^{20}F via ^{21}Ne(t,α)^{20}F reaction

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(Received 4 January 1988)

In the ^{21}Ne(t,α)^{20}F reaction at $E_t = 15.0$ MeV, angular distributions were measured over laboratory angular range 15°–67.5° for final states up to 4 MeV, and the results have been analyzed with distorted-wave Born approximation calculations. Extracted spectroscopic factors are in reasonable agreement with the available theoretical predictions and data from (d,^{3}He) reactions.

I. INTRODUCTION

The nucleus ^{20}F has been the subject of several one- and two-nucleon transfer reactions.[1–3] Specifically, the (d,^{3}He) reaction on ^{21}Ne gave valuable spectroscopic information on ^{20}F (Ref. 4) for single proton transfer, but was limited to states below $E_x = 2.2$ MeV. Several J^π assignments have come from compound reactions of the type ^{14}N(^{7}Li,p)^{20}F.[5] Spectroscopic knowledge of ^{20}F is summarized in the recent compilation.[6] We report here on a study of the ^{21}Ne(t,α)^{20}F reaction at a bombarding energy of 15 MeV. The motivation of the present work was to extract proton pickup spectroscopic factors for a larger range of excitation energies than previously available and to compare with theoretical predictions.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The experiment was performed with a 15.0-MeV triton beam from the University of Pennsylvania tandem accelerator. The target was Neon gas (enrichment = 86.5%) at 40 Torr in a rotating gas cell.[7] The outgoing α particles exited through a 230 μg/cm^2 window made of aluminum and were analyzed in a multiangle spectrograph and detected in nuclear emulsions. Typical resolution was 28 keV full width at half maximum. The absolute cross section scale was established from the known gas pressure (corrected for pressure of impurities) and gas cell geometry, and is accurate to ±20%.

The data were collected simultaneously at nine angles from 7.5° to 67.5° in steps of 7.5°. Owing to the large background, it is difficult to scan the 7.5° plate for α particles and thus the data at 7.5° (lab) are not available. The full angular distributions were scanned for $E_x \leq 3$ MeV, but the populations of states over 3 MeV were too weak to scan the full angular range. However, the region of excitation of 3–4 MeV was analyzed at several forward angles to allow extraction of reliable spectroscopic information. A typical spectrum is displayed in Fig. 1. It can be seen that all states below 5.2 MeV in ^{20}F are populated

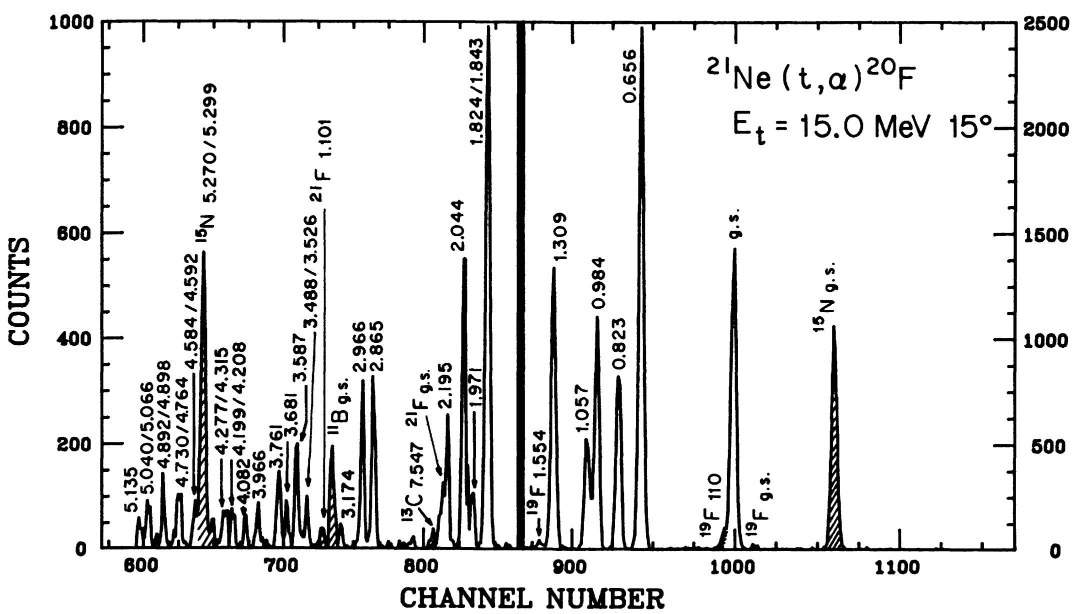

FIG. 1. Spectrum of alpha particles from the reaction ^{21}Ne(t,α)^{20}F, at $E_t = 15.0$ MeV and a laboratory angle of 15.0°. States in ^{20}F are labeled by their excitation energies. Peaks from impurities in the target are hatched and labeled by final nucleus and excitation energy.

