Neutron pickup from ^{22}Ne

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(Received 27 November 1978)

Levels below 10 MeV in ^{21}Ne have been investigated with the ^{22}Ne(^{3}He,α) reaction at a bombarding energy of 15 MeV, with an enriched gas target. Angular distributions were extracted for twenty-six levels (or groups of levels). Only two levels of each $J^\pi = 1/2^+$, $3/2^+$, and $5/2^+$ have spectroscopic factors larger than 0.03. Results for positive-parity states are in good agreement with shell-model calculations in an $(sd)^5$ basis. But the presence of additional levels above 6 MeV, not present in the shell-model calculation, suggests core excitation is important for the positive-parity states above that energy. The $1/2^-$ state at 2.79 MeV has only about half the strength expected for a pure 6p-1h state, with $T_p = 1$. Very little $1p_{3/2}$ pickup is observed below 10 MeV excitation.

[NUCLEAR REACTIONS ^{22}Ne(^{3}He, α), E=15.0 MeV; measured $\sigma(E_\alpha, \theta)$. ^{21}Ne deduced levels, l, J, Π. DWBA analysis. Enriched gas target.]

I. INTRODUCTION

Experimental information concerning ^{21}Ne has been summarized in the compilation of Endt and van der Leun,[1] and in the recent work of Hoffmann, Betz, and Röpke.[2] The nucleus ^{21}Ne has been investigated with a variety of reactions, including ^{13}C(^{12}C, α),[3] ^{12}C(^{13}C, α),[4] ^{18}O($\alpha, n\gamma$),[2,5-15] ^{19}F(^{3}He, p),[16,17] ^{19}F(^{3}He, $p\gamma$),[18,19] ^{19}F(α, d),[20] ^{17}O($\alpha, n\gamma$),[21] ^{20}Ne(n, γ),[22,23] ^{20}Ne(n, n),[24-26] ^{20}Ne(d, p),[27-30] ^{20}Ne($d, p\gamma$),[31-33] ^{21}Ne(p, p'),[34,35] ^{22}Ne(p, d),[36,37] ^{22}Ne(d, t),[37,38] ^{22}Ne(^{3}He, α),[39,40] and ^{23}Na(d, α).[41-45]. Additional information is available in Refs. 46–48.

Pickup angular distributions have been limited to low-lying states and to $T=\frac{3}{2}$ levels near 9-MeV excitation. We report here on a study of the ^{22}Ne(^{3}He, α) reaction leading to all levels below 6.5-MeV excitation and selected levels above there. The recent work of Ref. 2 has allowed the assignment of J^π values to most states below 6.5-MeV excitation, though in several cases the assignments are not completely rigorous.

Low-lying levels of ^{21}Ne can be easily understood[9,46] in terms of the Nilsson model, for both positive and negative parity. For higher excitation energies the correspondence between experimental levels and Nilsson-model states is very uncertain. Shell-model calculations[49,50] in an $(sd)^5$ basis are also able to account for much of the experimental information on the positive-parity states.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The experiment was performed with a 15-MeV beam from the University of Pennsylvania tandem accelerator. The target was Ne gas enriched in ^{22}Ne and contained in a gas cell with no entrance window.[51] The gas was recirculated and purified as described elsewhere.[52] Outgoing α particles were momentum analyzed in a multiangle spectrograph and detected in nuclear emulsion plates. Data were recorded at 22 angles from 7.5° (lab) to 90° in steps of 3.75°. The absolute cross section scale was determined from the gas-cell pressure and integrated beam current, and is believed to be accurate to 20%.

A spectrum is displayed in Fig. 1. Small impurity peaks are present from a small amount of ^{20}Ne in the target gas, but because of the much higher Q value for ^{22}Ne than for ^{20}Ne, they present no problem for the low-lying states. Our experimental resolution is about 40 keV full width at half maximum (FWHM) and is caused primarily by straggling in the target gas and in the exit windows of the gas cell. Excitation energies were computed from the measured peak positions and known magnet calibration, and are listed in Table I. The agreement with values from the literature is quite good. Within our experimental resolution, we observe all known levels below 6.5-MeV excitation, except for states listed at 5525 and 5683 in the compilation.[1] According to Ref. 2, these levels are not present, but rather resulted from a misidentification of γ rays in Ref. 9. Only two new levels were observed.

Angular distributions were extracted for all levels (or groups of unresolved levels) below 6.5-MeV excitation. Above that energy, the low yield and high density of states prevented the analysis for all except the strongest states. All angular distributions that were extracted are displayed in Figs. 2–4.

