PHYSICAL REVIEW C VOLUME 46, NUMBER 6 DECEMBER 1992

$^{18}O(^3He,p)^{20}F$ reaction

M. S. Chowdhury, M. A. Zaman,* and H. M. Sen Gupta
Department of Physics, University of Dhaka, Dhaka, Bangladesh

(Received 19 March 1992)

The $^{18}O(^3He,p)^{20}F$ reaction has been studied at 18 MeV. Energy levels are measured up to $E_x \sim 8.5$ MeV and several new levels are observed. Angular distributions are measured for many of the levels and distorted wave Born approximation analyses are carried out. The L assignments are made and J^π limits are obtained.

PACS number(s): 25.55.Hp, 27.30.+t

I. INTRODUCTION

The $(^3He,p)$ reaction at an energy well above the Coulomb barrier is expected to proceed mostly through a single step process and is well known in populating selectively with considerable strength, though less selectively than the (α,d) reaction, levels in the final nucleus having certain simple configurations. The present work deals with the $^{18}O(^3He,p)^{20}F$ reaction at 18 MeV and is a part of the $(^3He,p)$ reaction on the oxygen isotopes undertaken by some of the present authors [1–3]. An earlier paper [3], henceforth to be referred to as paper I, was concerned with a study of the $(sd)^4$ shell model states populated in the $^{18}O(^3He,p)$ reaction. A more detailed investigation of the reaction is carried out in the present work; energy levels in ^{20}F are obtained up to $E_x \sim 8.5$ MeV and the angular distributions are measured for many of the levels of either parity up to $E_x \sim 6.2$ MeV. The $^{18}O(^3He,p)^{20}F$ reaction was previously studied by Crozier and Fortune [4] at 18 MeV covering an excitation energy up to $E_x \sim 3.8$ MeV. A later $(^3He,p)$ reaction [5] was concerned with a study of a few 1^+ levels in ^{20}F up to $E_x \sim 4.08$ MeV.

II. EXPERIMENTAL PROCEDURE

The experiment was carried out with a beam of 18 MeV ^3He particles from the Tandem generator of the Nuclear Physics Laboratory, Oxford. The target material was prepared by burning tungsten filament in an atmosphere of oxygen enriched in ^{18}O. The oxide was then vacuum deposited onto about 10 $\mu g\,cm^{-2}$ thick carbon foil and the target was placed at the center of the Oxford multichannel magnetic spectrograph. The reaction products were momentum analyzed under a magnetic field of strength 10.83 kHz and recorded simultaneously in Ilford L4 plates 25 μm thick over the angles 11.25°–86.25° in steps of 7.5°. Particles other than protons were stopped in approximately 0.34-mm-thick Mylar foil placed on top of each plate. The total beam charge was 3530 μC. The plates were scanned at the Nuclear Physics Laboratory of the University of Dhaka, Dhaka and the energy spectrum is obtained at each angle. A typical spectrum at 18.75° is shown in Fig. 1. The energy resolution is ~20 keV (FWHM). The energy levels were obtained by a parabolic fit to several well established levels in ^{20}F, namely, 0.0, 0.656, 1.058, 1.824, 2.201, 3.587, and 5.223 MeV, as well as some contaminant levels. The latter served as useful reference lines in a region of the plates where the level density is high.

The energy levels obtained in the present work are shown in Table I. The criteria used in the identification of the levels were that the level energies at different angles agreed to within about 10 keV and that the levels had about the same widths at all the angles. Special care was taken in determining the areas under weak groups and the groups appearing as close doublets, as well as those sitting on a rather large background, as given in Ref. [6]; repeated scannings were done for such groups. Levels for which the cross section data did not agree to each other within statistics and/or are available at a few angles are excluded from the distorted wave Born approximation (DWBA) analyses.

The target gas used in this experiment was an old sample and the abundance of ^{18}O in the gas was rather uncertain. To obtain the absolute cross section scale, subsidiary short exposures were taken on the elastic scattering of 6 MeV ^3He particles from the same target as used in the main experiment. The yields of the elastic groups from $^{16,18}O$ at 78.75° and 86.25° (laboratory) were measured and were assumed to be in the ratio of the abundances of the two isotopes. The yields of the levels leading to ^{18}F at $E_x = 0.0$, 0.937, and 1.120 MeV arising from the $(^3He,p)$ reaction on ^{16}O in the main experiment were measured at several angles. The absolute cross sections for these levels are already known from a previous experiment at the same beam energy [1]. Hence the absolute cross section was obtained for the $^{18}O(^3He,p)^{20}F$ reaction. The error in the absolute cross section was estimated to be ~20%.

III. DWBA ANALYSIS

Local zero-range DWBA analyses were carried out using the code DWUCK4 due to Kunz. Microscopic DWBA

---

*Present address: Department of Physics, Jahangirnagar University, Savar, Bangladesh.

