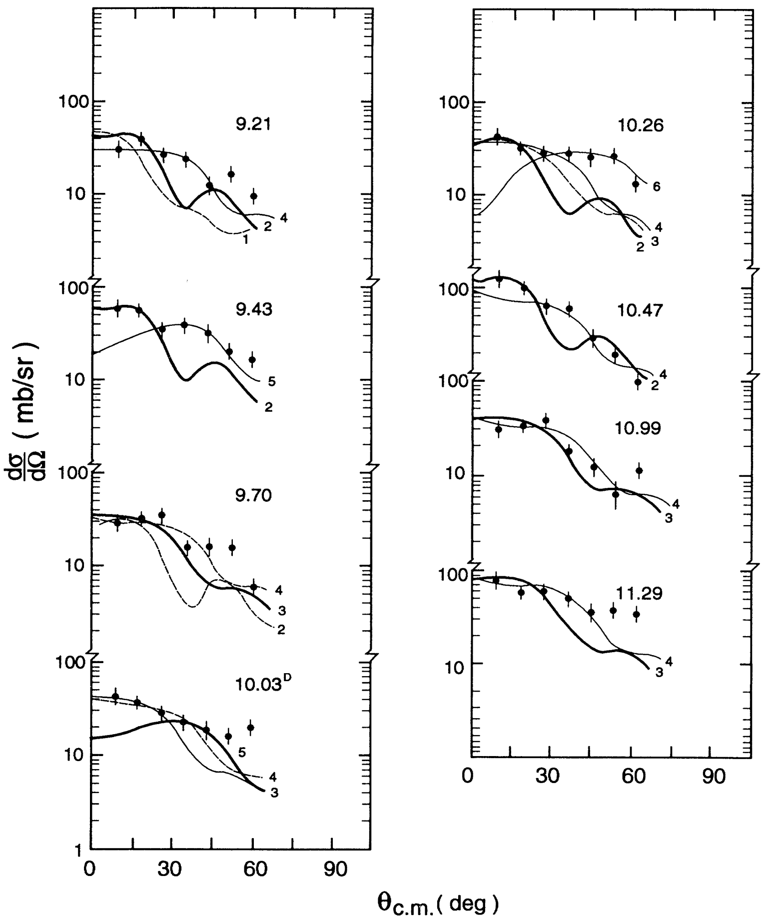

FIG. 6. As Fig. 3, but for higher-lying states.

example, their value of $S' = 6.5$ for their 7.45-MeV peak must be in error. By comparing cross sections for their 6.93-, 7.45-, and 8.64-MeV angular distributions — all of which they analyze as $L = 2$ — it would appear that a correct value is approximately $S'(7.45)$=2.25, assuming, of course, that no error was made for the other two states.

Another problem is the 5.97-MeV state, whose cross section in [7] is about six times that in [5]. As pointed out above, cross sections for all other states at the two energies are equal to within a factor of two. Comparison of $L = 1 + 2$ doublets at the two energies suggests $L = 1$ is somewhat more prominent at 16 MeV and $L = 2$ at 34 MeV. Hence, this is not a case of $L = 1$ being favored at the higher energy.

The authors of [7] do not mention the presence of deuteron peaks from an oxygen impurity. However, oxygen is present in their elastic spectrum and ^{16}O(^{16}Li,d) cross sections are large. We suggest the possibility that their 5.97-MeV cross section — which appears (from the three points they show) more as $L = 0$ than $L = 1$, and which is the only cross section of [7] that is more than twice ours — contains a large contribution from ^{16}O(^{6}Li,d)^{20}Ne(g.s.). If this is so, then other ^{23}Na peaks in [7] should be contaminated by ^{16}O$\rightarrow$^{20}Ne (exc) impurity peaks. Specifically, strong ^{20}Ne states are at $0.0(0^+)$, $1.63(2^+)$, $4.25(4^+)$, $5.78(1^-)$, $6.72(0^+)$, and $7.16(3^-)$ MeV. These would contaminate ^{23}Na states near excitation energies of 7.5, 9.9, 11.4, 12.3, and 12.9 MeV. It may even be that their 7.45-MeV peak contains some contribution from ^{20}Ne(2^+).

