Angular correlation and lifetime measurements in ^{22}Ne†

L. K. Fifield,* R. W. Zurmühle, D. P. Balamuth, and S. L. Tabor‡
Physics Department, University of Pennsylvania, Philadelphia, Pennsylvania 19174
(Received 15 December 1975)

Particle-γ angular correlations have been measured for a number of states above 7.3 MeV in ^{22}Ne using the ^{18}O(^{7}Li, $t\gamma$)^{22}Ne reaction with the tritons observed at 0°. New information on the spins and parities of several states in ^{22}Ne was obtained. In addition, by demonstrating that the ^{22}Ne nuclei were strongly aligned, these measurements provide support for a direct α-particle transfer mechanism for the ^{18}O(^{7}Li, t)^{22}Ne reaction. Angular correlation and lifetime measurements employing the ^{19}F(α, $p\gamma$)^{22}Ne reaction have also been performed for a number of states in ^{22}Ne, including several closely spaced doublets on which previous information is incomplete or inconsistent. Lifetimes were measured by the Doppler-shift attenuation method. The results are compared with recent large basis shell model calculations.

[NUCLEAR REACTIONS ^{18}O(^{7}Li,$t\gamma$), E=12.0 MeV; ^{19}F(α,$p\gamma$), E=12.0, 15.0, 18.5, 19.0 MeV; measured t-γ, p-γ angular correlations, Doppler-shift attenuation. ^{22}Ne deduced levels, τ, J, π, $B(\Lambda)$.]

I. INTRODUCTION

The ^{22}Ne nucleus is known to be among the most highly deformed of light nuclei, although the ground state rotational band is the only clearly defined band identified so far. The identification of further band structure in ^{22}Ne has been hampered by a lack of information on higher lying states and by a number of ambiguities associated with closely spaced doublets below 7.5 MeV. Hence we have sought to extend knowledge of the level structure of ^{22}Ne in two ways. First, particle-γ angular correlations employing the ^{18}O(^{7}Li, $t\gamma$)^{22}Ne reaction have been measured for a number of selectively excited[1] states between 7.3 and 8.6 MeV. Secondly, we have used a high resolution magnetic spectrometer in conjunction with the ^{19}F(α, $p\gamma$)^{22}Ne reaction to resolve the individual members of closely spaced doublets below 7.5 MeV, thereby removing some inconsistencies which existed in the literature. Lifetimes or lifetime limits have also been obtained for several states below 7.5 MeV in ^{22}Ne using the ^{19}F(α, $p\gamma$)^{22}Ne reaction.

The information thus obtained may then be compared, at least for positive parity levels, with the full s-d shell basis shell-model calculations of Preedom and Wildenthal.[2] These calculations have proved successful in reproducing both the known collective properties of ^{22}Ne, notably the energy spacing and $B(E2)$ values[3,4] within the ground state band, and properties such as the ^{22}F β decay[5] rates which are not dominated by collective effects. Information on states not in the ground state band provides a further test of the reliability of the shell-model calculations and may lead to the identification of additional band structure in ^{22}Ne.

In the angular correlation study of states strongly excited in the ^{18}O(^{7}Li, t)^{22}Ne reaction, the tritons were detected at zero degrees to the beam direction. Magnetic substates with $M=0$, ±1, ±2 may then be populated in the ^{22}Ne residual nucleus, and, in principle, the analysis of the t-γ angular correlations involves two variable population parameters. However, there is experimental evidence[6] that the dominant reaction process for the strong transitions, especially for nuclei at the beginning of the $2s$-$1d$ shell, is the direct transfer of an α cluster with zero spin and isospin. If this direct transfer were the sole mechanism, only states with natural parity would be excited in (^{7}Li, t) reactions, and further, only the $M=0$ substate would be populated in our geometry (neglecting spin-orbit effects). The former condition appears to be approximately valid as known unnatural parity states in ^{20}Ne and ^{22}Ne are not strongly excited by the (^{7}Li, t) reaction. In addition, it has been shown that the first excited state of ^{20}Ne populated by the ^{16}O(^{7}Li, t)^{20}Ne reaction at beam energies of 13 and 14 MeV is indeed aligned with predominant population of the $M=0$ substate and negligible population of the $M=\pm2$ substates. In the present work it has been assumed that for states in ^{22}Ne strongly populated by the (^{7}Li, t) reaction, the strong alignment observed in Ref. 7 is characteristic of the reaction mechanism and can be described by specifying the relative population of the $M=0$, ±1 substates only and assuming these sum to unity. As a result, angular correlations of deexcitation γ rays (especially those leading to the ground state) are expected to be quite anisotropic, and therefore sensitive to the spin of the initial state. The ^{18}O(^{7}Li, $t\gamma$)^{22}Ne angular correlation results reported here, in addition to providing new information on ^{22}Ne, lend support to these ideas. However, it should be explicitly pointed out that the use of a reaction model to limit the physically allowed range of population parameters at least partially vitiates the use of rigorous quantitative methods (e.g., the χ^2 test and associated confidence levels) for rejecting spin hypotheses and/or measuring multipole mixing ratios. On the other hand, even with the two variable population parameters which occur in the (^{7}Li, t) reaction it is occasionally possible to reject a spin hypothesis rigorously; in what follows we will clearly label those results which are model-dependent and those which are not.

Previous information on a number of closely spaced doublets in ^{22}Ne has been obtained from angular correlation studies employing the ^{19}F($\alpha, p\gamma$)^{22}Ne (Ref. 8) and ^{20}Ne($t, p\gamma$)^{22}Ne (Ref. 9) reactions.[8,9] In these studies, the individual members of the 5.33-5.36, 6.31-6.34, 6.64-6.69, and 6.82-6.86 MeV doublets were not resolved, which perhaps accounts for inconsistencies between the interpretation[8,9] of these measurements and the results of more recent work.[5,10,11] We have measured p-γ correlations for the individual members of each of these doublets using the ^{19}F($\alpha, p\gamma$)^{22}Ne reaction with the protons detected at 0° to the beam direction. The results for the 6.31-6.34 MeV doublet have been reported previously.[4] The 6.69 and 6.86 MeV states, rather than the 6.64 and 6.82 MeV states as previously reported,[8,9] were found to decay directly to the ^{22}Ne ground state. This observation removes a discrepancy[9,10] regarding the spin of the 6.82 state.

II. EXPERIMENTAL PROCEDURE

A. ^{18}O(^{7}Li, $t\gamma$)^{22}Ne angular correlations

States in ^{22}Ne between 7.34 and 8.59 MeV were populated in the ^{18}O(^{7}Li, t)^{22}Ne reaction with a 12 MeV ^{7}Li^{3+} beam from the University of Pennsylvania tandem accelerator. The tritons were detected at 0° to the beam direction by a position sensitive detector at the focal plane of a magnetic spectrometer.[12] The target used in studying the 8.59 MeV state consisted of 140 μg/cm^2 of WO_3, enriched to 98.4% in ^{18}O, on a 30 μg/cm^2 backing of ^{12}C, and was approximately 90 keV thick for 12 MeV ^{7}Li ions. The targets used in studying the remaining states consisted of 50 μg/cm^2 foils of natural titanium which were oxidized in water vapor enriched to 98.4% in ^{18}O, and which then had 40 μg/cm^2 of gold evaporated onto the back surface. The energy resolution achieved with these targets was determined by the target thickness and was approximately 70 keV for 12 MeV ^{7}Li ions. γ rays were detected in time coincidence with the tritons by an array of four 7.6 × 10.2 cm NaI(Tl) crystals placed at 90, 113, 136, and 159° to the beam direction. Four parameter coincidences consisting of the γ-ray energy, the energy and position signals from the triton detector, and the time-to-amplitude converter output were recorded on magnetic tape. Subsequent off-line analysis yielded the spectra of γ rays from the decay of a given state in ^{22}Ne, from which the angular correlations were extracted.