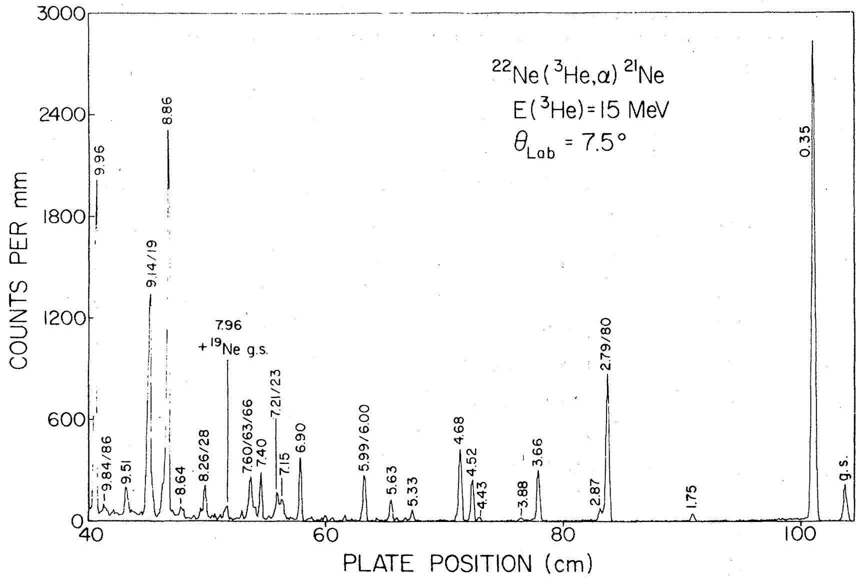

FIG. 1. Spectrum of the ^{22}Ne(^{3}He, α)^{21}Ne reaction at a bombarding energy of 15.0 MeV and a laboratory angle of 7.5°.

TABLE I. Comparison of present results for ^{21}Ne with those from the literature.

Compilation	(Ref. 1)	Ref. 2		Present			
E_x (keV)	J^π	E_x (keV)	J^π	E_x (keV)	nlj	NC^2S	S [i]
0.0	$\frac{3}{2}^+$	0.0	$\frac{3}{2}^+$	0.0 ± 1.6	$1d_{3/2}$	5.3	0.29
350.5 ± 0.1	$\frac{5}{2}^+$	350	$\frac{5}{2}^+$	351.5 ± 1.0	$1d_{5/2}$	45.6	2.53
1745.6 ± 0.2	$\frac{7}{2}^+$	1746	$\frac{7}{2}^+$	1748.9 ± 1.6	$(1g_{7/2})$	[2.6(1.1)] [a]	[0.14(0.006)]
2788.5 ± 0.3	$\frac{1}{2}^-$	2789	$\frac{1}{2}^-$	2793.3 ± 1.1	$1p_{1/2}$	14.0	0.78
2796.1 ± 0.6	$\frac{1}{2}^+$	2797	$\frac{1}{2}^+$		$2s_{1/2}$	7.4	0.41
2865.6 ± 0.2	$\frac{9}{2}^+$	2866	$\frac{9}{2}^+$	2868.8 ± 2.6	$(1g_{9/2})$	(0.86)	(0.05)
3662.1 ± 0.4	$\frac{3}{2}^-$	3665	$\frac{3}{2}^-$	3668.2 ± 1.0	$1p_{3/2}$	4.9	0.27
3733.7 ± 0.2	$\frac{5}{2}^+$	3737	$\frac{5}{2}^+$	3736.6 ± 2.4	$(1d_{5/2})$	(0.36) [b]	(0.02)
3882.9 ± 0.4	$\frac{5}{2}$	3885	$\frac{5}{2}^-$	3886.8 ± 2.9	$(1f_{5/2})$	(0.34) [c]	(0.02)
4432.2 ± 0.8	$\frac{11}{2}^+$	4431	$\frac{11}{2}^+$	4432.8 ± 2.8	$(1i_{11/2})$	(1.2)	(0.07)
4524.2 ± 0.6	$(\frac{3}{2}, \frac{5}{2})^+$	4525	$\frac{5}{2}^+$	4526.7 ± 1.4	$1d_{5/2}$	2.3	0.13
4683.6 ± 1.0	$(\frac{3}{2}, \frac{5}{2})$	4686	$\frac{3}{2}^+$	4689.1 ± 5.3	$1d_{3/2}$	6.0	0.33
4725.7 ± 1.4	$\frac{3}{2}^-$	4727	$\frac{3}{2}^-$		$(1p_{3/2})$	(<4.4) [d]	(≤0.24)
5334 ± 2	$\frac{5}{2}^+$	5335	$\frac{7}{2}^-$	5336.9 ± 2.9	$(1f_{7/2})$	(0.46) [e]	(0.03)
					$(1d_{5/2})$	(0.52)	(0.03)
5430.0 ± 1.4		5431	$\frac{7}{2}^+$	5431.4 ± 1.2	$(1g_{7/2})$	(0.33)	(0.02)
5525.0 ± 1.5 [f]		...		...			
5550 ± 2	$(\frac{3}{2}, \frac{5}{2})^+$	5549	$\frac{3}{2}^+$	5547.5 ± 1.8	$1d_{3/2}$	0.27	0.015
5629.4 ± 1.7		5628	$\frac{7}{2}^+$				
5682.8 ± 0.9 [f]		...		5673.8 ± 6.5	$1p_{1/2}$	1.44	0.08
5690.5 ± 1.3	$(\frac{1}{2}, \frac{3}{2})^-$	5688	$\frac{1}{2}^-$				

TABLE I. (*Continued*)