As mentioned above, [7] assigns 12 L values: five $L = 2$, four $L = 3$, two $L = 4$, and one $L = 5$. The L values for their other angular distributions were taken from J^{π} values that were known at that time. We list the L assignments from [7] in Table III and compare with our results.

Among the five $L = 2$ assignments, their data, as they state, appear to contain some $L = 1$ contribution for the 6.93-MeV level. Our data clearly require $L = 1$ or $L = 1 + 2$ for that state. Hence the L values are not in disagreement — even though the spectroscopic strengths are far apart — our $\mathcal{G}_1 = 5.8$, $\mathcal{G}_2 = 4.0$, compared with $\mathcal{G}'_1 = 4.0$, $\mathcal{G}'_2 = 12.6$ in [7]. They see no $L = 1$ contribution at 7.06 MeV, and our 7.08-MeV angular distribution suggests $L = 1$ or $L = 1 + 2$. Again L values are not necessarily in disagreement, but strengths are (see Table II).

For 8.64 MeV, Ref. [7] assigns $L = 2$. They do not comment on the excess of cross section at extreme forward angles, which probably imply $L = 1$. However, our 8.65-MeV angular distribution is either $L = 4$ or nonstripping, and not $L = 2$. This is a strong state, which is therefore unlikely to be dominated by CN processes. The disagreement is not understood.

The 9.44-MeV angular distribution, assigned $L = 2$ in [7], also contains (as they state) a contribution from some higher L value. We suggest $L = 2 + 5$. For this state the

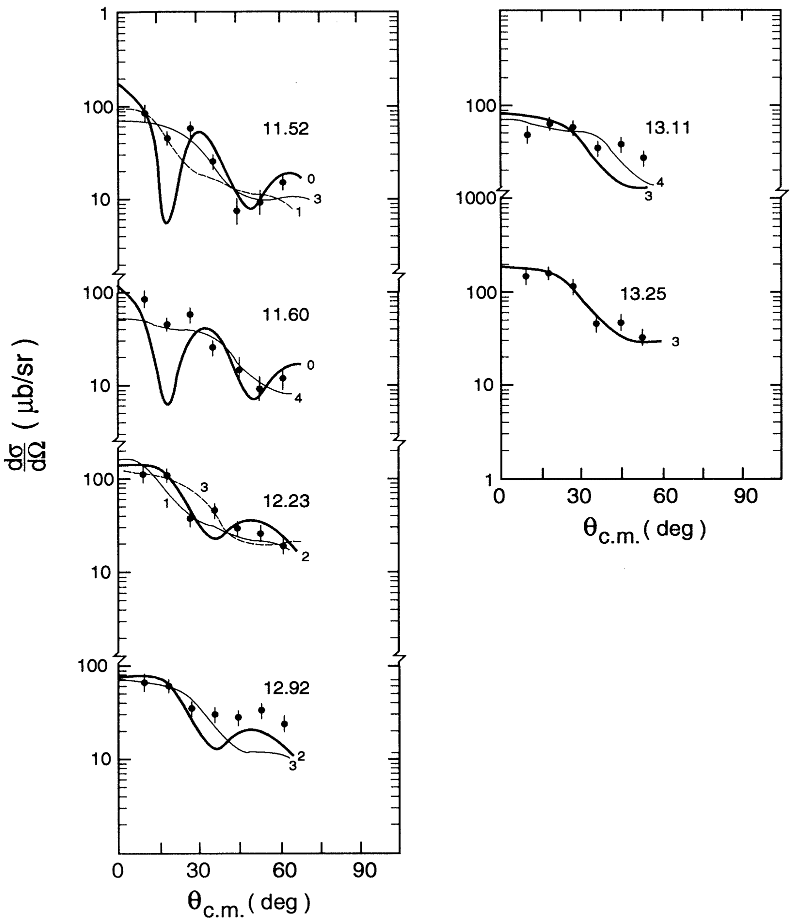

FIG. 7. As Fig. 3, but for states with highest excitation energy.

$L = 2$ strengths are not in severe disagreement. Results for 12.93 MeV are compatible.

The situation for $L = 3$ is even worse than for $L = 2$. Of the four $L = 3$'s assigned in [7] (see Table III), we do not observe two of them, another appears to be $L = (4)$ or nonstripping and one prefers $L = 2$ (although 3 is also possible).