The angular correlations were fitted with the computer code M2.[13] As only the $M=0$ and ±1 substates were assumed to be populated, the alignment of the γ decaying state could be described by a single parameter, $P(0)$, the fraction of nuclei in the $M=0$ substate. The fit determined the values of $P(0)$ and of the mixing ratio δ (if applicable) which minimized χ^2, the goodness of fit parameter.

B. ^{19}F($\alpha, p\gamma$)^{22}Ne angular correlation measurements

The ^{19}F($\alpha, p\gamma$)^{22}Ne reaction was employed to populate a number of states in ^{22}Ne between 5.3 and 7.4 MeV. The targets consisted of 65 μg/cm^2 of CaF_2 on 30 μg/cm^2 carbon backings. Beam energies of 15 MeV ($E_x = 5.2-5.7$, 6.5–7.0 MeV); 18.5 MeV (7.2–7.6 MeV), and 19.0 MeV (7.6-8.0 MeV) were used. The remainder of the experimental arrangement and the acquisition and analysis of the data were identical to those described in Ref. 4.

C. ^{19}F($\alpha, p\gamma$)^{22}Ne lifetime measurements

A beam of 12.0 MeV α particles excited states in ^{22}Ne via the ^{19}F($\alpha, p\gamma$)^{22}Ne reaction. Two targets were used, consisting of 150 μg/cm^2 of BaF_2 on 5 mg/cm^2 foils of gold and silver, respectively. Protons were detected in a surface barrier detector centered at +37.5° relative to the beam direction. γ rays in coincidence with protons were detected in a 65 cm^3 Ge(Li) detector placed at angles of −106° and −150° to the beam direction. Details of the experimental arrangement, of the extraction of the Doppler-shift attenuation factors $F(\tau)$, and of the derivation of the mean nuclear lifetimes τ have been given in Ref. 4. The results of this lifetime measurement are presented in Table I.

A further measurement employing the ^{19}F($\alpha, p\gamma$)^{22}Ne reaction at $E_\alpha = 15$ MeV provided γ-ray decay schemes and accurate excitation energies of many states in ^{22}Ne up to 9.24 MeV. The γ rays were detected in the Ge(Li) detector at 90° to the beam direction. The target consisted of 100 μg/cm^2 of ^{6}LiF on 30 μg/cm^2 of ^{12}C, and the protons were detected in an annular surface barrier detector spanning an angular range from 164° to 174°.

TABLE I. Results of the $^{19}F(\alpha,p\gamma)^{22}Ne$ lifetimes measurement.

State (MeV)	Transition	Backing	$F(\tau)$	τ (fsec)	$\tau_{adopted}$ (fsec)
4.46	4.46 → 1.27	Au	0.95 ± 0.04	22^{+15}_{-17}	<40
		Ag	0.94 ± 0.04	28^{+16}_{-18}	
5.14	4.46 → 1.27	Au	0.19 ± 0.06	1400^{+900}_{-500}	1150^{+600}_{-300} [a]
		Ag	0.16 ± 0.06	900^{+500}_{-300}	
5.36	5.36 → 1.27	Au	1.03 ± 0.09	<28	<30
		Ag	1.03 ± 0.12	<41	
5.52	5.52 → 3.36	Au	0.94 ± 0.06	<50	<50
		Ag	0.90 ± 0.07	43 ± 30	
5.63	5.63 → 3.36	Au	0.99 ± 0.13	<55	<60
		Ag	0.98 ± 0.12	<60	
	5.63 → 1.27	Au	0.94 ± 0.09	<60	
		Ag	0.92 ± 0.07	<65	
5.92	5.92 → 1.27	Au	0.88 ± 0.08	48 ± 30	51 ± 23
		Ag	0.87 ± 0.08	55 ± 35	
6.64	6.64 → 3.36	Au	0.82 ± 0.06	70 ± 24	69 ± 20
		Ag	0.84 ± 0.07	68 ± 30	
7.41	7.41 → 5.14	Au	0.78 ± 0.12	86^{+55}_{-46}	91^{+46}_{-38}
		Ag	0.77 ± 0.14	99^{+75}_{-62}	
7.42	7.42 → 5.52	Au	0.82 ± 0.07	71 ± 30	68 ± 21
		Ag	0.85 ± 0.07	64 ± 30	

[a] This lifetime is in good agreement with the recently reported results of Merdinger *et al.* (Ref. 18).

A 25 μm Ta foil in front of the proton detector prevented elastically scattered α particles from reaching the detector. The energy calibration of the Ge(Li) spectra was obtained from a prescaled singles spectrum accumulated simultaneously with the coincidence data, and containing lines from ^{88}Y and ^{113}Sn sources. Lines at 391.70 keV (^{113}Sn), 511.01 keV (annihilation radiation), 898.04 keV (^{88}Y), and 1836.13 keV (^{88}Y) defined the energy calibration. The results of this measurement are presented in Table II. Corrections have been made for second order Doppler shift and γ-ray recoil.

III. RESULTS

A. $^{18}O(^7Li,t)^{22}Ne$ angular correlations

The results of the $^{18}O(^7Li,t\gamma)^{22}Ne$ angular correlation measurements are presented in Table III and are summarized in Fig. 1. A discussion of individual levels follows.

7.34 MeV. Hinds, Marchant, and Middleton[14] have reported a doublet with a separation of about 10 keV at approximately this energy. One member is presumably the 7.341 MeV state (hereafter labeled 7.34(I)) populated[5] by an allowed β decay from ^{22}F. This state decays to the 3.36 MeV (4^+) level and probably has $J^\pi = 3^+$. The other member, which is observed to decay predominantly to the 5.33 MeV (1^+) level in the present work, is the 7.34 MeV level reported[1] in the $^{18}O(^7Li,t)^{22}Ne$ study. Scholz *et al.*[1] have suggested that this state [7.34(II)] has $J^\pi = 0^+$ on the basis of its strongly forward peaked angular distribution. γ-ray spectra for the two membersof the doublet are shown in Fig. 2 (see, also Sec. III C).

A state at 7.35 MeV has also been studied via the $^{20}Ne(t,p\gamma)^{22}Ne$ reaction.[9] The observed γ-ray spectrum was interpreted as arising predominantly from a decay to the 5.33 MeV level, although the relative branching of the 5.33 MeV level to the ground and 1.27 MeV states was not known at that time. However, such an interpretation is inconsistent with the measured[9] $(t,p\gamma)$ angular correlations. The 5.33 → 0.0 MeV correlation was accurately isotropic ($a_2 = 0.00 \pm 0.01$), whence the $M = 0$, $+1$, and -1 substates of the 5.33 MeV level must have been equally populated in the decay from the 7.35 MeV state. It then follows that the 5.33 → 1.27 MeV correlation should also have been isotropic, a point overlooked in Ref. 9. However, the correlation of the presumed 4.06 MeV γ ray was significantly anisotropic ($a_2 = 0.20 \pm 0.03$), implying some contribution from a transition other than the 5.33 → 1.27 MeV transition. Such a contribution might arise from the decay of the 7.34(I) state to the

TABLE II. γ rays observed in the $^{19}F(\alpha, p\gamma)^{22}Ne$ reaction and excitation energies in ^{22}Ne.