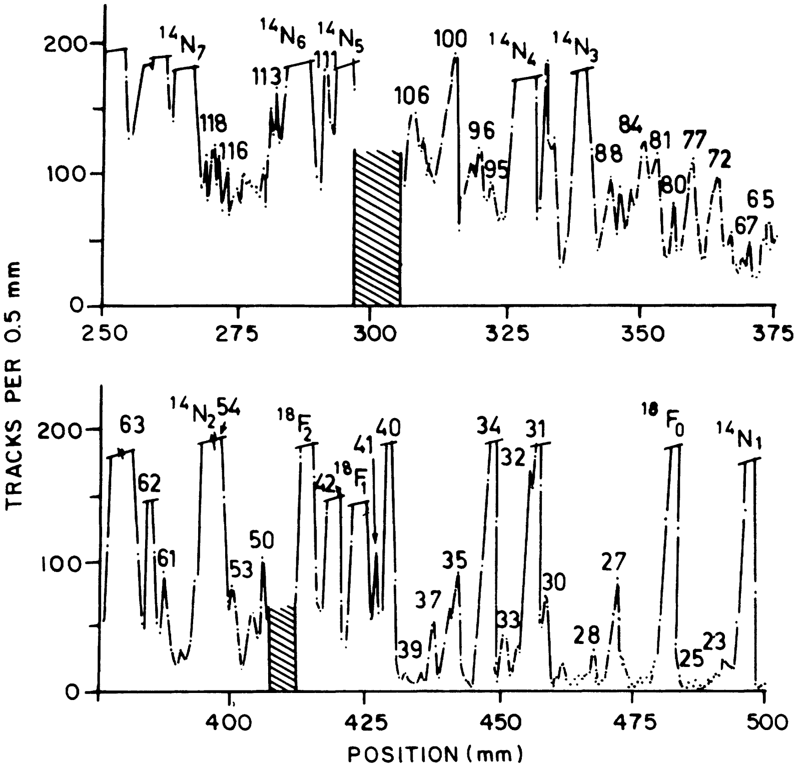

FIG. 1. Spectrum of protons arising from the (^{3}He,p) reaction on ^{18}O at 18.75° (laboratory); the clear portion of the spectrum is not shown. Shaded regions represent emulsion disturbance.

TABLE I. Summary of the results.

Group No.	E_x (MeV) a	E_x (MeV) b	Average $\sigma(\theta)$ (μb/sr)	L transfer a	L transfer d	J^π values b	J^π values a
0	0	0	117	2	2	2^+	c
1	0.656	0.656	256	2	2+4	3^+	c
2	0.823	0.823	104	4	4	4^+	c
3	0.997	0.984				1^-	
4	1.058	1.057	95	0+2	0+2	1^+	c
5	1.317	1.309	39	1		2^-	c
6	1.824	1.824	471	4	4	5^+	c
		1.844				2^-	
7	1.974	1.971	54	3		(3^-)	c
8	2.047	2.044	91	2	2	2^+	c
9	2.201	2.194	292	2+4		(3^+)	3^+
10	2.860	2.865	54	(2)		(3^-)	$(1^+,2^+,3^+)$
11	2.968	2.966	417	2+4	2+4	3^+	c
		2.968				(4^-)	
12	3.176	3.173	75	2	0+2[e]	1^+	c
13	3.486	3.488	624	0+2	0+2	1^+	c
		3.526				0^+	
14	3.587	3.587	369	2	2+4	$(1,2)^+$	c
15	3.680	3.680	137	4	4	1,2	$(3,4,5)^+$
16	3.762	3.761	95	3		$(2^-,3^+)$	2^-
17	3.961	3.965	69	0+2	0+2	1^+	c
18	4.082	4.082	103	0	0+2	$(1)^+$	1^+
19	4.210	4.199	126	4			$(3,4,5)^+$
		4.208					
20	4.282	4.277	82	4		$(1,2)^+$	$(3,4,5)^+$
		4.315				$(0,1)^+$	
		4.371				(2^+)	
21	4.516	4.509	82	3		$1^+,2$	2^-
22	4.590	4.581	109	n.a.			
		4.592					

TABLE I. (*Continued*).

Group No.	E_x (MeV) a	E_x (MeV) b	Average $\sigma(\theta)$ (μb/sr)	L transfer a	L transfer d	J^π values b	J^π values a
23	4.722	4.731	101	4		(3,4,4,5)	$(3,4,5)^+$
24	4.744		30	4			$(3,4,5)^+$
25	4.768	4.766					
26	4.904	4.892 4.898					
27	5.041	5.047	272	1		$(2)^-$	c
		5.068				$(1^-,2,3^+)$	
28	5.126	5.131				$(2^-,3,4^+)$	
29	5.223	5.224	363	1		$(1,2)^-$	c
30	5.278	5.282	105	0			$(1)^+$
31	5.319	5.319	471	1		0,1,2	$(0,1,2)^-$
32	5.340	5.349	97	2		$(3)^+$	c
33	5.404	5.413	198	4			$(3,4,5)^+$
		5.450					
34	5.445	5.455	431	2			
		5.463					$(1,2,3)^+$
35	5.543		206	1			$(0,1,2)^-$
36	5.562	5.555	147	1		$1,2^+$	$(0.1,2)^-$
		5.588					
37	5.627	5.620	201	1			$(0,1,2)^-$
38	5.645		98	3			$(2,3,4)^-$
	5.661						
39	5.708	5.713	112				
40	5.761	5.764	867	2		$(3)^+$	c
41	5.795	5.810	223	0		(1^+)	c
42	5.930	5.936	682	1		(2^-)	c
43	6.006	6.018				2^-	c
44	6.049	6.045				0,1,2	c
45	6.065						
46	6.079						
47	6.095	6.090				(0^-)	
48	6.111						
49	6.136						
50	6.154	6.161	201	4		$(2,3^+)$	3^+
51	6.189						
52	6.213	6.200	103	1		$(2^-,3,4^+)$	2^-
53	6.251	6.240					
54	6.287	6.299					
55	6.335	6.339					
56	6.355						
		6.375					
57	6.391						
58	6.413	6.416					
59	6.444	6.441					
60	6.458						
61	6.481	6.474					
62	6.509	6.519	530	0		$0^+,T=2$	c
63	6.578	6.588				2^-	
64	6.628	6.627				(3,4)	
		6.643				1^-	
		6.647					
65	6.680						
66	6.705	6.693					1^-
67	6.734						
68	6.766	6.766				$(2^-,3,4^+)$	
69	6.789						
70	6.801						
71	6.823	6.825					
72	6.856	6.857					
		6.857				2	

TABLE I. (*Continued*).