by the ^{21}Ne(t,α)^{20}F reaction. They do, however, divide into two groups—strong below 3.0 MeV and weak above that energy. Also, some known doublets were not resolved. Figures 2–4 show the experimental angular distributions and results of distorted-wave Born approximation (DWBA) calculations (see below). Excitation energies were calculated from observed peak positions after applying a correction for the energy loss of the α particles in the exit window. They are listed in Table I.

III. ANALYSIS AND DISCUSSION

Local, zero-range distorted-wave Born-approximation (DWBA) calculations, using the code DWUCK4 (Ref. 8) have been performed for states in the range $E_x = 0.0–4.082$ MeV. The optical-model parameters used in the calculations are listed in Table II. The parameters are similar to those of Ref. 9, but with some adjustments of potential depths for both t and α particle.

The experimental angular distributions were compared with the DWBA calculations by use of the relation

$$\sigma_{\mathrm{exp}}(\theta) = \frac{1}{2j+1} N C^2 S(l,j) \sigma_{\mathrm{DW}}(\theta) ,$$

where l and j are the transferred orbital and total angular momentum, respectively, $\sigma_{\mathrm{DW}}(\theta)$ is the theoretical pickup cross section calculated by the code DWUCK4, S the spectroscopic factor, C is an isospin-coupling Clebsch-Gordan coefficient ($C^2 = \frac{2}{3}$ here), and N is the overall normalization factor. A value of $N = 18.2$ for the (t,α) reaction[10] was used in the present analysis.

Because the ground state of ^{21}Ne has $J^\pi = 3/2^+$, a 0^+ level in ^{20}F can be populated only by $1d_{3/2}$ proton pickup, and a 4^+ level only via $1d_{5/2}$ (ignoring the 1g shell). A 3^+ state can be reached by either $1d_{3/2}$ or $1d_{5/2}$. Finally, 1^+ and 2^+ levels can contain $l = 0$ as well as $l = 2$.

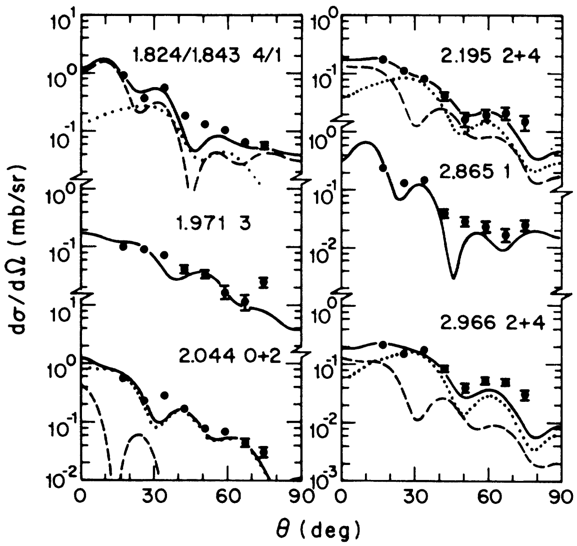

FIG. 3. As Fig. 2, but for $E_x = 1.8–3.0$ MeV.

Similar conditions hold for negative-parity states, but $1f$ pickup is expected to be weak. Whenever the J of the final state allows it, we assume $l = 2$ pickup to be $1d_{5/2}$ and $l = 1$ to be $1p_{1/2}$ in extracting spectroscopic factors.