E_x	E_x [a] (Literature)	E_γ [b] (keV)	Identification	$E_{Transition}$ [c] (keV)
1274.5 ± 0.4	1274.58 ± 0.03	1274.1 ± 0.4	1.27 → 0.0	1274.5
3356.6 ± 1.0	3357.2 ± 0.5 [d]	2081.4 ± 0.9	3.36 → 1.27	2082.0
4456.7 ± 1.6	4457 ± 3	3181.2 ± 1.5	4.46 → 1.27	3182.1
5147.5 ± 1.7	5144 ± 4	690.6 ± 0.6 [b]	5.14 → 4.46	690.8
5337.0 ± 7.0	5335 ± 9	5335.0 ± 7.0	5.33 → 0.0	5337.0
5365.2 ± 2.0	5360 ± 8	4089.8 ± 1.9	5.36 → 1.27	4090.7
5522.1 ± 1.4	5523.4 ± 0.7 [d]	2164.8 ± 0.9	5.52 → 3.36	2165.5
5641.2 ± 1.5	5641.1 ± 0.8 [d]	2283.1 ± 1.2	5.64 → 3.36	2283.8
		4366.4 ± 2.0	5.64 → 1.27	4367.9
5909.9 ± 1.8	5914 ± 11	1453.3 ± 1.4	5.92 → 4.46	1453.7
		4633.0 ± 2.6	5.92 → 1.27	4634.6
6235.2 ± 7.1	6241 ± 13	897.9 ± 1.4	6.24 → 5.33	898.2
6311.4 ± 1.7	6305.4 ± 3 [e]	2953.9 ± 1.4	6.31 → 3.36	2954.8
6345.1 ± 1.7	6345.0 ± 1.0 [d]	2987.6 ± 1.4	6.34 → 3.36	2988.5
6636.0 ± 1.7	6644 ± 8	3278.9 ± 1.4 [b,f]	6.64 → 3.36	3279.4
6689.7 ± 5.0	6692 ± 11	6687.1 ± 5.0	6.69 → 0.0	6689.7
6817.4 ± 2.3	6819 ± 7	2360.0 ± 1.6 [b]	6.82 → 4.46	2360.7
7341.6 ± 6.0	7341.1 ± 1.1 [d]	3983.6 ± 5.8	7.34 → 3.36	3985.0
7405.5 ± 2.2	7402 ± 7	2257.5 ± 1.3 [b]	7.40 → 5.14	2258.0
7421.0 ± 1.6	7423.6 ± 0.9 [d]	1898.4 ± 0.8	7.42 → 5.52	1898.9
7644.6 ± 4.0	7632 ± 8	6367.6 ± 4.0	7.64 → 1.27	6370.0
7721.3 ± 2.9	7721 ± 8	3263.6 ± 2.4	7.72 → 4.46	3264.6
8080.9 ± 5.0	8077 ± 8	6803.8 ± 5.0 [b]	8.08 → 1.27	6806.3
8161.3 ± 7.0	8163 ± 10 [g]	6884.0 ± 7.0	8.16 → 1.27	6886.7
8490.6 ± 2.4	8499 ± 8	2145.0 ± 1.6 [b]	8.49 → 6.34	2145.5
8592.6 ± 5.3	8583 ± 8	5234.1 ± 5.0 [b]	8.59 → 3.36	5236.0
8860.3 ± 3.5	8859 ± 10	2548.2 ± 3.0	8.86 → 6.31	2548.9
9097.3 ± 2.9	9097 ± 10	4639.2 ± 2.4	9.10 → 4.46	4640.6
9169.7 ± 3.6	9179 ± 10 [g]	5811.1 ± 3.4	9.16 → 3.36	5813.1
9250.7 ± 7.2	9242 ± 15	3133.8 ± 1.5	9.24 → 6.12	3134.7

[a] Taken from Ref. 3 unless otherwise indicated.
[b] Observed γ-ray energies. Only the strongest lines are included in the table. The following decay modes were also observed (observed intensities in parentheses, normalized to 100 for the sum of decays from a given state): 5.14 → 1.27 (61), 5.64 → 1.27 (65), 5.92 → 4.46 (17), 6.82 → 1.27 (56), 8.08 → 3.36 (41), 8.49 → 3.36 (43), 8.59 → 1.27 (38).
[c] Corrected for second order Doppler shift and γ-ray recoil.
[d] See Ref. 5.
[e] Derived by Davids *et al.* (Ref. 5) from unpublished data of Davies and Forster.
[f] From $^{19}F(\alpha, p\gamma)^{22}Ne$ data at $E_\alpha = 12.0$ MeV.
[g] E. R. Flynn, O. Hansen, and O. Nathan, Nucl. Phys. A228, 189 (1974).

3.36 MeV state, or from a 5.36 → 1.27 MeV transition following a possible 7.34(II) → 5.36 MeV decay. The correlation of the presumed 2.01 MeV γ ray was also anisotropic. Again, contributions to this correlation could arise from 3.36 → 1.27 or 7.34(II) → 5.36 MeV transitions. It follows that the interpretation of the γ-ray spectrum observed in the $^{20}Ne(t, p\gamma)^{22}Ne$ study in terms of a single decay mode of a 7.35 MeV state through the 5.33 MeV state is incorrect. The tentative 1^- assignment to the 7.35 MeV level made under this assumption of a single decay mode must then be regarded as suspect.

In contrast to the angular correlation results of Ref. 9, Table III indicates that in the present work the angular correlations of the four strongest transitions were isotropic within statistics, as was the correlation of all events above the 511 keV photopeak. Together with the absence of decays to the ground and 1.27 MeV (2^+) states, the isotropy of the correlations observed in the $^{18}O(^7Li, t)^{22}Ne$ reaction lends strong support to the 0^+ assignment suggested in Ref. 1, although spins 1 and 2 clearly cannot be rigorously excluded. [Of course, spin 1 would require equal population of all magnetic substates to produce an isotropic angular correlation; for spin 2, an isotropic correlation can be obtained for other values of $P(M)$ as well. However, neither

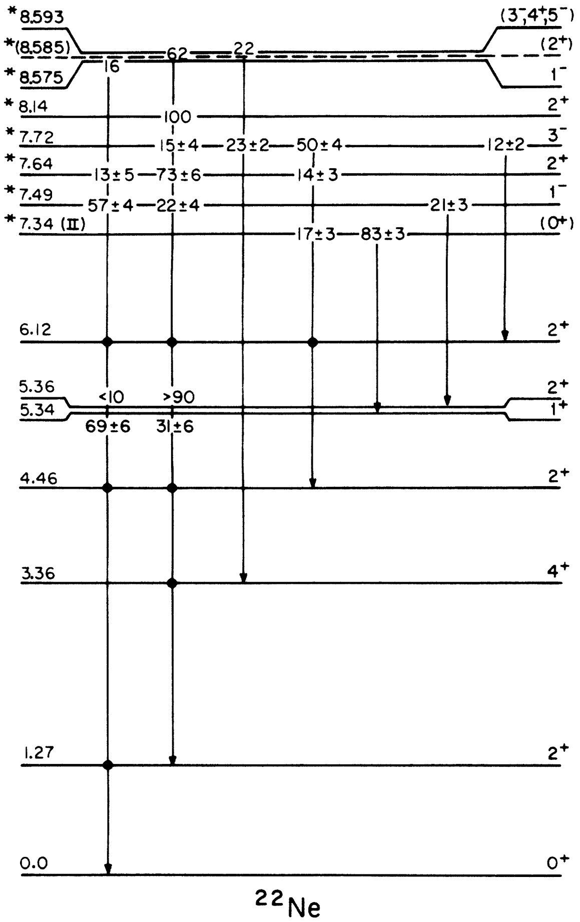

FIG. 1. Level diagram of ^{22}Ne summarizing the results of the ^{18}O(^{7}Li,$t\gamma$)^{22}Ne angular correlation measurements. Levels marked with an asterisk are those for which new information is provided by the present work. The possible triplet of levels at approximately 8.59 MeV is discussed in the text.