Group No.	E_x (MeV) a	E_x (MeV) b	Average $\sigma(\theta)$ (μb/sr)	L transfer a	L transfer d	J^π values b	J^π values a
73	6.870						
74	6.893						
75	6.909	6.905					
76	6.928	6.936					
77	6.945						
78	6.960	6.968				1^-	
79	6.988						
80	7.016						
81	7.051						
		7.067				0^-	
82	7.078	7.078					
83	7.078	7.076				(1^+)	
84	7.094						
85	7.135						
86	7.157						
87	7.172	7.166				$2^{(+)}$	
88	7.207						
		7.232					
		7.283					
89	7.309	7.319				(1)	
90	7.364	7.37				(1)	
91	7.409	7.420				(2^+)	
92	7.507	7.495				(2)	
93	7.553						
94	7.575						
95	7.606						
96	7.643						
97	7.660	7.655				(2^+)	
98	7.679						
99	7.697						
100	7.727	7.734					
101	7.759						
102	7.777						
103	7.797						
104	7.813						
105	7.837	7.483			1		
106	7.852						
107	7.873						
108	7.888						
		7.985				1	
109	8.068	8.05	115	2		$2^+, T=2$	c
		8.062					
110	8.120	8.113					
111	8.143	8.147					
112	8.242						
		8.268					
113	8.320						
114	8.349	8.349					
		8.421					
115	8.445						
116	8.465						
117	8.496	8.50					
118	8.521						

[a] Present work.

[b] Ajzenberg-Selove [13].

[c] Consistent with Ref. [13].

[d] Crozier and Fortune [4].

[e] Medoff *et al.* [5].

TABLE II. Optical model parameters (lengths in fm and depths in MeV).

		V	r_0	a	W	$4W_D$	r_I	a_I	V_s	r_s	a_s	r_C	Ref.
^{3}He	H4	177	1.138	0.724	18.0		1.602	0.769	5.0	1.138	0.724	1.40	[7]
	H5	130	1.31	0.724	18.0		1.602	0.769	5.0	1.31	0.724	1.40	[8]
p	P3	V'	r'	0.57		$4W'$	r'	0.50	5.5	r'	0.57	r'	[9]
	P4	V''	1.25	0.65		54	1.25	0.47	7.5	1.25	0.65	1.25	[10]
n,p bound state		(a)	1.25	0.65					$\lambda=25$			1.25	

[a] Adjusted,

$$V'=60.0-0.3E+0.4(Z/A^{1/3})+27(N-Z)/A\ ,$$

$$r'=1.15-0.001E\ ,$$

$$W'=9.6+10(N-Z)/A-0.06E\ ,$$

$$V''=53.3-0.55E+0.4(Z/A^{1/3})+27(N-Z)/A\ .$$

calculations were done for the transitions to the $(sd)^4$ shell model states, while pure configurations were assumed for other states.

The optical model potential was of the standard Woods-Saxon form for both the real and imaginary parts of the ^{3}He central potential, as well as for the real part of the proton potential, while Wood-Saxon derivative was considered for the imaginary part of the proton potential. Various potential parameters were used in the study of the ^{17}O(^{3}He,p)^{19}F reaction [2]. It turned out that an overall good description of the angular distributions is given by the combinations H4-P3 and H5-P4, containing the spin-orbit potential in both the entrance and exit channels. These combinations were also used by Crozier and Fortune [4] and in paper I for the ^{18}O(^{3}He,p) reaction at 18 MeV. These were used in the present work and are shown in Table II. The potential parameters are taken from Refs. [7–10].

The bound state wave functions were generated assuming a (real) Woods-Saxon potential well with the geometrical parameters $r_0=1.25$ fm and $a=0.65$ fm including a Thomas-Fermi spin-orbit term of strength $\lambda=25$. The well depths are adjusted so as to give each nucleon a separation energy equal to half that of the transferred np pair. The binding energy of the spin singlet pair was taken to be 2.22 MeV lower than that of the spin triplet np pair.

The two-particle spectroscopic amplitudes [11] required in the microscopic DWBA calculations were derived from the three single particle energies and the sixty-three two-body matrix elements given by the shell model calculations of Halbert *et al.* [12].

IV. RESULTS AND DISCUSSIONS

Energy levels in ^{20}F are measured up to $E_x \sim 8.5$ MeV and are shown in Table I. Also included in the table for a comparison are the levels compiled by Ajzenberg-Selove [13]. Most of the levels up to $E_x \sim 6.2$ MeV are observed in the (^{3}He,p) reaction. The known levels either weakly populated in the present work or hardly above background are 0.997, 1.844, 3.526, 4.315, 4.371, 5.068, and 5.588 MeV and members of the doublets 4.581–4.592 and 4.892–4898 MeV. Some of these are discussed later in this section. Angular distributions are measured for almost all the levels up to $E_x \sim 6.2$ MeV and L values are determined from the DWBA analyses (summarized in Table I). The L transfers in most cases are consistent with the known J values (limits) [13]. Some of the angular distributions are shown in Figs. 2–6 together with the DWBA curves.