Table I summarizes the excitation energies, transferred orbital angular momenta, and spectroscopic strengths measured in the present study. Also shown in the table are the available results of the experimental study on ^{21}Ne(d,^{3}He)^{20}F.[4] In Figs. 2–4, the experimental angular distributions for the states are shown together with the DWBA calculations. For 0.984- and 1.309-MeV states with negative parity, DWBA fits with $1p_{1/2}$ transfer are very good. The angular distributions for (3^-) (Ref. 6)

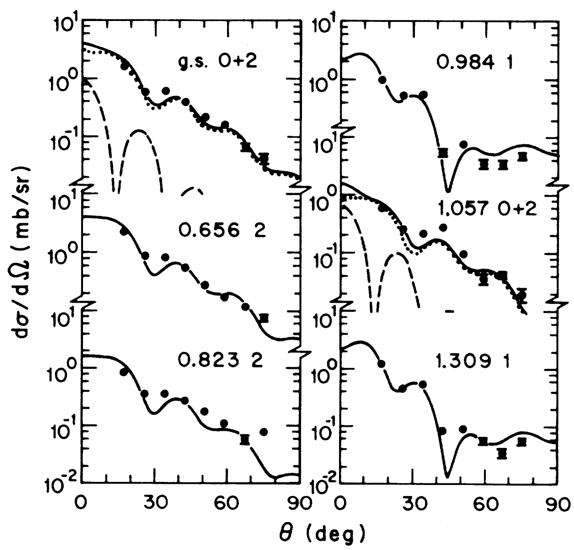

FIG. 2. Angular distributions for the reaction ^{21}Ne(t,α)^{20}F, compared with DWBA calculations for l transfers listed.

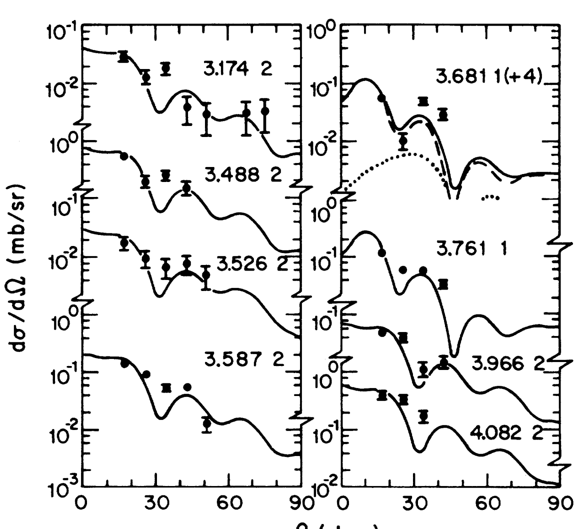

FIG. 4. As Fig. 2, but for $E_x = 3.0–4.1$ MeV.

TABLE I. Results of $^{21}Ne(t,\alpha)^{20}F$ reaction.

Previous[a] E_x (MeV)	J^{π}	Present E_x(MeV±keV)	l	C^2S	(d,^{3}He)[b] C^2S
0.0000	2^+	−0.005±2	0+2	0.026+0.362	0.24+0.58
0.6559	3^+	0.658±2	2	0.504	0.66
0.8229	4^+	0.821±2	2	0.212	0.26
0.9837	1^-	0.983±2	1	0.488	0.84
1.0569	1^+	1.055±3	0+2	0.016±0.122	0.08+0.25
1.3092	2^-	1.306±2	1	0.522	0.86
1.8244	5^+	1.833±3	5	0.147	
1.8434	2^-	1.833±3	1	0.283	0.69
1.9707	(3^-)	1.968±3	3	0.035	
2.0440	2^+	2.042±2	0+2	0.008+0.125	0.01+0.15
2.1948	(3^+)	2.190±2	2+4	0.020+0.049	0.16($l=2$)
2.8649	(3^-)	2.863±2	1	0.090	
2.9661	3^+	2.965±2	2+4	0.022+0.110	
2.968	(4^-)				
3.1740	1^+	3.170±3	2	0.006	
3.4884	1^+	3.488±4	2	0.013	
3.5260	0^+	3.526±4	2	0.008	
3.5871	$(1,2,3)^+$	3.587±4	2	0.037	
3.6810	$(1,2,3)^+$	3.682±6	1(+4)	0.021(+0.005)	
3.7611	$(2^-,3^+)$	3.761±5	1	0.051	
3.9660	1^+	3.967±6	5	0.014	
4.0823	$(1)^+$	4.077±5	5	0.011	

[a]Reference 6.
[b]Reference 4.

states at 1.971 and 2.865 MeV appear to be populated by $l=3$ and 1 transfers, respectively. Our results support (3^-) assignments for both states and negative parity is confirmed for them. The angular distribution for the 3.761-MeV state with possible $(2^-,3^+)$ (Ref. 5) was fitted by $l=1$ transfer. Thus, if it is a single state, we now prefer a 2^- assignment for it. Spectroscopic factors for these negative parity states are listed again in Table III and compared with theoretical values.