Compilation (Ref. 1) E_x (keV)	J^π	Ref. 2 E_x (keV)	J^π	Present E_x (keV)	nlj	NC^2S	S[i]
5775 ± 3		5773	$\frac{3}{2}^{(+)}, \frac{5}{2}^{(+)}$				
5821 ± 2	$\frac{3}{2}$	5819	$\frac{7}{2}^-$	5813.1 ± 6.5	$(1f_{7/2})$	(0.36)[b]	(0.02)
5823 ± 3		5822	$\frac{3}{2}^+, \frac{5}{2}^+$		$(1d_{3/2})$	(0.44)	(0.02)
5992.9 ± 1.2		5990	$\frac{1}{2}^+$	5990.1 ± 0.6	$(2s_{1/2})$	(2.00)[g]	(0.11)
					$1p_{3/2}$	2.24	0.12
6030.7 ± 0.9		6032	$\frac{9}{2}^-$	6044.5 ± 10.8	···	···	
6169 ± 5		6175	$\frac{7}{2}^+$	6168.8 ± 4.5	···	···	
6265.1 ± 1.3		6268	$\frac{9}{2}^+$	6266.1 ± 3.2	···	···	
6446.6 ± 0.9	$(\frac{9}{2}, \frac{13}{2})$	6446	$\frac{13}{2}^+$	6448.2 ± 3.9	···	···	
6553 ± 3		6550	$\frac{9}{2}$	6550.3 ± 2.5	···	···	
6606 ± 2	$(\frac{3}{2}, \frac{5}{2})^+$	6609	$\frac{3}{2}^+(\frac{5}{2}^+)$	6609.9 ± 0.5	···	···	
6642 ± 3		6639	$\frac{9}{2}$	···	···	···	
6747.4 ± 1.8		6737	$(\frac{3}{2}^+, \frac{5}{2}^+)$	···	···	···	
				6900.6 ± 1.2	$1p_{3/2}$	2.84	0.16
7008 ± 3		7006	$\frac{7}{2}$	···	···	···	
7043 ± 4		7041	$\frac{9}{2}$	···	···	···	
8856 ± 6	$(\frac{5}{2})^+, T=\frac{3}{2}$	···	···	8855.9 ± 1.4[h]	$2s_{1/2}$	≤ 6.4	≤ 0.36
					$1d_{5/2}$	16.8	3.7
9139 ± 6	$\frac{1}{2}^+, T=\frac{3}{2}$	···	···	9138.0 ± 3.4	$2s_{1/2}$	4.6	1.0
9963 ± 6	$(\frac{1}{2}, \frac{3}{2})^-, T=\frac{3}{2}$	···	···	9961.8 ± 0.7	$1p_{3/2}$	15.2	3.4

[a] The second number results if the bound state is calculated with $V_{so}=0$.
[b] Angular distribution not characteristic of direct pickup.
[c] Angular distribution shape favors $l=2$.
[d] Least-squares fit with $l=2+1$ yields $S(l=1)=0$, consistent with interpretation of $\frac{3}{2}^-$ as a particle state.
[e] Angular distribution shape favors $l=2$.
[f] According to Ref. 2, this level does not exist; we find no evidence for it.
[g] Least-squares fit with $l=0+1$ yields $S(l=0)=0$.
[h] Apparent doublet.
[i] Computed for $N=18$.

III. ANALYSIS AND DISCUSSION

Theoretical angular distributions were calculated with the code DWUCK,[53] using optical-model parameters (listed in Table II) from a previous study[54] of the ^{20}Ne(^{3}He, α) reaction. Experimental angular distributions are related to those calculated with DWUCK by the expression

$$\sigma_{\exp}(\theta) = NC^2S\,\frac{\sigma_{\rm DW}(\theta)}{2J+1}\,,$$

where J is the transferred (and here, total) angular momentum, S is the spectroscopic factor, and C^2 the square of an isospin Clebsch-Gordan coefficient. For $T=\frac{1}{2}$ final states, $C^2=1.0$ and for $T=\frac{3}{2}$, $C^2=\frac{1}{4}$. The overall normalization factor N is not well known, but our results, when compared with previous spectroscopic information, allow an estimate of N. We return to this point below.

The theoretical curves were normalized to the data as displayed in Figs. 2 and 3, resulting in the factors NC^2S listed in the next-to-last column of Table I. The nlj values listed there are those for which the distorted-wave Born-approximation (DWBA) curves were calculated. For fixed l, our results do not allow the determination of $J=l\pm\frac{1}{2}$, but the spectroscopic factors correspond to the nlj values listed.

The $\frac{3}{2}^+$ and $\frac{5}{2}^+$ states at $E_x=0$ and 0.35 MeV, respectively, have angular distributions characteristic of direct pickup. As previously observed,[36] the $\frac{5}{2}^+$ state is about ten times as strong as the ground state (g.s.). If we normalize our value of NC^2S to the previous value of S for the strong $\frac{5}{2}^+$