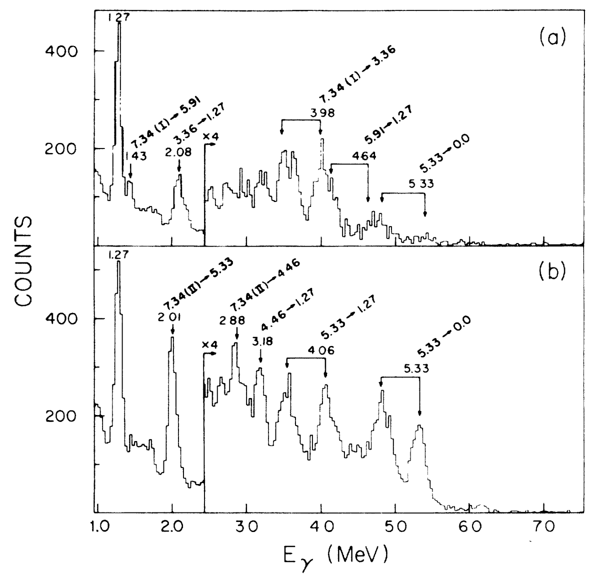

FIG. 2. Spectra of γ rays from states at 7.34 MeV in ^{22}Ne populated in (a) the ^{19}F(α,p)^{22}Ne reaction at E_a = 18.5 MeV and in (b) the ^{18}O(^{7}Li,t)^{22}Ne reaction at a beam energy of 12.0 MeV. As discussed in the text, only the 7.34(II) MeV state is believed to be populated in the (^{7}Li,t) reaction, while in the (α,p) reaction the 7.34(II) state is only weakly populated [whence the 5.33 → 0.0 MeV transition in (a)] and the 7.34(I) MeV is strongly populated. The peaks are marked both with the γ-ray energy in MeV and with the transition in ^{22}Ne.

of these spins can produce an isotropic correlation if the population parameters are those one would expect from an α-transfer process.] The relative intensities measured in the present work of 61 ± 5 and 39 ± 5 for the 5.33 and 4.06 MeV γ rays are consistent with little or no population of the 7.34(I) MeV state in the ^{18}O(^{7}Li, t)^{22}Ne reaction (see Sec. III B), in line with the expectation that unnatural parity states should not be strongly excited in this reaction. [In a recent study[15] of the ^{20}Ne(t,p)^{22}Ne a state at 7.34 MeV was suggested to be populated by an $L = 4$ transition. However, the data presented appear to be consistent with a doublet consisting of a 0$^+$ state and a 3$^+$ state, with the latter excited by a nondirect or higher order process.]

7.49 MeV. The results of the ^{21}Ne(d,p)^{22}Ne (Ref. 10) and ^{22}Ne(α,α')^{22}Ne (Ref. 11) studies constrain the J^π of the 7.49 MeV level to (1, 3)$^-$. The observation of a 7.49 → 0.0 MeV decay mode weakens the 3$^-$ possibility, whence $J^\pi = 1^-$ in agreement with an earlier[9] spin assignment to this level. Analysis of the 7.49 → 0.0 MeV correlation confirmed the 1$^-$ assignment, an acceptable fit being obtained for $J = 1$ only. (In this case a grid search was performed for the $J = 2$ hypothesis in which all population parameters were varied; $J = 2$ was rejected at the 1% confidence level.) In addition to the decay branches to the 0.0 and 5.36 MeV states reported by Howard *et al.*,[9] a branch to the 1.27 MeV level was observed.

7.64 MeV. The J^π of this state is restricted to (1, 2)$^+$ by the observation of an $l_n = 0 + 2$ neutron transfer in the ^{21}Ne(d,p)^{22}Ne reaction.[10] Analysis of the 7.64 → 0.0 MeV correlation measured in the present work excluded $J = 1$ at the 0.1% confidence level, and for $J = 2$ implied that the fraction of nuclei in the $M = +2$ and -2 substates, $P(2)$, was 0.02 ± 0.12 (see Sec. III B). Hence in the simultaneous analysis of the 7.64 → 0.0, 7.64 → 1.27, and 1.27 → 0.0 MeV correlations the assumption $P(2) = 0$ is justified. The three correlations together with the plot of χ^2 versus δ ($E2/M1$) for the 7.64 → 1.27 MeV transition are shown in Fig. 3.

TABLE III. Results of $^{18}O(^{7}Li, t\gamma)^{22}Ne$ angular correlation measurements.

State (MeV)	Transition E_i	E_f	A_2/A_0	A_4/A_0	J_i^π	J_f^π	$P(0)$	δ
7.34	7.34	5.33	0.09 ± 0.09	−0.08 ± 0.13	(0^+)	1^+		
	5.33	1.27	−0.03 ± 0.11	0.01 ± 0.16	1^+	2^+		
	5.33	0.0	−0.01 ± 0.06	−0.02 ± 0.08	1^+	0^+		
	1.27	0.0	0.00 ± 0.08	0.03 ± 0.13	2^+	0^+		
7.49	7.49	0.0	−0.72 ± 0.05	−0.03 ± 0.08	1^-	0^+	0.83 ± 0.03	
7.64	7.64	0.0	0.64 ± 0.16	−0.81 ± 0.24	2^+	0^+	0.60 ± 0.05	
	7.64	1.27	0.30 ± 0.06	−0.03 ± 0.08	2^+	2^+		0.08 ± 0.05
	1.27	0.0	0.21 ± 0.08	0.21 ± 0.12	2^+	0^+		
7.72	7.72	1.27	0.09 ± 0.10	−0.14 ± 0.15	3^-	2^+	a	
	7.72	4.46 }	−0.08 ± 0.04	0.04 ± 0.06	3^-	2^+		
	4.46	1.27 }			2^+	2^+		
8.14	8.14	1.27	−0.13 ± 0.05	−0.11 ± 0.07	2^+	2^+	0.45 ± 0.09	0.48 ± 0.05
	1.27	0.0	0.30 ± 0.08	0.01 ± 0.12	2^+	0^+		
8.59	8.59	0.0	−0.59 ± 0.06	−0.04 ± 0.10	1^-	0^+	0.74 ± 0.04	
	8.59	1.27	0.15 ± 0.04	−0.02 ± 0.06				
	8.59	3.36	−0.19 ± 0.07	−0.02 ± 0.11	3^-	4^+	a	−0.04 ± 0.03
					4^+	4^+	a	0.83 ± 0.16

[a] The fit was insensitive to the value of $P(0)$ in these cases.

7.72 MeV. An $l_n = 1$ stripping pattern[10] in $^{21}Ne(d,p)^{22}Ne$ and natural parity[11] restrict the spin and parity of the 7.72 MeV state to $(1,3)^-$. The measured angular distribution of tritons[1] from the $^{18}O(^{7}Li, t)^{22}Ne$ reaction favored the 3^- assignment.

In the present work, γ-decay modes (in order of intensity) were observed to the 4.46 (2^+), 3.36 (4^+), 1.27 (2^+), and 6.12 (2^+) MeV levels. The observation of a branch to the 3.36 MeV level confirms the 3^- assignment. Angular correlations were extracted for the 7.72 → 1.27 MeV transition and for the sum of the unresolved 7.72 → 4.46 and 4.46 → 1.27 MeV transitions. Both correlations were close to isotropic.

Assuming J^π (7.72) = 3^-, the angular correlation for the 7.72 → 1.27 MeV γ ray implies an $M2/E1$ mixing ratio $\delta < -0.1$ if the $|M| = 2$ substate is restricted to zero in the fit; an acceptable fit can be obtained for a pure $E1$ transition, but only with a large population parameter $P(2)$. The angular correlation for the unresolved 7.72 → 4.46 → 1.27 MeV cascade is consistent with either possibility and provides no additional information. Clearly a lifetime measurement for the 7.72 MeV level would help in determining whether a nonzero $M2/E1$ mixing ratio is possible; unfortunately the 7.72 MeV level is not populated in the $^{19}F(\alpha, p)$ reaction at $E_\alpha = 12.0$ MeV. The 7.72 MeV state was also studied via the $^{19}F(\alpha, p\gamma)^{22}Ne$ reaction at $E_\alpha = 19$ MeV. Decay modes to the same four states were observed with relative intensities which agreed within errors with those obtained in the $^{18}O(^{7}Li, t\gamma)^{22}Ne$ work.