One of the major puzzles of the 34-MeV work is the absence of $L = 4$ states. One might think that the higher energy would be more likely to populate the higher L values. Yet, only two $L = 4$'s are assigned in [7]. We see only one of them, and assign $L = 3$ or 4.

The $L = 5$ at 10.04 MeV in [7] is assigned $L = 3$ or 4 in the present work. Their $L = 5$ or 6 at 10.60 MeV is not observed in the present data.

We turn now to a brief discussion of each of the states.

6.31 MeV. The fit is poor, but data clearly prefer $L = 0$ for this known $\frac{1}{2}^+$ state. Dashed curve is empirical $L = 0$ from [5].

6.34 MeV. This known $\frac{9}{2}^-$ state is weak and not well fitted by $L = 5$. Reference [7] did not resolve the 6.31- and 6.34-MeV states, but fitted the sum with $L = 0 + 5$. Our strengths are consistent with theirs.

6.6 MeV. This is a known doublet, with $J^\pi = (\frac{5}{2}, \frac{9}{2})^+$ and $(\frac{5}{2}, \frac{7}{2})^+$. Our data are reasonably consistent with $L = (4)$, though a small $L = 2$ contribution cannot be ruled out. The cross section is small enough that it may be mostly CN. Reference [7] does not show an angular distribution, but they also tentatively suggest $L = (4)$. Our strength is consistent with theirs.

6.73 MeV. This state is known to have $J^\pi = \frac{3}{2}^+$. Our cross section is small, but $L = 2$ is reasonable. Our strength agrees with that of [7].

6.82 MeV. This doublet is very weak, but could be fitted by $L = 3$ or $L = 3 + 2$. The two known states have $J^\pi = \frac{5}{2}^-$ and $(\frac{3}{2}, \frac{5}{2})^+$. Dashed curve is a smooth curve drawn through the 6.73-MeV data.

6.92 MeV. This is another doublet: 6.921 MeV, $\frac{3}{2}^-$ and 6.947 MeV, $\frac{3}{2}^{(+)}$. Our data are well fitted by $L = 1$. [Dashed curve has $2(N-1) + L = 7$, rather than 9. All other negative parity states above this E_x use $2(N-1) + L = 9$.] Reference [7] prefers mostly $L = 2$ for this peak, but with an $L = 1$ component. If we fit with $L = 1 + 2$, our $L = 1$ strength is larger than theirs, and $L = 2$ significantly smaller.

7.08 MeV. The components of this doublet are 11 keV apart, with $J^\pi = (\frac{3}{2} - \frac{7}{2}^+)$ and $\frac{3}{2}^-$. Our data clearly favor $L = 1$ or 1+2, whereas [7] claims pure $L = 2$. If we fit with $L = 1 + 2$, our $L = 2$ strength is considerably smaller than that of [7].

7.13 MeV. This complex contains three known states, none with J^π uniquely assigned (see Table I). Our data could be fitted with a sum of $L = 2$ and $L = 4$ or 5.

TABLE II. Comparison of L values and spectroscopic strengths in $^{19}F(^{6}Li,d)^{23}Na$, at $E(^{6}Li,d)$=16.0 and 34.0 MeV (where n.s. represents nonstripping).