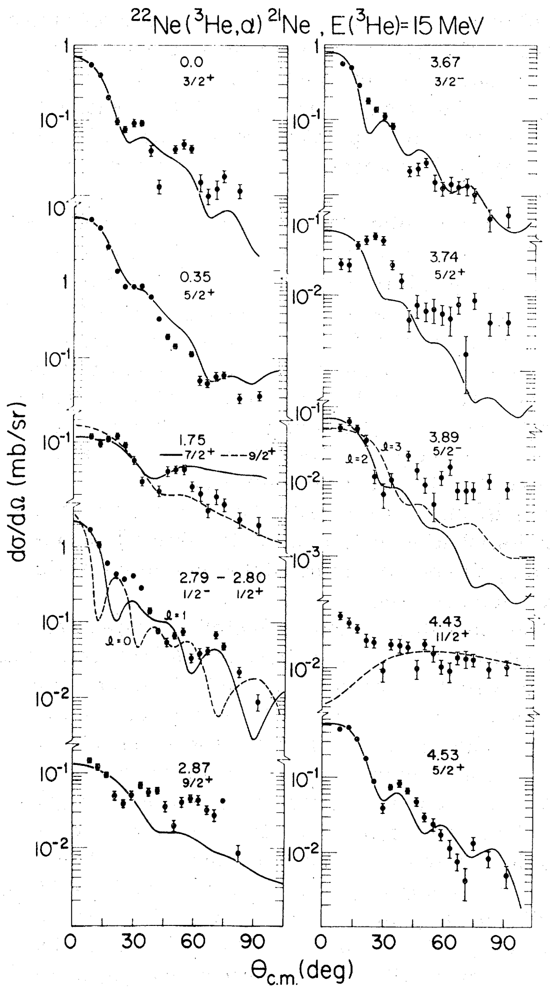

FIG. 2. Angular distributions for the ^{22}Ne(^{3}He, α) reaction leading to levels between 0 and 4.6 MeV excitation in ^{21}Ne. Curves are the results of DWBA calculations.

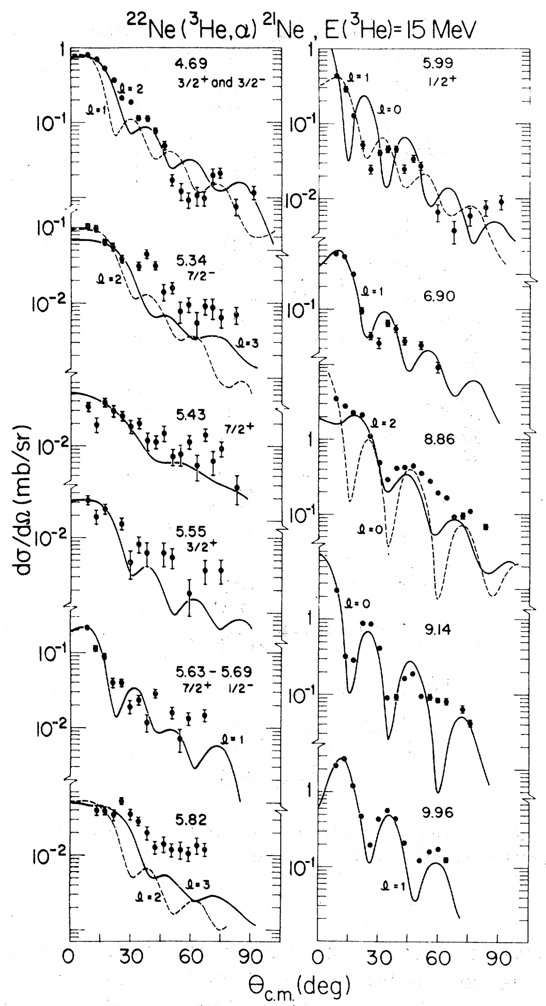

FIG. 3. Same as Fig. 2, but for 4.6–10 MeV excitation.

state, we get $N = 18$, in agreement with another recent similar comparison.[55] With this normalization, our results are in reasonable agreement with other measurements of spectroscopic factors in ^{21}Ne, where they exist (see Table III).

The $\frac{7}{2}^+$ and $\frac{9}{2}^+$ states at 1.75 and 2.87 MeV, respectively, are significantly weaker than the two lowest states, but they nevertheless have appreciable cross sections. The solid curve for the $\frac{7}{2}^+$ state was calculated on the assumption of $1g_{7/2}$ pickup, resulting in a spectroscopic factor of $S = 0.14$, much too large for the expected small component of $1g_{7/2}$ in the ^{22}Ne (g.s). The large distance of the $1g_{7/2}$ orbital from the Fermi surface results in a very deep well needed to bind the transferred neutron. Coupled with the use of a Thomas spin-orbit potential of $\lambda = 25$, this results in a very large spin-orbit strength, $V_{so} = \lambda V/180.3$. Consequently, we show as a dashed curve the DWBA calculation for $\lambda = 0$. This curve is very similar to that for $1g_{9/2}$. However, the resulting spectroscopic factor ($S = 0.06$) and the spectroscopic factor for the $\frac{9}{2}^+$ state ($S = 0.05$) are both too large. It is likely that these states are populated by a two-step process involving inelastic scattering followed (or preceded) by pickup. Such effects are well known in regions of strongly deformed nuclei.