Several new levels are identified above $E_x \sim 6.2$ MeV, but reliable cross sections could be measured for these levels only at a few angles so that no L assignment is possible. Angular distributions in this region of excitation could be measured only for two levels, namely, $E_x=6.51$ and 8.07 MeV. These are respectively the analogues of the ground and lowest 2^+ states of ^{20}O [14]. Angular distributions are well reproduced by the DWBA curves respectively with $L=0$ and 2 (paper I).

A. Positive-parity levels

In paper I angular distributions were presented for the following levels:

$$E_x=0.0 \text{ and } 2.047 \text{ MeV},\ J^{\pi}=2^{+}_{1,2}\ ,$$

$$E_x=0.656,\ 2.201, \text{ and } 2.968 \text{ MeV},\ J^{\pi}=3^{+}_{1,2,3}\ ,$$

$$E_x=0.823 \text{ and } 3.680 \text{ MeV},\ J^{\pi}=4^{+}_{1,2}\ ,$$

$$E_x=1.058,\ 3.486, \text{ and } 3.961 \text{ MeV},\ J^{\pi}=1^{+}_{1,2,3}\ ,$$

$$E_x=1.824 \text{ MeV},\ J^{\pi}=5^{+}_{1}\ ,$$

$$E_x=6.509 \text{ and } 8.068 \text{ MeV},\ J^{\pi}=0^{+},\ 2^{+}, T=2\ .$$

These are believed to have a dominant $(sd)^4$ configuration (Ref. [15] and many others). The L transfers are included in Table I for the sake of completeness. The measured angular distributions are usually better given by the combination of optical model parameters H4-P3 than by H5-P4 (paper I). The 3.587 MeV level, not included in paper I, is strongly excited in the (^{3}He,p) reaction with angular distribution well fitted by the $L=2$ DWBA cure (Fig. 2) and may perhaps be a good candidate for the third 2^+ $(sd)^4$ shell model state,

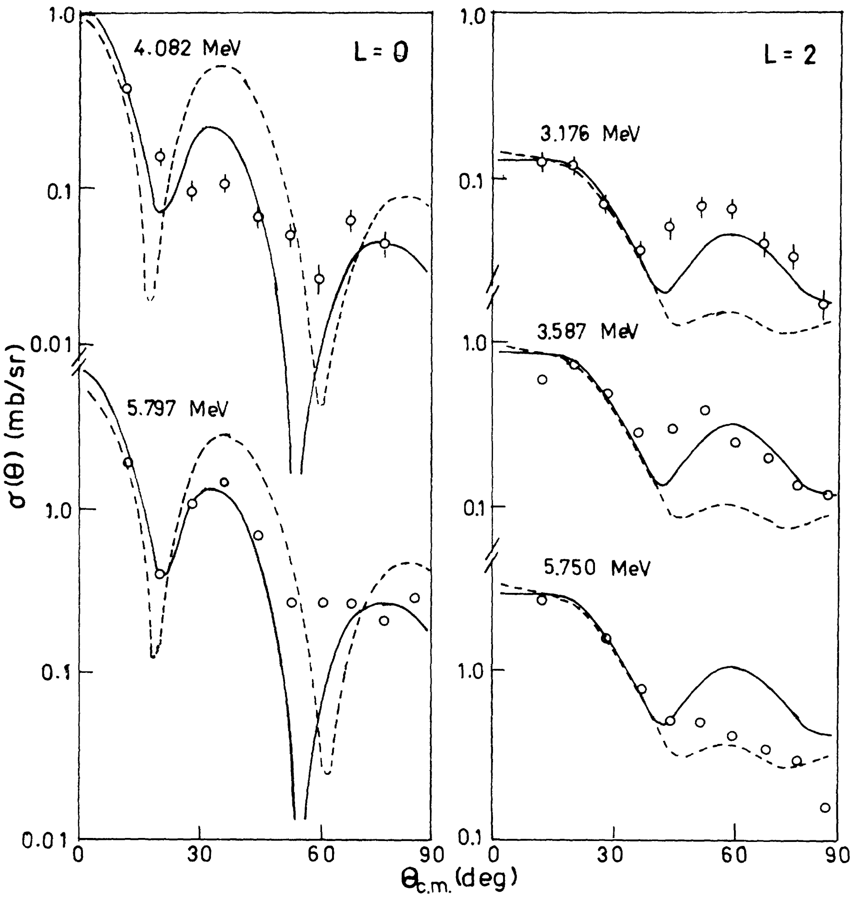

FIG. 2. Angular distributions fitted with $L=0$ and $L=2$ DWBA curves. Solid lines and broken lines in this and the following figures represent fits for H4-P3 and H5-P4, respectively.