	16 MeV[a]			34 MeV[b]	
E_x (MeV)	L	$(2J+1)S_{rel}$[c]	E_x (MeV)	L	$(2L+1)S_{rel}$[d]
4.43	0	1.1	4.43	0*	1.2
4.78	4	11.5	4.78	4	8.0
5.38	2	2.0	5.39	2	(1.2)
5.54	(6)	(< 22)	5.54	(6)	(8.4)
5.7[T]	3 or 2	3.1 or 4.4	5.74	2	7.8
5.93	(3 or 4 or n.s.)	(2.1 or 2.5)	–	–	
5.97	1	1.2	5.97	1*	1.2
6.31	0	1.9	6.32	0+(5)	2.6
6.34	(5) or n.s.	(≤ 13)			12
6.6[D]	(4) or n.s.	(≤ 5.6)	(6.59	(4)	(2.0))[e]
6.73	2	1.9	6.73	2	3.0
6.92	1 or	8.6 or	6.93	(1)+2	(4.0)+12.6
	1+2	5.8+4.0			
7.08	1 or	3.9 or	7.06	2	9.0
	1+2	2.8+1.9			
7.13	2(+4 or 5)	2.7	–	–	–
7.27	3	2.7	(7.27	(2 or 3)	–)[e]
7.39	4 or n.s.	8.4	–	–	–
7.48	1+2	6.5+5.1	7.45	2(+1)	39
7.56	2	2.0	(7.59	(2)	–)[e]
7.73	0(+3 or 4)	(1.8)	(7.68	(1 or 2)	–)[e]
7.84	(5) or n.s.	(≤ 6.9)	(7.84	n.s.	–)[e]
7.89	1	1.5	–	–	–
7.98	(2+5) or n.s.	(1.4+4.4)	–	–	–
8.36	2(+5 or 6)	2.0	(8.30	–	–)[e]
8.47	(4)	(25)	8.47	3	17.6
8.65	4 or n.s.	(13)	8.64	2	10.8
8.82	5	5.5	(8.85	> 2	–)[e]
8.94	(4) or n.s.	(5.6)	8.95	3*	4.0
9.11	2(+6)	3.0(+28)	–	–	–
9.21	(4)	(7.3)	9.21	1	4.4
9.43	2(+5)	6.2(+15)	9.44	2(+large L)	(12)
9.70	3(or 4)	3.1 (or 6.2)	9.70	2	6.0
–	–	–	9.81	2	4.8
10.03	3 or 4	3.8 or 7.3	10.04	5	18
10.26	6+(2 or 3 or 4)	(31)	–	–	–
10.47	2 or	12.5 or	(10.44	(2)	–)[e]
	2(+4)	4.8(+9.4)			
–	–	–	10.60	5 or 6*	–
–	–	–	10.77	2* or 3	7.8
10.99	3 or 4	5.2 or 9.8	10.96	4	17
11.29	(4)	(20)	–	–	–
11.52	(0)	(15)	–	–	–
11.60	(4(+0))	(15)	–	–	–
–	–	–	12.03	3	16
12.23	2 (or 3)	28 (or 18)	12.18	3	18
–	–	–	12.30	3	10
–	–	–	12.73	2	14
–	–	–	12.81	4	25
12.92	2 or 3	16 or 10	12.93	2	13
13.11	(4)	(20)			
13.25	3	27			

[a]Results for states below 6.0 MeV are from Ref. [5], others are from present work.
[b]Reference [7]. Asterisks in the L column indicate not enough points in angular distribution of Ref. [7] to determine L (L was taken from known J^{π}).
[c]S_{rel} normalized so as to give $S_{rel} = 1$ for g.s.
[d]S_{rel} normalized so as to give $S_{rel} = 1$ for 4.78-MeV state.
[e]No angular distribution in Ref. [7], but state is discussed in their text.

TABLE III. Comparison of L values assigned in previous ^{19}F(^{6}Li,d) and our results for those states.

Previous[a]		Present
L	E_x (MeV)	L
2	6.93	1 or 1+2
2	7.06	1 or 1+2
2	8.64	4 or nonstripping
2	9.44	2(+5)
2	12.93	2 or 3
3	8.47	(4)
3	12.03	not seen
3	12.23	2(or 3)
3	12.30	not seen
4	10.96	3 or 4
4	12.81	not seen
5	10.04	3 or 4
5 or 6	10.60	not seen

[a]Reference [7].

Reference [7] did not see this state, or the next one.

7.18 MeV. This is the weakest state for which we have an angular distribution. It appears to be of nonstripping character.

7.27 MeV. The two members of this doublet are 10 keV apart. We observe $L = 3$, implying $J^\pi = \frac{5}{2}^-$ or $\frac{7}{2}^-$ for one member. Reference [7] does not have an angular distribution, but they suggest $L = 2$ or 3.

7.39 MeV. An $L = 4$ curve gives a reasonable fit. Two states are known here, 22 keV apart, with $J^\pi = (\frac{1}{2} - \frac{7}{2}^+)$ and $(\frac{5}{2} - \frac{9}{2}^+)$. This state was not seen by [7].