The $\frac{1}{2}^- - \frac{1}{2}^+$ doublet at 2.79–2.80 MeV is not resolved, but the combined angular distribution shows that both l values are present. A fit to a sum of theoretical curves for $l = 0$ and 1 results in the strengths listed in Table I. These values should be reasonably accurate because the $l = 1$

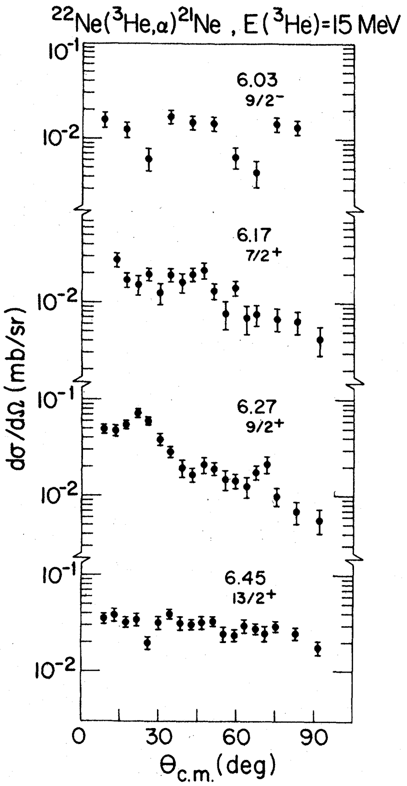

FIG. 4. Angular distributions for four additional levels between 6.0 and 6.5 MeV excitation.

curve has a minimum at the second peak of the $l=0$ curve, and is large at the first $l=0$ minimum. The l admixture was obtained by requiring that the summed curve pass through the data points at these two angles. We return to this point later (Sec. IV).

The angular distribution for the $\frac{3}{2}^-$ level at 3.67 MeV is only moderately well fitted with a $1p_{3/2}$ DWBA curve. The spectroscopic factor $S=0.27$ shows that this level contains only a minor fraction of the $1p_{3/2}$ strength, which is expected to lie significantly higher. This state and the $\frac{5}{2}^-$ level at 3.89 MeV are thought to be described as a $1p_{1/2}$ hole coupled to the first 2^+ level of ^{22}Ne.

The $\frac{5}{2}^+$ state at 3.74 MeV is very weak, and its angular distribution is not characteristic of direct pickup. This result is surprising, since the ^{22}Ne (g.s.) contains so many shell-model components that it would be expected that any state whose J^π allows direct pickup should be so populated. This suggests a very special configuration for this state.

The angular distribution for the $\frac{5}{2}^-$ state at 3.89 MeV is not very similar to the DWBA curve for $1f_{5/2}$ pickup. This is not surprising since the ^{22}Ne(g.s.) contains virtually no $1f_{5/2}$ nucleons. But it is surprising that the forward-angle data are reasonably well described by $l=2$. The parities of these two $\frac{5}{2}$ levels are now thought to be firmly established (Ref. 2 and references therein). In the absence of those results, our data would have suggested the alternative possibility.

The $\frac{11}{2}^+$ state at 4.43 MeV has a nondescript angular distribution and, like the low-lying $\frac{7}{2}^+$ and $\frac{9}{2}^+$ states, is very likely populated via an inelastic two-step process.

The 4.53-MeV $\frac{5}{2}^+$ and 4.69-MeV $\frac{3}{2}^+$ states are thought to be $\frac{5}{2}^+$, $\frac{3}{2}^+$ members of a $K^\pi=\frac{1}{2}^+$ rotational band, with band head at 2.8 MeV. Both angular distributions are reasonably well described by $l=2$ DWBA curves, but with small spectroscopic factors. The $\frac{3}{2}^+$ level is unresolved from a $\frac{3}{2}^-$ state at 4.73 MeV, but the extracted excitation energy for the doublet suggests that virtually all the cross section arises from the $\frac{3}{2}^+$ member. Further evidence comes from the angular distribution—fitting with a mixture of $l=1$ and 2 gives a best fit for $S(l=1)=0$. The weakness of the $\frac{3}{2}^-$ state in pickup is consistent with its large spectroscopic factor[28] in ^{20}Ne(d,p), and with the large Coulomb energy shift for the mirror state of ^{21}Na, both of which suggest this is dominantly a particle state.

States at 5.34, 5.43, and 5.55 MeV are very weak. Angular distributions for the first two are not characteristic of direct pickup, consistent with their spins and parities of $\frac{7}{2}^-$ and $\frac{7}{2}^+$, respectively. The spectroscopic factor extracted for the $\frac{3}{2}^+$ state at 5.55 MeV ($S=0.015$) is very small and may indicate that its character is similar to that of the $\frac{5}{2}^+$ state at 3.74 MeV. On the other hand, Ref. 2 notes the similarity of the (large) Coulomb energy for this state and for the $\frac{1}{2}^+$ state at 5.99 MeV and the

TABLE II. Optical-model parameters used in analysis of ^{22}Ne(^{3}He, α)^{21}Ne. (Strengths in MeV, lengths in fm.)

Channel	V	r_0	a	W	r_0'	a'	V_{so}	r_{so}	a_{so}	r_{0c}
^{3}He	130	1.31	0.61	24	1.43	1.01	10	1.31	0.61	1.40
α	180	1.42	0.56	16.5	1.42	0.56	···	···	···	1.40
n	···	1.26	0.60	···	···	···	λ= 25	1.26	0.60	···

TABLE III. Comparison of present and previous results for neutron pickup on ^{22}Ne.