The angular correlation of the 7.72 → 1.27 MeV γ ray restricts $\delta(M2/E1)$ to values greater than −0.25 and is consistent with a pure $E1$ decay. Thus a value of $-0.25 \le \delta \le -0.1$ can be inferred from the present work if the assumption is made that the (^{7}Li, t) reaction does not populate the $|M| = 2$ substates.

8.14 MeV. A state at 8.14 MeV is populated by an $l_n = 2$ transfer in $^{21}Ne(d,p)^{22}Ne$ (Ref. 10) and has natural parity,[11] implying $J^\pi = (0, 2, 4)^+$. The anisotropic angular correlation of the 8.14 → 1.27 MeV transition rules out $J = 0$, and an acceptable fit cannot be obtained for the 8.14 → 1.27 and 1.27 → 0 MeV transitions if $J = 4$. (This conclusion does not depend on the assumption restricting the population of the $|M| = 2$ substates. For a 4 → 2 → 0 cascade the angular correlations of the two γ rays must be identical independent of the initial alignment; this requirement is strongly violated by the observed 8.14 → 1.27 and 1.27 → 0.0 MeV transitions.) Hence $J^\pi = 2^+$. However, the value quoted (and the error) for the $E2/M1$ mixing ratio for the 8.14 → 1.27 MeV transition was obtained assuming $P(2) = 0$ and is not in this sense a model-independent determination.

8.59 MeV. A group at 8.59 MeV is a factor of 3 stronger than any other group in the triton spectrum[1] from the $^{18}O(^{7}Li, t)^{22}Ne$ reaction at 12 MeV. The spectrum of γ rays in coincidence with this group shows decays to the 0.0, 1.27 (2^+), and 3.36

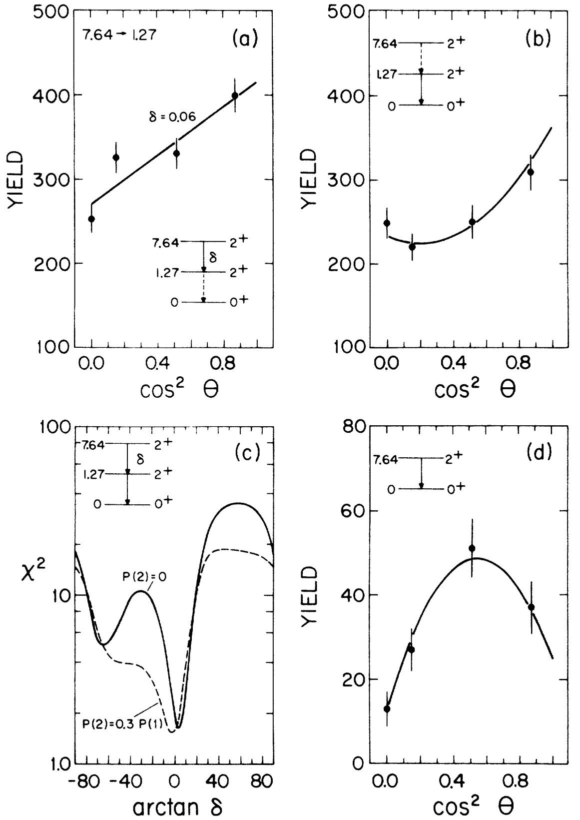

FIG. 3. The angular correlations for the 7.64 → 1.27 MeV (a), 1.27 → 0 MeV (b), and 7.64 → 0 MeV (d) transitions together with the predicted correlations. χ^2 for the simultaneous fit of all three correlations is also shown (c) as a function of the mixing ratio of the 7.64 → 1.27 MeV transition.

(4^+) MeV states with relative intensities of 16, 62, and 22%. Analysis of the 8.59 → 0.0 MeV angular correlation yielded a good fit for $J = 1$. For $J = 2$, an acceptable fit could not be obtained subject to the restriction that only the $M = 0, \pm 1$ substate populations be nonzero; for large values of the $|M| = 2$ population parameter $[P(2) + P(-2) = 0.9]$ an acceptable fit was obtained. Since the 8.59 MeV level is the strongest state in the spectrum, we assume that the reaction mechanism is inconsistent with such a strong population of the $|M| = 2$ substate; hence we take $J^\pi = 1^-$, the parity being taken from the fact that only natural parity states are strongly excited by the (^{7}Li, t) reaction. The decay mode to the 3.36 MeV state then implies the existence of more than one state at this energy. Analysis of the 8.59 → 3.36 MeV correlation yielded acceptable fits for $J = 3, 4$, and 5, while $J = 2$ and 6 were excluded at the 0.1% confidence level using the assumption $P(2) + P(-2) < 0.5$.

Analysis of the 8.59 → 1.27 MeV transition is complicated by the fact that both of the states already established at 8.59 MeV may contribute to the correlation of this transition, and by the possibility of a third state at this energy. A state at 8.585 MeV with an $l_n = 0 + 2$ stripping was reported in the ^{21}Ne(d, p)^{22}Ne reaction. The presence of an $l_n = 0$ component is incompatible with either of the spin and parity assignments established in the present work and indicates the existence of a third state with $J^\pi = (1, 2)^+$ at approximately 8.59 MeV. If in fact $J^\pi = 2^+$ for this third state, it could contribute significantly to the 8.59 → 1.27 MeV correlation observed in the present work. Support for this possibility is provided by triton spectra in coincidence with γ-ray events (a) in the full energy and escape peaks of the 8.59 → 0.0 MeV transition, (b) in the full energy and escape peaks of the 8.59 → 1.27 MeV transition, and (c) in the full energy peak peak of the 3.36 → 1.27 MeV transition. In the latter case a spectrum of tritons in coincidence with events immediately above the 3.36 → 1.27 MeV peak was subtracted. The centroid of the group in spectrum (c) was displaced relative to that in spectrum (a) by + 18 ± 2 keV, while the centroid of (b) fell midway between (a) and (c) at + 9 ± 2 keV from (a). So either the two states already identified make approximately equal contributions to the 8.59 → 1.27 MeV transition, or a significant contribution arises from a third state intermediate in energy between the other two. The angular correlation of the 8.59 → 1.27 MeV transition does not permit us to distinguish between the two possibilities, acceptable fits being obtained both for $J = 2$ alone, and for approximately equal proportions of $J = 1$ and 3, or $J = 1$ and 4. From Table II, however, we see that only about 20% of the 8.59 → 1.27 MeV transition can be attributed to decay of the 8593 keV state, which supports the hypothesis of a third level.

Taking the energy of the state which decays to the 3.36 MeV level from Table II (8593 ± 5 keV), it follows that the state which decays directly to the ground state is at 8575 ± 7 keV.

B. Reaction mechanism of the ^{18}O(^{7}Li,t)^{22}Ne reaction

It was possible to test the assumption of negligible population of the $M = \pm 2$ substates using the ground state decay of the 7.64 MeV level. The spin of this state had previously been restricted to $(1, 2)^+$, and analysis of the t-γ angular correlation obtained in the present work rigorously excluded $J = 1$ (as there is only one variable population parameter for a spin 1 level), whence $J^\pi = 2^+$. It was then possible to determine the population of the various substates from a Legendre polynomial fit to the data.[7] The population parameters so determined were $P(0) = 0.68 \pm 0.08$, $P(\pm 1) = 0.30 \pm 0.10$, and $P(\pm 2) = 0.02 \pm 0.12$, demonstrating that the assumption of negligible population of the $M = \pm 2$ substates is justified in this case. It is also worth noting that in each case in which there exists a transition to the ground state, in which the correlation unambiguously fixes $P(0)$, (i.e., for the 7.49, 7.64, and 8.575 MeV levels), population of the $M = 0$ substate predominated over population of the $M = \pm 1$ substates, in agreement with the conclusions of the $^{16}O(^7Li, t)^{20}Ne$ study of Ref. 7.