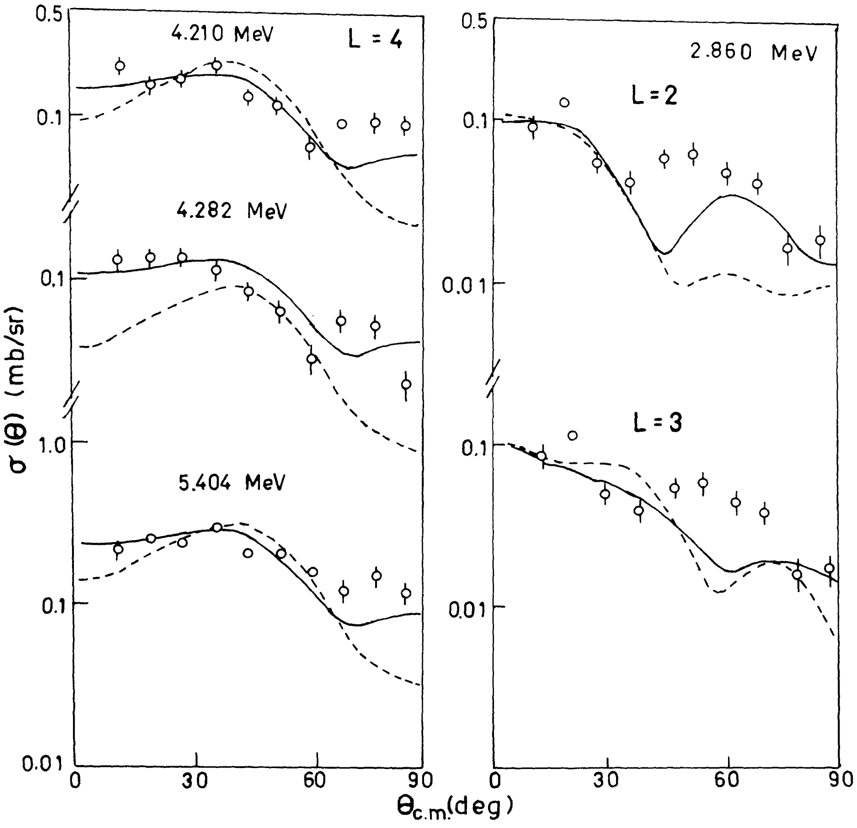

FIG. 3. Angular distributions fitted with $L=4$ DWBA curves and angular distributions for the 2.860 MeV level compared with $L=2$ and $L=3$ curves.

but this J value will not be consistent with the $L=2+4$ transition found the previous (^{3}He,p) work [4]. The J^{π} value of the level is given as $(1,2)^{+}$ in the ^{19}F(n,γ)^{20}F reaction [16] and adopted [13]. Our angular distribution has no measurable $L=0$ component so that the $J^{\pi}=1^{+}$ value seems unlikely. In conjunction with the (n,γ) work [16] we tentatively assign $J^{\pi}=(1)^{+}, 2^{+}$ to the level.

In addition to the above levels, several other positive-parity levels are observed in the present work (Table I). The angular distributions for these levels are fairly well reproduced by the DWBA calculations, again in most cases better by the combination H4-P3 than the other. Some of the results are shown in Figs. 2–5. The L transfers are, in general, consistent with the J^{π} values (limits) given from several previous investigations [13]. The present work together with the previous studies lead to unique J^{π} values to the 5.795 and 6.154 MeV levels. The J^{π} limits are also suggested in the present work for some other levels; these are 4.210, 4.744, and 5.404 MeV (Table I). The 4.744 MeV level is new and is discussed later in this section.

The levels 3.49, 3.53, and 4.32 MeV with $J^{\pi}=1^{+}$, 0^{+}, and $(0,1)^{+}$, respectively [13], were populated in the ^{19}F(d,p)^{20}F reaction [17] with a pure $l_n=0$ transfer. In the (^{3}He,p) reaction ([4], [5], and present work) only the 3.49 MeV level is populated with a mixture of $L=0+2$ transfers, thus confirming the $J^{\pi}=1^{+}$ assignment. The nonexcitation of the 3.53 MeV level in the (^{3}He,p) reaction is consistent with the 0^{+} assignment of the level. The lack of observation of the 4.32 MeV level would similarly suggest it is $J^{\pi}=0^{+}$.

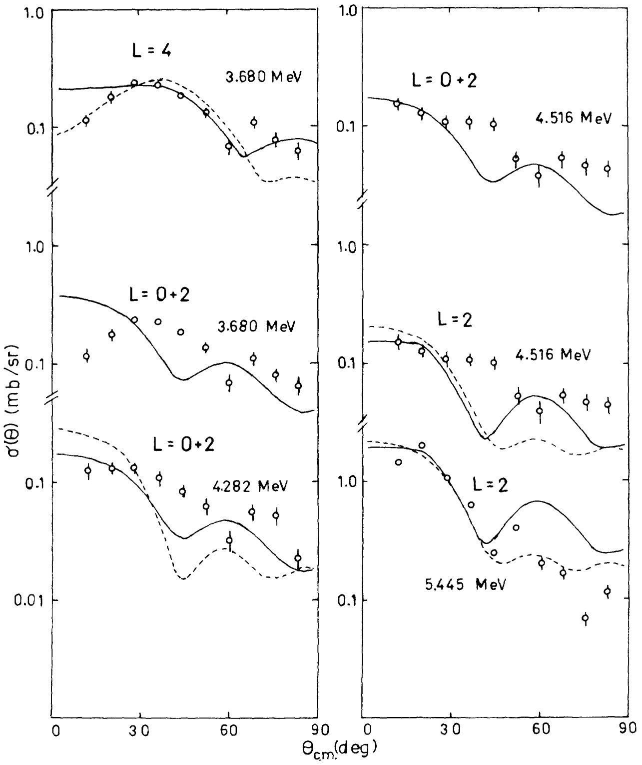

FIG. 4. Angular distributions to the levels at 3.680, 4.282, 4.516, and 5.445 MeV compared with the DWBA curves. See also Figs. 3 and 6 respectively for the 4.282 and 4.516 MeV levels.