7.48 MeV. Our data clearly require $L = 1 + 2$, consistent with known $J^\pi = (\frac{3}{2}, \frac{5}{2})^+$ and $(\frac{1}{2}, \frac{3}{2})^-$ for states at 7.452 and 7.488 MeV, respectively. Reference [7] finds $L = 2 + 1$. They give no $L = 1$ strength, and — as mentioned elsewhere in this report — their $L = 2$ strength seems too large for their measured cross section by a factor of about three.

7.56 MeV. Only one state is known here, with $J^\pi = (\frac{5}{2}, \frac{7}{2}^+)$. Our finding of $L = 2$ would imply $\frac{5}{2}^+$. Reference [7] does not resolve this state from its neighbors, but they do mention that a state at 7.59 MeV appears to have $L = 2$, consistent with the present result.

7.68 MeV. This is another single state. Our results suggest $L = 2$ or 4 or nonstripping. Reference [7] claims $L = (1$ or $2)$ from a 7.68-MeV member of their unresolved peak (no angular distribution shown).

7.73 MeV. This is a 26-keV doublet with $J^\pi = (\frac{1}{2} - \frac{5}{2})$ and $(\frac{5}{2}, \frac{7}{2}^+)$. Our data seem to prefer $L + 0$ (+3 or 4). This state is not mentioned in [7].

7.84 MeV. Our data are either $L = 5$ or nonstripping. Reference [7] (no angular distribution) suggests nonstripping. The state known here has $J = \frac{5}{2}^+$ or $\frac{7}{2}$.

7.89 MeV. This state and the next one are not seen by [7]. The (^{6}Li,d) reaction is not likely to make a $T = \frac{3}{2}$ state, so we are left with two possibilities: $(\frac{3}{2}, \frac{5}{2}^+)$ and $J = \frac{5}{2}$, neither of which is consistent with our $L = 1$. Our data suggest a new state with $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$. This is one of only two instances in which our results are in contradiction to the compilation.

7.98 MeV. This could be any of three states, about which little is known. Our results suggest $L = 2 + 5$.

We now come to a 300 keV region (8.0–8.3 MeV) that contains [16] eight states (all with no J^π information), none of which we, or [7], see.

8.36 MeV. This angular distribution appears characteristic of $L = 2$ (+5 or 6). A state at 8.360 MeV has $J^\pi = \frac{3}{2}^+ - \frac{7}{2}^+$. Other states are known at 8.417 MeV, $J = \frac{3}{2}$, and 8.329 MeV, no J^π information.

8.47 MeV. If our $L = (4)$ is correct, then the state we see is the upper member of the doublet, not the $(\frac{3}{2}, \frac{5}{2})^+$ member observed in ^{22}Ne(^{3}He,d). Curiously, [7] assigns $L = 3$.

8.65 MeV. The data suggest $L = 4$ or nonstripping. Reference [7] has $L = 2$. Known states (Table I) could accommodate either or both, but the difference in character at the two energies is not understood. This is certainly not a weak state.

8.82 MeV. We favor $L = 5$ or nonstripping for this collection of 2, 3, or 4 states. Reference [7] (no angular distribution) also finds a larger L value.

8.94 MeV. The data suggest $L = (4)$ or nonstripping. However, $L = 3$ cannot be ruled out. The known state here has $J^\pi = \frac{7}{2}^-$.

9.11 MeV. The data suggest $L = 2 + 6$. Four states are known near here — three with no J^π information, one with $J^\pi = \frac{1}{2} - \frac{7}{2}^+$. Reference [7] does not see this state.

9.21 MeV. The data for this state are compared with an $L = 1$ curve in [7], because a $\frac{3}{2}^-$ state is known at this energy. Our data suggest $L = (4)$ or nonstripping. Three states are known within our resolution and six or more within the resolution of [7].

9.43 MeV. A good fit is provided by $L = 2 + 5$. Reference [7] finds $L = 2$, plus another larger L. Our peak could contain three or four known states, but the $\frac{7}{2}^-$ at 7.396 MeV is probably not making a contribution. Within the known limits, our data imply $J^\pi(9.426) = \frac{3}{2}^+$ or $\frac{5}{2}^+$ and $J^\pi(9.401) = \frac{9}{2}^-$ or $\frac{11}{2}^-$.