C. $^{19}F(\alpha,p\gamma)^{22}Ne$ angular correlation measurements

The results of the $^{19}F(\alpha, p\gamma)^{22}Ne$ angular correlation measurements are summarized in Table IV and Fig. 4. A discussion of individual states follows.

5.33-5.36 MeV doublet. The J^π of these states have been established previously as 1^+[9] and 2^+[10], respectively. The motivation for studying them in the present work was to obtain accurate branching ratios for the two states separately for use in the analysis of the angular correlations of the 7.34 MeV state. In addition, the mixing ratio of the 5.36 → 1.27 MeV transition was determined to be 0.27 ± 0.08, in excellent agreement with the value of 0.25 ± 0.08 determined by Kutschera, Pelte, and Schrieder[8] from an analysis of angular correlation data from the unresolved 5.33 → 5.36 MeV doublet.

6.64-6.69 MeV doublet. Kutschera *et al.*,[8] who were unable to resolve the 6.64 and 6.69 MeV states, assigned $J = 1$ to the 6.64 MeV level from a decay mode from the doublet to the ground state, and concluded from the presence of a decay to the 3.36 MeV state that the 6.69 MeV state has $2 \le J \le 6$. The present study shows the reverse to be the case: The 6.69 MeV state decays strongly to the ^{22}Ne ground state, while the 6.64 MeV state decays to the 1.27 and 3.36 MeV states only. Spectra of the γ rays in coincidence with protons populating the 6.64 and 6.69 MeV levels are shown in Fig. 5. The angular correlation of the 6.69 → 0.0 MeV decay fixes $J = 1$; the requirement[11] that the 6.69 MeV state has natural parity implies $J^\pi = 1^-$. The 6.64 MeV state is observed[10] with an $l_n = 2$ stripping pattern in the $^{21}Ne(d, p)^{22}Ne$ reaction. The decay mode to the 3.36 MeV level then limits the spin and parity of the 6.64 MeV state to 2^+, 3^+, or 4^+. The 4^+ possibility is ruled out by the angular correlation of the 6.64 → 1.27 MeV transition.

6.82-6.86 MeV doublet. The 6.82 MeV state is known[11] to have natural parity and is populated via an $l_n = 0 + 2$ neutron transfer[10] in the $^{21}Ne(d, p)^{22}Ne$ reaction. This would appear to establish $J^\pi = 2^+$ for the 6.82 MeV state. However, Howard *et al.*[9] conclude that a γ decay to the ^{22}Ne ground state arises from the 6.82 MeV member of the unresolved 6.82-6.86 MeV doublet, and they assign

TABLE IV. Results of $^{19}F(\alpha, p\gamma)^{22}Ne$ angular correlation measurements.

State (MeV)	E_α (MeV)	Transition E_i	E_f	J_i^π	J_f^π	A_2/A_0	A_4/A_0	δ
5.36	15.0	5.36	1.27	2^+	2^+	0.05 ± 0.08	0.20 ± 0.11	0.27 ± 0.08
		1.27	0.0	2^+	0^+	0.30 ± 0.12	-0.10 ± 0.17	
6.64	15.0	6.64	1.27	2^+	2^+	-0.06 ± 0.07	0.09 ± 0.11	a
				3^+	2^+			-0.16 ± 0.04, >3.7
		6.64	3.36	2^+	4^+	0.02 ± 0.06	-0.17 ± 0.09	*E*2
				3^+	4^+			0.11 ± 0.04, >2.1
		3.36	1.27	4^+	2^+	0.41 ± 0.11	-0.17 ± 0.16	*E*2
6.69	15.0	6.69	0.0	1^-	0^+	-0.31 ± 0.08	-0.13 ± 0.13	
6.82	15.0	6.82	1.27	2^+	2^+	0.03 ± 0.04	-0.10 ± 0.06	0.32 ± 0.03, <−6.2
		6.82	4.46	2^+	2^+	0.37 ± 0.14	0.21 ± 0.21	$-3.7 \le \delta \le 0.47$
		4.46	1.27	2^+	2^+	0.28 ± 0.10	0.20 ± 0.14	-0.09 ± 0.02 [b]
6.86	15.0	6.86	0.0	1^+	0^+	-0.88 ± 0.11	-0.10 ± 0.19	
6.89	15.0	6.89	1.27	(0^+)	2^+	-0.06 ± 0.05	0.01 ± 0.07	
7.34	18.5	7.34	3.36	3^+	4^+	0.36 ± 0.09	0.11 ± 0.12	$0.16 \le \delta \le 3.8$
				4^+	4^+			$-1.8 \le \delta \le 0.5$
7.41	18.5	7.41	1.27	$1^-, 3^-$	2^+	0.00 ± 0.11	0.30 ± 0.16	
7.72	19.0	7.72	1.27	3^-	2^+	-0.33 ± 0.16	-0.03 ± 0.16	c
		7.72	4.46	3^-	2^+	-0.08 ± 0.04	0.07 ± 0.07	c
		4.46	1.27	2^+	2^+			
7.92	19.0	7.92	1.27	2^+	2^+	0.42 ± 0.08	-0.13 ± 0.11	0.0 ± 0.07
		1.27	0.0	2^+	0^+	0.13 ± 0.11	0.64 ± 0.16	

[a] $\delta < -3.5$, $0.09 \le \delta \le 1.2$, or $\delta > 1.9$.
[b] From Ref. 3.
[c] See Sec. IIA.

$J^\pi = 1^-$ to the 6.82 MeV state, in contradiction to the above result. We have established that the 6.86 MeV state rather than the 6.82 MeV state has a decay branch to the ^{22}Ne ground state, while the 6.82 MeV state decays to the 1.27 and 4.46 MeV states, thereby resolving the above contradiction. The angular correlation of the ground state decay establishes $J = 1$ for the 6.86 MeV state, which, when combined with the $l_n = 2$ transfer observed[10] in ^{21}Ne$(d,p)^{22}$Ne fixes $J^\pi = 1^+$. The angular correlations of the 6.82 → 1.27 and 6.82 → 4.46 MeV transitions are consistent with a $J^\pi = 2^+$ assignment.

6.89 MeV. It has been suggested[11] from the strongly forward peaked angular distribution observed in the ^{18}O(^{7}Li, t)^{22}Ne reaction that the 6.89 MeV state has $J^\pi = 0^+$. This state was observed to have a single decay mode to the 1.27 MeV level in ^{22}Ne. The angular correlations of both the 6.89 → 1.27 and 1.27 → 0.0 MeV transitions were isotropic within statistics, supporting the 0^+ assignment. Good fits to the angular correlations were also obtained for spin values of 1 and 2.

7.34 MeV. An allowed β decay[5] from the ^{22}F-(ground state) to the 7.34(I) MeV state in ^{22}Ne limits the J^π values of the latter state to $(3, 4, 5)^+$. This 7.34(I) MeV state was found to be moderately excited in the ^{19}F$(\alpha,p)^{22}$Ne reaction at 18.5 MeV, whereas the 7.34(II) MeV state observed in the ^{18}O(^{7}Li, t)^{22}Ne reaction was only weakly excited. In addition to the decay branch of the 7.34(I) MeV level to the 3.36 MeV (4^+) level reported in Ref. 5, we also observe a weaker branch to the 5.92 MeV (2^+) level, which rules out the 5^+ possibility and makes the 4^+ possibility rather unlikely, thereby lending considerable support to the 3^+ assignment proposed in Ref. 5. (Other weak branches are probably also present in the decay scheme; the branching ratios presented for this state in Fig. 4 were obtained by assuming that the branches to the 5.92 and 3.36 MeV levels sum to 100%.) The angular correlation of the 7.34 → 3.36 MeV transition yields acceptable fits for all three spin possibilities.