In agreement with the previous (^{3}He,p) reaction [4], the angular distribution to the 3.680 MeV level is well fitted by the $L=4$ transfer (Fig. 4). The angular distribution to the 4.282 MeV level is similarly given by the $L=4$ DWBA curve (Fig. 3). This L value is consistent with the positive parity of the latter level [13], but is in disagreement with the $J=1,2$ to both levels as given from the ^{19}F(n,γ)^{20}F reaction [16]. An attempt was made to see whether or not these two angular distributions are given by $L=0+2$, but no satisfactory fit is obtained (Fig. 4). The present work thus clearly favors $L=4$ transfer over $L=0+2$. One way of explaining the discrepancy between the present work and the (n,γ) work (Hungerford *et al.* [16]) will be to assume each level a doublet.

The level at $E_x=5.445$ MeV is very strong and is likely to be a multiplet, namely, a triplet (unresolved 5.450, 5.455, and 5.463 MeV), one member of which, namely, 5.463 MeV, has $J^{\pi}=(1,2,3)^{+}$ [13]. The (^{3}He,p) angular distribution is fairly well reproduced by the $L=2$ DWBA curve, as shown in Fig. 4. We, however, do not propose to assign any J^{π} limit for the cluster group, even though the $L=2$ transfer is in excellent agreement with the positive parity and the J^{π} limit of one of the levels ($E_x=5.463$ MeV).

The J^{π} value of the 4.731 MeV level was tentatively given as $3^{-},4^{-},4^{+},5^{+}$ in the ^{14}N(^{7}Li,p)^{20}F reaction [18]. This level perhaps corresponds to one or the other of the 4.722 and 4.744 MeV levels found in the present work or the unresolved doublet. Angular distributions of the two levels are presented in Fig. 5 together with the $L=4$ DWBA curves. This L transfer is in agreement with the $J^{\pi}=4^{+},5^{+}$ above [18] and the negative parity can thus be excluded.

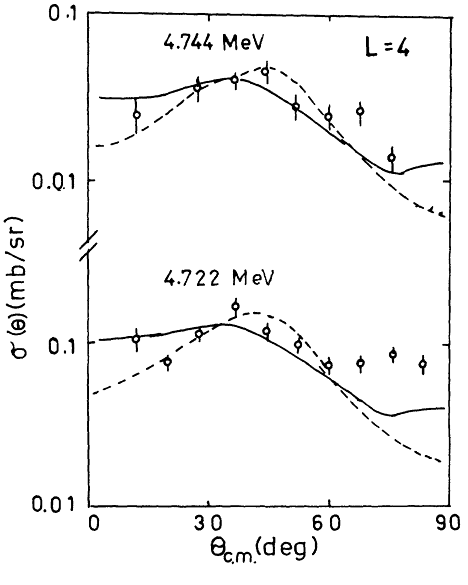

FIG. 5. Angular distributions to the levels at 4.722 and 4.744 MeV compared with the $L=4$ DWBA calculations.

B. Negative-parity levels

Several negative-parity levels are excited in the present work and angular distributions are measured for most of the levels up to $E_x \sim 6.2$ MeV. DWBA analyses are carried out assuming a pure configuration and the L transfers thus obtained are summarized in Table I. Some typical fits are shown in Fig. 6. A reasonably good fit is obtained in most cases again using the combination of potential parameters H4-P3.

The L transfers are consistent with the known odd parity and J values (limits) of all the levels (Table I) except possibly the 2.860 MeV levels. The latter is discussed later in this section. In conjunction with previous studies through various other reaction [13] a unique assignment of J value could be made to two of the levels, namely 2^- to each of the levels 3.762 and 6.213 MeV. New assignments of J^π limits are also made in some cases, and negative parity to some others with previously known J limits as shown in Table I.

The J^π value of the 4.509 MeV level is given as $1^+,2$ by Hungerford *et al.* [16] from a study of the $^{19}\mathrm{F}(n,\gamma)^{20}\mathrm{F}$ reaction. The angular distributions in the present work are better given by an $L=3$ transfer (Fig. 6) than by $L=2$ or $0+2$ (Fig. 4). The positive parity is thus not confirmed in our experiment and $J^\pi=2^-$ may perhaps be assigned to the level.

Negative-parity levels in the $^{18}\mathrm{O}(^3\mathrm{He},p)^{20}\mathrm{F}$ reaction can be reached from the core excitation, as well as through the transfer of a nucleon of the np pair to the $1f$-$2p$ shells. It is interesting to note that the low-lying negative-parity levels are weakly populated or even not at all populated so that these arise most likely from the core excitation ($1p$ shell). Likewise, the strongly excited negative-parity levels appear at $E_x > 5$ MeV and it is reasonable to associate them with transition to the particle state.

The 4.73 and 4.76 MeV levels are suggested to arise from core excitation from a study of the $^{16}\mathrm{O}(^7\mathrm{Li},{}^3\mathrm{He})^{20}\mathrm{F}$ reaction [19]. The former level has already been discussed in Sec. IV A above: The level at 4.76 MeV is weakly excited in the present work and the angular distribution could not be measured so that nothing can be said about the spin-parity of the level from our work.