E_x (MeV)	J^π	$NC^2S(^3\text{He},\alpha)$ [a]	$S(p,d)$ [b]	$S(^3\text{He},\alpha)$ [c]
0.0	$\frac{3}{2}^+$	5.3	0.25	0.14
0.35	$\frac{5}{2}^+$	45.6	2.5(1.86) [d]	2.4
2.79	$\frac{1}{2}^-$	14	0.7	0.57
2.80	$\frac{1}{2}^+$	7.4	···	···
3.66	$\frac{3}{2}^-$	4.9	0.19	···
4.73	$\frac{3}{2}^-$	~0	···	···

[a] Present work.
[b] Reference 36.
[c] Reference 39.
[d] Reference 37.

$(\frac{5}{2}, \frac{3}{2})^+$ state at 6.74 MeV, and suggests that they are probably of the same structure.

As mentioned in Sec. II, we find no evidence for states listed at 5.525 and 5.683 MeV in the compilation, both of which are suggested by Ref. 2 not to be present.

A state of 5.69 MeV excitation has been assigned $J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$ from an $l=1$ angular distribution in ^{20}Ne(d,p) and $J^\pi = \frac{1}{2}^-$ by mirror correspondence to a known $\frac{1}{2}^-$ state at 4.98 MeV in ^{21}Na. Our data for the $\frac{7}{2}^+$-$\frac{1}{2}^-$ doublet at 5.63–5.69 MeV imply that the $\frac{1}{2}^-$ state is the dominant member. The $1p_{1/2}$ spectroscopic factor is about 10% of that for the $\frac{1}{2}^-$ state at 2.8 MeV. The centroid of the two $\frac{1}{2}^-$ states is at 3.06 MeV. No other $\frac{1}{2}^-$ states are known in ^{21}Ne. The small pickup strength for the 5.69-MeV state is consistent with its identification as primarily a particle state, which is supported by its large Coulomb energy.

The compilation lists three states near 5.8 MeV excitation, at 5.775, 5.821, and 5.823 MeV, the middle one listed with $J = \frac{3}{2}$. Reference 2 suggests three states also: 5.773, $\frac{3}{2}^{(+)}$, $\frac{5}{2}^{(+)}$; 5.819, $\frac{7}{2}^-$; and 5.822, $\frac{3}{2}^+$, $\frac{5}{2}^+$. The 5.822 assignment arises from an $l=2$ angular distribution in ^{20}Ne(d,p). Our angular distribution for a weak state at 5.82 MeV is not characteristic of direct pickup. The large deviation in excitation energy from angle to angle suggests we are populating two almost resolvable states.

The compilation lists a state at 5.993 MeV with no J^π assignment, whereas Ref. 2 gives $\frac{1}{2}^+$ for a state at 5.990 MeV. We observe a reasonably strong state at $E_x = 5.990$ MeV, but with an $l=1$ angular distribution. There is no evidence for an $l=0$ component. The best fit to an $l=0+1$ admixture is for $S(l=0)=0$. Thus, the state we observe at 5.990 MeV has $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$. If a $\frac{1}{2}^+$ state exists at this energy, it is very weak in pickup.

Between 6.0 and 6.6-MeV excitation, we observe all the states that were previously known, but their angular distributions (four of which are displayed in Fig. 4) are rather featureless. This is not surprising, since they all have high spin ($J \geq \frac{7}{2}$).

Between 6.6 and 8.8 MeV, we observe only two states with sufficient strength to allow reliable extraction of excitation energies—a $\frac{3}{2}^+$ $(\frac{5}{2}^+)$ state at 6.61 MeV (which is very weak) and a rather strong state at 6.90 MeV, which has an $l=1$ angular distribution. This state appears to have been previously unreported, since no level was known within 100 keV of our measured energy.

Between 8.8 and 10 MeV, we observe three very strong states, all of which have peak cross sections of more than 2.0 mb/sr. These are undoubtedly the $T = \frac{3}{2}$ states that have been previously reported in (d,t) and $(^3\text{He},\alpha)$, with l values of 2, 0, and 1, respectively. However, in the present reaction, the lowest of the three appears to also contain an $l=0$ component.

In a study of the ^{17}O$(\alpha,n\gamma)$ reaction,[21] in which the $T = \frac{3}{2}$ state at 8.857 was observed, a much stronger resonance, attributed to $T = \frac{1}{2}$, was observed at 8.839 MeV. This may be the state we observe with $l=0$.

We compare in Table IV the present results with predictions of an $(sd)^5$ shell-model calculation. Experimental positive-parity levels are compared in Fig. 5 with the energies calculated in Ref. 49 and with energies from a more recent shell-model calculation.[50] Qualitative agreement is good between weak and strong states predicted and observed. For strong states there is good quantitative agreement, except that the shell model S's are consistently smaller than the measured ones. Our spectroscopic factors for sd transfers to $T = \frac{1}{2}$ levels sum to 4.14, whereas the shell-model sum for levels below 7-MeV excitation is only 2.76. It thus appears that our spectroscopic factors are all too large. The same feature is observed for the $T = \frac{3}{2}$ levels—the experimental spectroscopic factors are significantly stronger than the predicted ones. If we add in the $T = \frac{3}{2}$ strengths, the measured sum of C^2S is 5.34. The

TABLE IV. Comparison of experiment and theory for ^{21}Ne states with $J^\pi=\frac{1}{2}^+$, $\frac{3}{2}^+$, or $\frac{5}{2}^+$.