7.41 MeV. An $l_n = 1$ stripping pattern observed in the ^{21}Ne$(d,p)^{22}$Ne reaction[10] and known natural

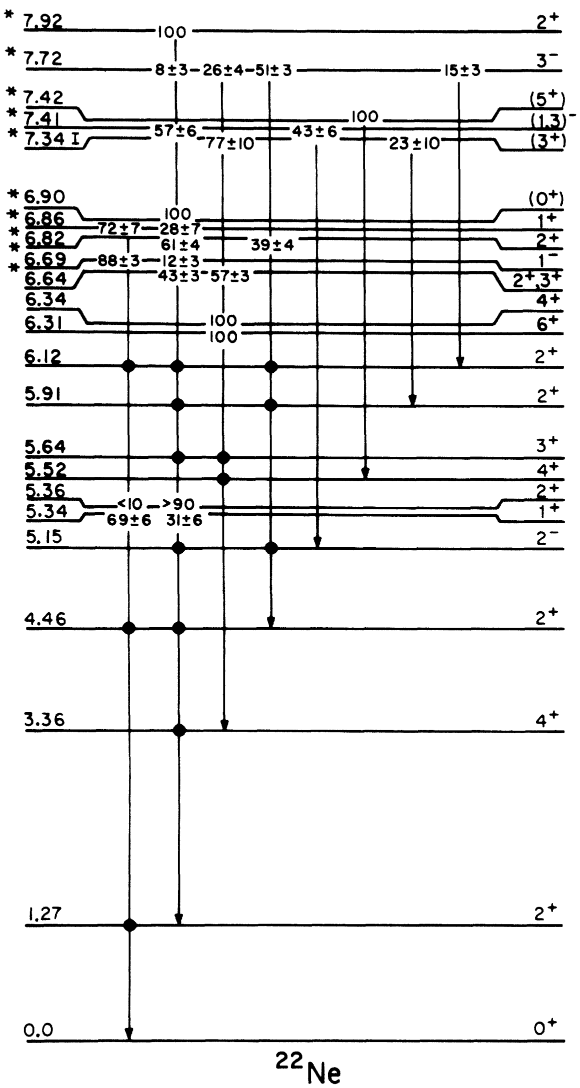

FIG. 4. Level diagram of ^{22}Ne summarizing the results of the ^{19}F$(\alpha,p\gamma)^{22}$Ne angular correlation measurements. States for which the present work has provided new information are marked with an asterisk.

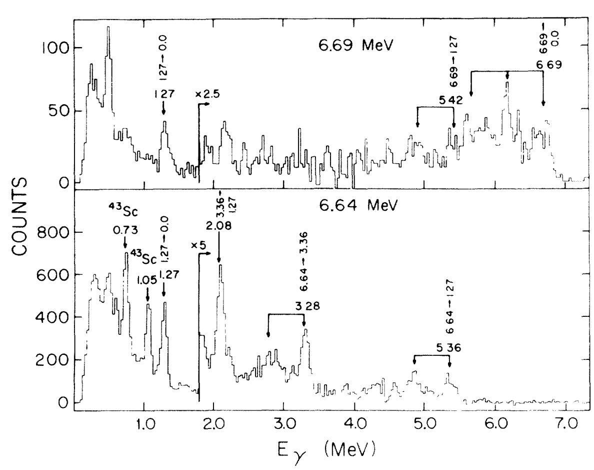

FIG. 5. Spectra of γ rays in coincidence with protons from the ^{19}F$(\alpha,p)^{22}$Ne reaction populating the 6.69 and 6.64 MeV levels in ^{22}Ne. The peaks are marked both with the γ-ray energy in MeV and with the transition in ^{22}Ne. The peaks labeled ^{43}Sc arise from the decay of the 1.93 MeV level in ^{43}Sc populated by the ^{40}Ca$(\alpha,p)^{43}$Sc reaction.

parity[11] limit the spin and parity of the 7.41 MeV level to $(1, 3)^-$. Decay modes to the 1.27 (2^+) and 5.14 (2^-) MeV states were observed in the present work. The angular correlations of the 7.41 → 1.27 MeV transition yielded acceptable fits consistent with a pure $E1$ transition for both spin possibilities. The primary decay to the 5.14 MeV state was obscured by γ rays from the 7.42 MeV (5^+) state which was weakly populated at the beam energy employed and was not resolved from the 7.41 MeV state in the proton spectrum.

7.92 MeV. The spin and parity of the 7.92 MeV level have previously been established[10,11] to be 2^+. A single decay mode to the 1.27 MeV level was observed in the present work, and an acceptable fit to the 7.92 → 1.27 and 1.27 → 0.0 MeV angular correlations was obtained for $J = 2$ only in agreement with the previous assignment.

IV. DISCUSSION

Apart from the distinctive ground state rotational band, the known energy levels of ^{22}Ne are more difficult to classify into rotational bands than are the levels of, say, ^{20}Ne or ^{24}Mg. Preedom and Wildenthal[2] have suggested two bands based on excited states in ^{22}Ne from the results of their shell model calculations, one built on the 4.46 MeV (2^+) state, the other on the 4^+ state at 5.52 MeV. Their classification of states into these bands is based on strongly enhanced intraband transitions and on an approximate $J(J+1)$ energy dependence, and is shown schematically in Fig. 6. In contrast, earlier shell-model calculations[16] assigned the 4.46 and 5.52 MeV levels to the same band on the basis of a calculated 8.1 W.u. (Weisskopf units) $E2$ transition between the two levels. Support for this latter classification is provided by recent SU(3) shell-model calculations[17] using the Preedom and Wildenthal interaction.[2] The wave functions for each of the 4.46 (2_2^+), 5.64 (3_1^+), 5.52 (4_2^+), and 7.42 (5_1^+) MeV states were found to contain more than 65% in intensity of the (82) representation of SU(3) belonging to the [42] spatial symmetry, and these states may therefore be considered to be members of the $K^\pi = 2^+$ band expected from the (82) representation. On the other hand, the (63) representation of SU(3) predominates in the wave functions of the 6.34 (4_3^+) MeV and 5_2^+ levels. (The latter state has not yet been identified experimentally.)

With the exception of the 7.42 (5_1^+) → 5.52 (4_2^+) MeV transition, the intraband $E2$ transitions have not been observed, as $E2$ transitions of the strength predicted by the shell-model calculations[2] cannot compete with higher energy $M1$ transitions. The lifetime of the 7.42 MeV state, which decays exclusively to the 5.52 MeV state, has been determined in the present work, but until the $E2/M1$ mixing ratio of this transition has been measured, no comparison between predicted and experimental $B(E2)$'s is possible. The near degeneracy of three members of the cascade from this state makes them difficult to resolve in a NaI(Tl) crystal, and an angular correlation measurement employing a Ge(Li) detector would probably be required. An upper limit on the $B(M1)$ of the 7.42 → 5.52 MeV transition can be obtained from the lifetime of the 7.42 MeV state; the result, $B(M1) \leq 0.18\mu_N^2$, is considerably smaller than the shell-model prediction[2] of $0.64\mu_N^2$.