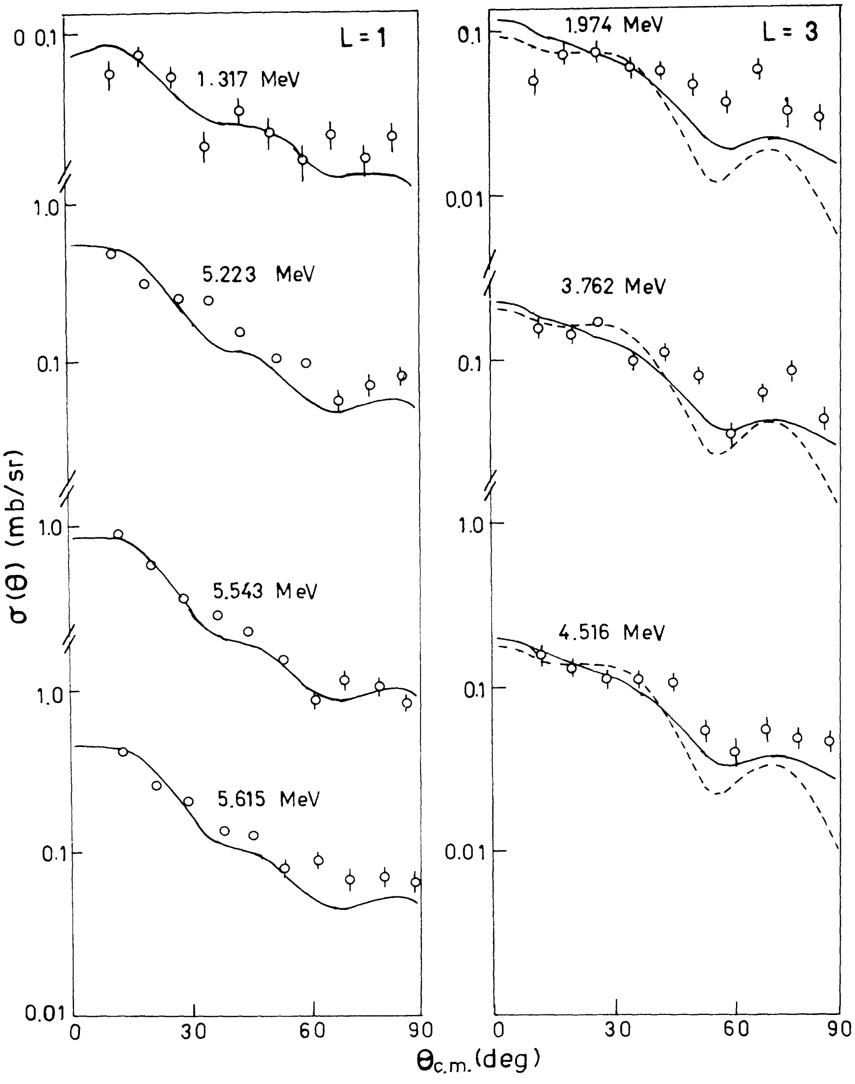

FIG. 6. Angular distributions fitted with $L=1$ and $L=3$ DWBA curves.

In addition to the $(sd)^4$ shell model calculations by Halbert *et al.* [12] mentioned earlier in this section for the positive-parity levels in ^{20}F, several shell model calculations have been carried out for low-lying levels of either parity (Ref. [20] and references therein). Low-lying negative-parity levels can be built by coupling the $1p_{1/2}$ hole to the ground ($J^\pi=3/2^+$), 0.350 MeV ($J^\pi=5/2^+$), and 1.748 MeV ($J^\pi=7/2^+$) levels in the isotonic nucleus ^{21}Ne (Johnstone *et al.* [21]) as given below. The probable candidates are the following

g.s., $J^\pi=3/2^+$: 0.98 and 1.31 MeV levels in ^{20}F, with $J^\pi=1^-$ and 2^-, respectively,

0.350 MeV, $J^\pi=5/2^+$: 1.84 and 1.97 MeV levels in ^{20}F, with $J^\pi=2^-$ and 3^-, respectively ,

1.748 MeV, $J^\pi=7/2^+$: 2.86 and 2.97 MeV levels in ^{20}F, with $J^\pi=3^-$ and 4^-, respectively .

That these are hole states is clear from various reactions [13], including the ($^3He,p$) reaction (Ref. [4] and present work). Of these, the level at 0.98 MeV (0.997 MeV in our work) was observed only at a few angles so that the angular distribution could not be measured in the present work; the maximum cross section was about 20 μb/sr or so. There is no indication of the excitation of the 1.843 and 2.968 MeV levels in the present work. The latter if at all excited is not separated from the strong 2.966 MeV level. The angular distributions for the 1.317 and 1.974 MeV levels are reasonably well fitted by $L=1$ and 3 transitions respectively (Fig. 6). The $J^\pi=(3^-)$ to the 2.860 MeV level requires an L transfer of 3 in the ($^3He,p$) reaction. The $L=3$ DWBA fit is unsatisfactory (Fig. 3). A somewhat better fit, but not very satisfactory either, is given by an $L=2$ transfer. The $J^\pi=3^-$ assignment of the level is based on the $l_n=3$ fit in the $^{19}F(d,p)^{20}F$ reaction [16] together with the measurement of the integrated cross section in the $^{14}N(^7Li,p)^{20}F$ reaction [18]. The assignment however does not appear to be very convincing.