Experiment[a]			Theory[b]				
			$K+{}^{17}$O			$K+12FP$	
E_x	J^π	S	E_x	S	J^π	E_x	S
0.0	$\frac{3}{2}^+$	0.29	0	0.11	$\frac{3}{2}^+$	0	0.13
0.35	$\frac{5}{2}^+$	2.53	0.46	2.16	$\frac{5}{2}^+$	0.18	2.19
2.80	$\frac{1}{2}^+$	0.41[c]	2.04	0.15	$\frac{1}{2}^+$	2.56	0.16
3.74	$\frac{5}{2}^+$	(0.02)	3.37	0.02	$\frac{5}{2}^+$	3.55	0.00
4.52	$\frac{5}{2}^+$	0.13	4.33	0.01	$\frac{5}{2}^+$	4.33	0.02
4.68	$\frac{3}{2}^+$	0.33	3.58	0.23	$\frac{3}{2}^+$	3.68	0.25
5.33	$(\frac{5}{2}^+)$	0.03	...	...		...	...
5.50	$\frac{3}{2}^+$	0.015	4.62	0.03	$\frac{3}{2}^+$	4.76	0.01
5.78	$\frac{3}{2}^+$, $\frac{5}{2}^+$	(0.02)	6.22	0.04	$\frac{5}{2}^+$	6.11	0.03
5.82	$\frac{3}{2}^+$, $\frac{5}{2}^+$		7.32	0.00	$\frac{3}{2}^+$	6.14	0.00
5.99	$\frac{1}{2}^+$	~0	4.27	0.01	$\frac{1}{2}^+$	4.38	0.01
			7.56	0.00	$\frac{1}{2}^+$	7.16	0.00
6.61	$\frac{3}{2}^+(\frac{5}{2}^+)$	weak	...	...	...	...	...
6.74	$\frac{3}{2}^+(\frac{5}{2}^+)$	weak	...	...	...	...	...
8.86	$\frac{1}{2}^+$	≤0.36	8.42	0.00	$\frac{1}{2}^+$	8.10	0.00
8.86	$\frac{5}{2}^+$, $T=\frac{3}{2}$	3.7	0	1.58	$\frac{5}{2}^+$, $T=\frac{3}{2}$	0	1.62
9.14	$\frac{1}{2}^+$, $T=\frac{3}{2}$	1.0	−0.25	0.66	$\frac{1}{2}^+$, $T=\frac{3}{2}$	0.06	0.60

[a] Present work.
[b] Reference 49.
[c] See, however, Sec. IV of text.

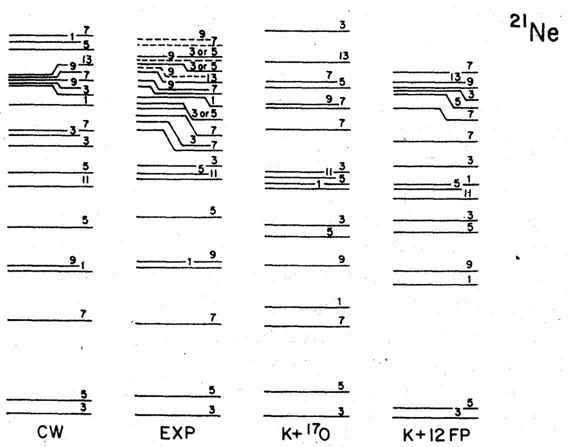

FIG. 5. Comparison between experimental and theoretical positive-parity level schemes of ^{21}Ne. The shell-model results are from Ref. 50 (left column) and Ref. 49 (right two columns). A dashed level in the experimental column denotes uncertain parity.

sum-rule limit for this quantity is 4.0 in the absence of core excitation in the ^{22}Ne(g.s.), which is expected to be small. Thus, if we had normalized N to the sum rule rather than to the 0.35-MeV $\frac{5}{2}^+$ state, we would have obtained $N=24$ rather than 18.

From Fig. 5 we see that there is good correspondence between predicted and observed levels below about 6-MeV excitation. But above that energy, more levels are known than are predicted. This is true even if all the levels of unknown parity (indicated by dashed lines) have negative parity. For example, $(\frac{3}{2}, \frac{5}{2})^+$ levels at 6.61 and 6.74 MeV have no obvious shell-model counterparts. This probably represents the presence of 7p-2h configurations, which are expected to begin near 6–7 MeV from a Bansal-French-Zamick[56,57] type calculation. Overall, however, the agreement between experiment and the shell model is quite good. The extra states in the region near 6 MeV have very little spectroscopic strength.

The present results for negative-parity states are compared in Table V with the results[54] for

TABLE V. Comparison of pickup spectroscopic factors for negative states of ^{19}Ne and ^{21}Ne.

^{19}Ne [a]			^{21}Ne [b]		
E_x (MeV)	J^π	S	E_x (MeV)	J^π	S
0.27	$\frac{1}{2}^-$	2.0	2.79	$\frac{1}{2}^-$	0.78
1.62	$\frac{3}{2}^-$	0.21	3.66	$\frac{3}{2}^-$	0.27
4.55	$(\frac{3}{2}^-)$	0.37	4.73	$\frac{3}{2}^-$	~0
			5.67	$\frac{1}{2}^-$	0.08
6.01	$(\frac{3}{2}^-)$	1.06	5.99	$\frac{1}{2}^-$, $\frac{3}{2}^-$	0.12
6.74	$(\frac{3}{2}^-)$	2.26	6.91	$\frac{1}{2}^-$, $\frac{3}{2}^-$	0.16

[a] Reference 54.
[b] Present work.