Among the states with positive parity, the states at 0.656, 0.823, 2.195, and 2.966 MeV with $J^{\pi}=3^+,4^+,(3^+)$, and 3^+,[5,6] respectively, should all be populated by pure $l=2$ transfer. Indeed, an $l=2$ curve fits the first two reasonably well, but the angular distributions of the other two appear to require an $l=4$ component. Deformation of ^{21}Ne(g.s.) can cause some population of the $1g_{9/2}$ orbital, but this effect should be small. The states at 3.174, 3.488, 3.526, 3.587, and 3.966 MeV with $J^{\pi}=1^+,1^+,0^+,(1,2,3)^+$, and 1^+,[6] respectively, are all seemingly populated by pure $l=2$ transfer, even though the angular distributions for higher states have fewer data points. Among them, 3.526 is the only 0^+ state below 4 MeV, and it is weakly populated in the present study. Nevertheless, the curve for $1d_{3/2}$ transfer basically fits the angular distribution of the state. The extracted spectroscopic factors for these states with positive parity are listed in Table I and compared with theoretical predictions in Table IV.

Several states are populated by a mixture of l transfers. As in the (d,^{3}He) reaction, the angular distributions at 0.0, 1.057, and 2.044 MeV are fitted by $l=0+2$ transfer. However, the spectroscopic factors for $l=0$ transfer to the ground and 1.057-MeV states of the present study are smaller than those of the theoretical predictions and the (d,^{3}He) reactions as well, while the spectroscopic factors for $l=2$ transfer for these states are in good agreement with the values from the (d,^{3}He) experiment and the theoretical models. The extracted spectroscopic factors for the 2.044-MeV state for both $l=0$ and 2 transfer are in agreement with those of (d,^{3}He) and the theoretical predictions. The states at 1.824-1.843 MeV are not resolved. Nevertheless, the fact that DWBA calculations with $l=1+4$ fit the data is consistent with the assignment of 5^+ for 1.824-MeV state and 2^- for 1.843-MeV

TABLE II. Optical-model parameters used in analysis of $^{21}Ne(t,\alpha)^{20}F$. Strengths in MeV, lengths in fm.

Channel	V	r_0	a_0	W	r_0'	a_0'	V_{s0}	r_c
^{3}He	126.5	1.007	0.82	16.30	1.059	1.091	10.0	1.007
α	214.9	1.38	0.604	12.05	1.60	0.488		1.58
Bound state		1.26	0.60	$\lambda=25$				1.30

TABLE III. A comparison of C^2S for the states with negative parity.

E_x (MeV)	J^π	l	C^2S This work	PHF[a]	Shell model[a]
0.984	1^-	1	0.488	0.75	0.59
1.309	2^-	1	0.522	1.25[b]	0.72
1.843	2^-	1	0.283		0.23
1.971	(3^-)	3	0.035		
2.865	(3^-)	1	0.090		
3.761	(2^-)	1	0.051		

[a]Reference 4.
[b]This value is sum for 1.309- and 1.843-MeV states.

state.[6] As mentioned earlier for states at 2.915 and 2.966 MeV, an $l=2+4$ mixture gives a good description, consistent with 3^+ assignments[6] for both states. The 2.968-MeV (4^-) (Ref. 6) state is not separated from the nearby 3^+ state, but appears to be very weakly populated in this reaction, because there is no $l=3$ component, when we did fit for 2.966-MeV state. For the 3.681 state, Ref. 5 gave four allowed combinations of doublets with $J^\pi=4^++1^+$, 3^++2^+, 3^++1^-, or 5^++0^-. The present study shows $l=1(+4)$ transfer, and thus prefers the last two possibilities, i.e., doublets with $J^\pi=3^++1^-$ or 5^++0^-.