V. CONCLUSION

Energy levels in ^{20}F are obtained up to $E_x \sim 8.5$ MeV and most of the levels known from various other reactions [13] are also observed in the present work. Several new levels are identified at $E_x > 6.2$ MeV, but reproducible (hence reliable) cross sections could be measured at only a few angles for these levels so that no assignment of L transfer could be made. Angular distributions are measured over a wide angular range for two levels at high excitation, namely at $E_x=6.51$ and 8.07 MeV. These distributions are found to be characterized by $L=0$ and 2 transfers respectively. These L transfers with large cross sections and the separation between the levels are consistent with their identification as analogue states [14].

Unambiguous assignments of L transfers are made to most of the levels up to $E_x \sim 6.2$ MeV, many more than in previous works on the $^{18}O(^3He,p)^{20}F$ reaction. The present L values in most cases are consistent with the J^π limits given from previous works, and as compiled by Ajzenberg-Selove [13]. In conjunction with previous studies through various other reactions, the present work leads to a unique assignment of J^π values to some of the levels (namely, at $E_x=3.762$, 6.154, and 6.213 MeV and also perhaps to the 4.516 MeV). New assignments of J^π limits could be made to some other levels (namely, $E_x=4.210$, 4.744, 5.404, 5.627, and 5.645 MeV). The tentative $J^\pi=3^-$ assignment to the 2.860 MeV level [17,18] is not supported in the present work, but in view of the not-very-satisfactory $L=2$ fit in our study, we do not propose a positive parity very confidently either. It is disturbing to note that there is no other 3^- state around $E_x=3$ MeV which could perhaps be a better candidate for the hole state. The level under discussion may alternatively be a close doublet. Better statistical accuracy is obviously required for a definite J^π assignment.

Discrepancies in the assignment of spin-parity of some of the levels given from different reactions can perhaps be attributed to the occurrence of close doublets in the complicated level spectrum of the odd-odd nucleus ^{20}F, one or the other member of which is selectively populated in the different reactions. Several such examples of doublets are already known to exist in ^{20}F.

ACKNOWLEDGMENTS

The authors would like to thank Professor K. W. Allen for suggesting the problem and Dr. D. Roaf, Dr. F. Watt, and Dr. M. J. Hurst for help in the experiment at Oxford. They are thankful to Professor P. D. Kunz for the program DWUCK4 and Dr. J. M. Nelson for the programs MULTISHELL and TENSOR. One of the authors (H.M.S.G.) acknowledges financial support from the Royal Society, London.

[1] H. M. Sen Gupta, M. J. Hurst, and F. Watt, J. Phys. G **2**, 935 (1976).
[2] H. M. Sen Gupta, M. A. Zaman, F. Watt, and M. J. Hurst, Nuovo Cimento **93A**, 217 (1986).
[3] H. M. Sen Gupta, M. S. Chowdhury, F. Watt, and M. J. Hurst, Nuovo Cimento **98A**, 715 (1987).
[4] D. J. Crozier and H. T. Fortune, Phys. Rev. C **10**, 1697 (1974).
[5] R. Medoff, L. R. Medsker, S. C. Headly, and H. T. Fortune, Phys. Rev. C **14**, 1 (1976).
[6] H. M. Sen Gupta, J. B. A. England, E. M. E. Rawas, F. Khazaie, and G. T. A. Squier, J. Phys. G **16**, 1039 (1990).

[7] H. T. Fortune, N. G. Puttaswamy, and J. L. Yntema, Phys. Rev. **185**, 1546 (1969).

[8] H. Kattenborn, C. Mayer-Bohricke, and B. Mertens, Nucl. Phys. **A119**, 657 (1968).

[9] B. A. Watson, P. P. Singh, and R. E. Segel, Phys. Rev. **182**, 977 (1969).

[10] F. G. Perey, Phys. Rev. **131**, 745 (1963).

[11] The spectroscopic amplitudes are not shown but may be obtained from one of the authors (H.M.S.G.).

[12] E. C. Halbert, J. B. McGrory, B. H. Wildenthal, and S. P. Pandya, Adv. Nucl. Phys. **4**, 315 (1971).

[13] F. Ajzenberg-Selove, Nucl. Phys. **A475**, 1 (1987).

[14] J. Cerny, R. H. Pehl, and G. T. Garvey, Phys. Lett. **12**, 234 (1964); J. C. Hardy, H. Brunnader, J. Cerney, and J. Jänecke, Phys. Rev. **183**, 854 (1969); G. F. Millington, R. M. Hutcheon, J. R. Leslie, and W. McLatchie, Phys. Rev. C **13**, 879 (1976).

[15] H. T. Fortune and J. D. Garett, Phys. Rev. C **14**, 1695 (1976).

[16] P. Hungerford, T. von Egidy, H. H. Schmidt, S. A. Kerr, H. G. Börner, and E. Monnand, Z. Phys. A **313**, 339 (1983).

[17] H. T. Fortune, G. C. Morrison, R. C. Bearse, J. L. Yntema, and B. H. Wildenthal, Phys. Rev. C **6**, 21 (1972); H. T. Fortune and R. R. Betts, *ibid.* **10**, 1292 (1974).

[18] H. T. Fortune and J. N. Bishop, Nucl. Phys. **A293**, 221 (1977); H. T. Fortune and R. Eckman, Phys. Rev. C **31**, 2076 (1985).

[19] H. T. Fortune and J. N. Bishop, Nucl. Phys. **A304**, 221 (1978).

[20] M. M. King Yen, S. T. Hsieh, H. C. Chiang, and D. S. Chuu, J. Phys. G **8**, 245 (1982).

[21] I. P. Johnstone, B. Castel, and P. Sostegno, Phys. Lett. **34B**, 34 (1971).