9.70 MeV. Our data prefer $L = 3$, with (4) a poorer second choice. Reference [7] suggests $L = 2$, but an $L = 2$ curve looks nothing like our angular distribution. At the time of [7], three states were known here, all with $J^\pi = \frac{3}{2}^+$ or $\frac{5}{2}^+$. Now, however, two additional states are known, one with $J = \frac{7}{2}$, the other with no J^π information.

10.03 MeV. This peak is wide enough to require contributions from at least two states. Within our resolution, 4−7 states exist. Our $L = 3$ or 4 is compatible with what is known about those states (see Table I). Reference [7] suggests $L = 5$, but an $L = 5$ curve does not agree with our data.

10.26 MeV. This state is not seen in [7]. Our angular distribution appears to contain $L = 6$, plus some other (lower) L (=2, 3, or 4). Three to five states are known within our resolution, three with $J^\pi = \frac{5}{2}^+, \frac{1}{2}^+$, and $\frac{3}{2}^+$. Our results suggest one of the others has $J^\pi = \frac{11}{2}^+$ or $\frac{13}{2}^+$.

10.47 MeV. Our angular distribution requires $L = 2$ or $L = 2$ (+4). Reference [7] does not present an angular distribution, but they do know of the existence of the 10.436-MeV (now 10.440) $\frac{5}{2}^+$ state. If $L = 4$ is indeed present, then it must arise from either the 10.409 (no J^π information) or 10.448, $J = \frac{5}{2}^+$ or $\frac{7}{2}$. The latter is more likely, given the large separation of the former. This identification would imply $J^\pi(10.448) = (\frac{7}{2}^+)$.

For states at higher excitation, we compare only with [7].

10.99 MeV. Our data suggest $L = 3$ or 4, while [7] assigns $L = 4$. The strengths are consistent if L is 4.

11.29, 11.52, 11.60 MeV. Neither of these states was seen by [7]. They all could contain $L = 4$, and the latter two many have some $L = 0$.

Reference [7] observed states at 10.60, 10.77, 12.03, 12.30, 12.73, and 12.81 MeV — none of which are apparent in the present work. The reason for this is unclear.

12.23 MeV. Our state has $L = 2$ (or 3). This may be the state observed by [7] with $L = 3$ at 12.18 MeV. If $L = 3$, the strengths are consistent.

12.92 MeV. Our state has $L = 2$ or 3. Reference [7] saw a state at 12.93 MeV with $L = 2$. For this L value, the strengths are consistent.

13.11, 13.25 MeV. Neither or these states was seen by [7]. The first has $L = ((4)$ or $(3))$, the second has $L = 3$.

It would appear that the different normalizations chosen for $S_{\rm rel}$ by us and [7] make their $\mathcal{G}'$ values slightly larger than ours — by a factor of 1.5–2.0 for $L = 2$. Within this factor, we agree for the $L = 0$, (5), and 2 strengths at 6.31, 6.34, and 6.73 MeV, respectively — all of which are states of known J^π. Our $L = (4)$ upper limit is larger than the tentative one quoted in [7]. They do not show an angular distribution for this state.

The serious disagreement at 7.45 MeV has been referred to above. If their S' is 2.25, rather than 6.5, the discrepancy is less serious. We prefer $L = 3$ (or 4) for the 9.70-MeV state, while [7] used $L = 2$ from known J^π. However, both angular distributions may contain contributions from several states — and not necessarily the same ones, because of the factor of three different resolution.

IV. CONCLUSIONS

Of our 38 angular distributions, [7] shows data for 14 of them. The L values can be reconciled in eight cases, and they disagree in six. Of the eight with compatible L values, we have a serious strength disagreement for only two — the $L = 2$ content at 7.08 and 7.45 MeV.

Of our other 24 angular distributions, 12 are in agreement with known J^π (or limits), two are in disagreement, and our information is new for the other 10 — some of which, however, are nonstripping.

Of the six cases of L discrepancies with [7], none of our results are in contradiction with known [16] J^π values. Our results would suggest that a different member of a doublet (or multiplet) is being populated than was assumed in [7].

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