Several theoretical calculations are available. In Tables III and IV, we list the results from the projected Hartree-Fock (PHF) calculation for the three negative-parity states, the shell-model calculation quoted in Ref. 4 for most states below 2.2 MeV and the shell-model predictions by Wildenthal[11] using the Chung-Wildenthal interaction for states with positive parity up to 5.3 MeV excitation. In general, all of them give reasonable accounts of the observed spectroscopic factors. Table V lists the summed spectroscopic factors for different l values from the present study, along with the experimental results of (d,^{3}He) and theoretical predictions. We find from Table V that the summed spectroscopic factors from this work for $1p$ and $2s$-$1d$ shell are in reasonable agreement with the predictions of both shell-model calculations. In addition, the present study gives spectroscopic factors for $1f$ and $1g$ shell pickup, but these are beyond the theoretical results available. We notice the summed spectroscopic factor 1.892 for $2s$-$1d$, $1f$ and $1g$ shell from this study is in good agreement with 1.837 from the shell model (C—W) calculation for $2s$-$1d$ shell. Our $l=0$ sum, however, is significantly smaller than any of the experimental or theoretical values. The weakness of $l=0$ transfer makes our $l=0$ spectroscopic factors somewhat uncertain, but we estimate the uncertainty to be only about a factor of two. The reason for the discrepancy is not known.

IV. CONCLUSION

In the present study on ^{21}Ne(t,α)^{20}F at 15.0 MeV, we have made a comparison between experimental angular distributions and DWBA calculations for all excited states of ^{20}F below 4.1 MeV. Combined with the previous results, we confirm the states at 1.971 and 2.865 MeV as having negative parity, and the previous assignment (3^-) for them are supported. For the 3.761 $(2^-,3^+)$ state, a 2^- assignment is preferred. For the 2.195-MeV (3^+) state, we confirm positive parity and 3^+ is reason-

TABLE IV. A comparison of C^2S from present work and from shell-model predictions for $2s$-$1d$ shell transfer.

Experimental results E_x (MeV)	J^π	$2s$	$1d$	Shell model 1[a] $2s$	$1d$	Shell model 2[b] E_x (MeV)	$s_{1/2}$	$d_{3/2}$	$d_{5/2}$
0.0	2^+	0.026	0.362	0.35	0.25	0.0	0.303	0.015	0.32
0.656	3^+		0.504		0.71	0.589		0.009	0.543
0.823	4^+		0.212		0.25	0.758			0.209
1.057	1^+	0.016	0.122	0.17	0.03	1.158	0.168	0.050	0.027
2.044	2^+	0.008	0.125	0.007	0.13	2.135		0.069	0.043
2.195	(3^+)		0.020		0.002	2.104		0.021	
2.966	3^+		0.022			2.779		0.013	0.021
3.174	1^+		0.006						
3.488	1^+		0.013			3.484	0.0	0.0	0.0
3.526	0^+		0.008			4.127		0.0	
3.587	$(1,2,3)^+$		0.037			$3.618(2^+)$	0.007	0.001	0.001
						$3.611(3^+)$		0.002	0.002
3.966	1^+		0.014			4.297	0.007	0.001	
4.082	1^+		0.011			5.277	0.002	0.003	

[a]Reference 4.
[b]Reference 11.

TABLE V. Summed spectroscopic factors $\sum C^2S$.

Description	1*p*	2*s*	1*d*	1*f*	1*g*	Note
Present work	1.455	0.050	1.456	0.035	0.351	(0–4.1 MeV)
(d,^{3}He)[a]	2.39	0.32	1.91			(0–2.2 MeV)
Shell model 1[a]	1.54	0.52	1.242			(0–2.2 MeV)
Shell model 2[b]		0.487	1.350			(0–5.3 MeV)
Nilsson model	1.92	0.50	1.59			(0–3.0 MeV)

[a]Reference 4.
[b]Reference 11.

able. The doublet at 1.824-1.843 MeV with 5^+ and 2^- are supported by this study. For the 2.966-MeV doublet, the 3^+ component is the stronger. For the 3.681-MeV state (or doublet), we find that at least one member has negative parity. Thus, if earlier indications are correct, we prefer the two combinations with $3^+ + 1^-$ *or* $5^+ + 0^-$ among the previous four combinations. The extracted spectroscopic factors are in general accounted for by shell-model predictions. The 1*f* and 1*g* components observed in the present study are beyond the available shell-model predictions, but the summed 1*f* and 1*g* strength is small.

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