^{19}Ne. In ^{20}Ne(^{3}He, α), the lowest $\frac{1}{2}^-$ state has a strength that is consistent with a pure 4p-1h configuration. Strong states near 6–7-MeV excitation in ^{19}Ne contain a large fraction of the $1p_{3/2}$ pickup strength. In ^{21}Ne, if the lowest $\frac{1}{2}^-$ state were pure 6p-1h with $T_p = 1$, its spectroscopic factor would be $\frac{4}{3}$ rather than 2.0, the reduction coming about by requiring that the state have good isospin. However, the measured spectroscopic factor is significantly smaller, suggesting perhaps that it contains appreciable 8p-3h components. Weak-coupling arguments give about 3 MeV for the unperturbed position of the 6p-1h state and about 5.5 MeV for 8p-3h. The presence of additional $1p_{1/2}$ pickup strength near 5.5 MeV would support the idea that these two configurations have mixed.

The $T = \frac{3}{2}$ levels are very strong. Even if we renormalize to $N = 24$ rather than 18, the $\frac{5}{2}^+$ and $\frac{1}{2}^+$ $T = \frac{3}{2}$ levels still have spectroscopic factors significantly larger than the shell-model values,[49] and slightly larger than the sum rule limit would allow. Similar problems have been noted before,[58] for neutron pickup to $T_>$ states.

IV. 2.8-MeV DOUBLET

Because of the current interest[59,60] in parity mixing between the $\frac{1}{2}^+$ and $\frac{1}{2}^-$ levels at 2.8 MeV, we have tried to estimate the uncertainty in our spectroscopic factors extracted for this unresolved doublet. For parity-mixing calculations, it is important to know that the shell-model wave function used in the calculations give a good account of other data for these states.

As remarked earlier, the first minimum of the theoretical $l = 0$ curve coincides with the second data point of the combined angular distribution for the 2.8-MeV doublet (Fig. 2). Thus, within the usual uncertainties of extracting relative spectroscopic factors with DWBA (~20%), the $l = 1$ spectroscopic factor for the doublet is reliable. The value for $l = 0$ depends on the most forward angle and on angles near 25°, where the second $l = 0$ maximum occurs. The S values listed in Table I were extracted by requiring that the summed $l = 0 + 1$ curve pass through the second and fourth data points.

However, it is to be noted that the experimental angular distribution for the nearby $\frac{3}{2}^-$ state at 3.67 MeV, which must be pure $l = 1$, does not exhibit the predicted minimum. Thus, it may be that a considerable fraction of the cross section near 25° in the 2.8-MeV doublet angular distribution actually arises from the $\frac{1}{2}^-$ member. If this is so, it would reduce the $l = 0$ spectroscopic factor below the value listed in Table I. We have investigated this effect by using the experimental $l = 1$ angular distribution shape (from the 3.67-MeV state) to extract the relative amount of $l = 0$ in the doublet angular distribution. The result is a reduction in $S(l = 0)$ from 0.41 to 0.28, while leaving $S(l = 1)$ virtually unchanged.

This uncertainty, when combined with the usual 20% DWBA uncertainty, suggests that the $l = 0$ spectroscopic factor could be as small as 0.23 or as large as 0.49. The smaller number is still 1.5 times the shell-model value, but is in no worse agreement than some of the other weak states.

V. CONCLUSIONS

In the reaction ^{22}Ne(^{3}He, α)^{21}Ne, 26 angular distributions have been measured. Spectroscopic factors for $\frac{1}{2}^+$, $\frac{3}{2}^+$, and $\frac{5}{2}^+$ levels are in reasonable agreement with shell-model calculations.[49] Most of the $1d_{5/2}$ pickup strength resides in the first-excited state of ^{21}Ne. The $1d_{3/2}$ strength is approximately evenly split between the g.s. and a state at 4.68 MeV, and the $2s_{1/2}$ strength is about evenly split between two states at 2.80 and 8.86 MeV. All other $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$ levels with $T = \frac{1}{2}$ are very weak ($S \le 0.03$). The presence of additional levels above 6 MeV suggests the importance of 7p-2h excitations above that energy.

Normalizing our spectroscopic factor for the 0.35-MeV state to that previously measured results in N(^{3}He, α) = 18. Comparison of summed strengths for $l = 0$ and 2 gives $N = 24$. Normalizing to the shell-model strength for the 0.35-MeV state would have resulted in $N = 21$. Thus, our results are consistent with $N = 21 \pm 3$. A recent analysis[55] has yielded $N = 18$.

The $\frac{1}{2}^-$ state at 2.79 MeV has only about one-half the strength for a pure 6p-1h state with $T_p = 1$, perhaps suggesting mixing between 6p-1h and 8p-3h configurations. We observe virtually none of the $T = \frac{1}{2}$ $1p_{3/2}$ pickup strength, which presumably lies at higher excitation energies than those investigated here.

ACKNOWLEDGMENTS

Financial support for this work was provided by the National Science Foundation. We are grateful to G. Stephans for his assistance in the data analysis and to the authors of Refs. 2 and 50 for communicating their results prior to publication.

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