The higher members of the two bands proposed by Preedom and Wildenthal[2] have not yet been observed experimentally, and the observation of these states together with measurement of their transition rates would provide a more stringent

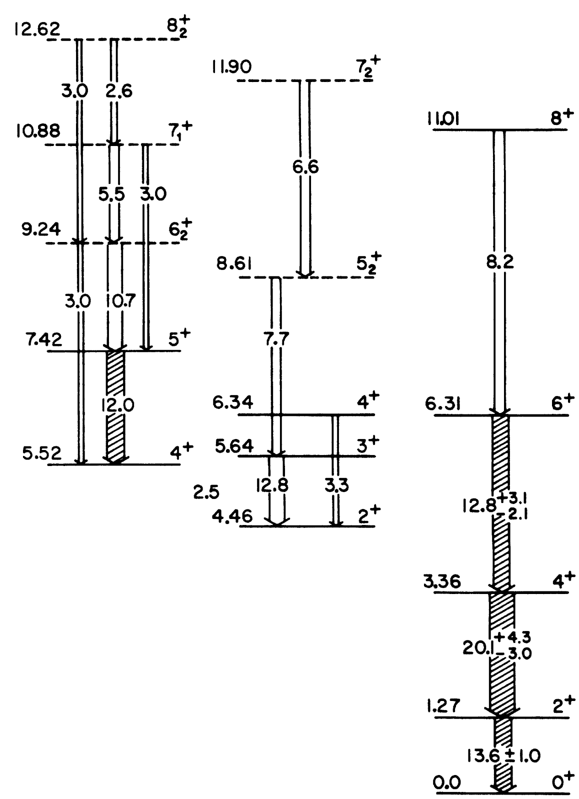

FIG. 6. Partial level diagram of ^{22}Ne showing the rotational bands proposed by Preedom and Wildenthal (Ref. 2). States denoted by a solid line and transitions indicated by shaded arrows have been observed experimentally, whereas states denoted by dashed lines and transitions indicated by unshaded arrows have been taken from the calculations of Preedom and Wildenthal. Only $E2$ transition rates are shown, and the strengths are presented in Weisskopf units. The measured transition rates were taken from Refs. 3 and 4.

TABLE V. Electromagnetic transition strengths in ^{22}Ne.

E_i (MeV)	E_f (MeV)	τ_i (fs)	Branch (%)	J_i^π	J_f^π	$\lvert\delta\rvert$	$B(M1)_{exp}$ (μ_N^2)	$B(M1)_{th}$ [a] (μ_N^2)	$B(E2)_{exp}$ (e^2fm^4)	$B(E2)_{th}$ [a] (e^2fm^4)
4.46	1.27	<40	97 ± 2	2^+	2^+	0.09 ± 0.02 [b]	>0.04	0.30	>0.3	1.4
5.36	1.27	<30	100	2^+	2^+	0.27 ± 0.08	>0.03	0.014	>2.6	5.2
5.52	3.36	<50	100	4^+	4^+	0.07 ± 0.12 [c]	>0.11			
5.63	3.36	<60	23 ± 3	3^+	4^+	0.12 ± 0.17 [c]	>0.06	0.09		0.79
						5 ± 3	$>1.3 \pm 10^{-3}$		>142	
5.63	1.27		77 ± 3	3^+	2^+	0.18 ± 0.03 [c]	$>2.8 \times 10^{-3}$	0.04	>0.05	2.2
5.91	1.27	51 ± 23	85 ± 5	2^+	2^+	0.47 ± 0.04 [c]	$0.0008^{+0.007}_{-0.003}$	0.20	$1.1^{+0.9}_{-0.4}$	0.34
6.64	3.36	69 ± 20	57 ± 3	2^+	4^+	$E2$			$17.8^{+7.3}_{-4.0}$	
				3^+	4^+	0.11 ± 0.04	$0.013^{+0.006}_{-0.003}$		$0.25^{+0.22}_{-0.15}$	
6.64	1.27		43 ± 3	2^+	2^+	0.39 ± 0.08 [d]	$2.0^{+0.8}_{-0.5} \times 10^{-3}$		$0.15^{+0.06}_{-0.04}$	
						$E2$ [d]			$1.1^{+0.5}_{-0.3}$	
				3^+	2^+	0.16 ± 0.04	$2.2^{+0.8}_{-0.5} \times 10^{-3}$		$0.03^{+0.02}_{-0.01}$	
7.41	5.14	91^{+46}_{-38}	43 ± 6	$1^-, 3^-$	2^-		<0.05			
7.41	1.27		57 ± 6	$1^-, 3^-$	2^+	$E1$	$1.7^{+1.3}_{-0.6} \times 10^{-5}$			
7.42	5.52	68 ± 21		5^+	4^+		<0.18	0.64		44

[a] From calculations of Preedom and Wildenthal (Ref. 2).
[b] See Ref. 3.
[c] See Ref. 8.
[d] From simultaneous fit to three transitions listed in Table IV.

test of the shell-model calculations than is possible at present.

Of the other positive parity states predicted by Preedom and Wildenthal[2] and not placed in rotational bands, information on only two is provided by the present work. the 2_4 model state is predicted to lie at 6.05 MeV, and the known 2^+ states at 5.92 and 6.12 MeV would be possible candidates. The measurement of the lifetime of the 5.92 MeV level in the present work, together with the known mixing ratio of the 5.92 → 1.27 MeV transition allows the determination of both the $B(M1)$ ($0.008\mu_N^2$) and $B(E2)$ (1.40 e^2fm^4) of this transition. These are to be compared with the predicted values for the $2_4 \rightarrow 2_1$ transition of $0.2\mu_N^2$ and 0.34 e^2fm^4, respectively, from which we may conclude that the 5.92 MeV state is probably not to be identified with the 2_4 shell-model state.

The other positive parity state on which we have new information is the state at 6.64 MeV ($J^\pi = 2^+, 3^+$). It is interesting to speculate that this state may be the 3_3 model state predicted[2] at 7.40 MeV. Although the discrepancy between predicted and observed energies is large, it should be noted that the 3_2 state predicted at 6.30 MeV actually appears to be at 7.34 MeV.[5] The measured lifetime of the 6.64 MeV state lends some support to a 3^+ assignment, for if $J^\pi = 2^+$, the $B(E2)$ of the 6.64 → 3.36 MeV transition has the rather large value of 18 e^2fm^4 (5 W.u.), whereas if $J^\pi = 3^+$ this transition is probably mostly $M1$. The nonobservation of this state in the ^{22}F β-decay study, even though it would be fed by an allowed transition if $J^\pi = 3^+$, could be attributed to the large logft value of 7.08 predicted[2] for such a transition. For comparison, the logft of the allowed β decay to the nearby 6.34 MeV state is 5.36, whence the relative intensities of the 6.34 → 3.36 MeV transitions would be approximately in the ratio of 100:1 if the 6.64 MeV state were the 3_3 model state. Such a weak transition probably could not have been observed in the ^{22}F β-decay experiment of Davids *et al.*[5]

†Work supported by the National Science Foundation.
*Present address: Nuclear Physics Laboratory, Oxford, England.
‡Present address: Physics Division, Argonne National Laboratory, Argonne, Illinois 60439.
[1]W. Scholz, P. Neogy, K. Bethge, and R. Middleton, Phys. Rev. C 6, 893 (1972).
[2]B. M. Preedom and B. H. Wildenthal, Phys. Rev. C 6, 1633 (1972).
[3]P. M. Endt and C. van der Leun, Nucl. Phys. A214, 1 (1973).
[4]L. K. Fifield, R. W. Zurmühle, and D. P. Balamuth, Phys. Rev. C 10, 1785 (1974).
[5]C. N. Davids, D. R. Goosman, D. E. Alburger, A. Gallmann, G. Guillaume, D. H. Wilkinson, and W. A. Lanford, Phys. Rev. C 9, 216 (1974).

[6]R. Middleton, in *Proceedings of the Fifth International Conference on Nuclear Reactions Induced by Heavy Ions, Heidelberg, Germany,* edited by R. Bock and W. R. Hering (North-Holland, Amsterdam, 1970), p. 263.

[7]D. P. Balamuth, Phys. Rev. C 3, 1565 (1971).

[8]W. Kutschera, D. Pelte, and G. Schrieder, Nucl. Phys. A111, 529 (1968).

[9]A. J. Howard, R. G. Hirko, D. A. Bromley, K. Bethge, and J. W. Olness, Nuovo Cimento 11A, 575 (1972).

[10]P. Neogy, R. Middleton, and W. Scholz, Phys. Rev. C 6, 885 (1972).

[11]R. W. Ollerhead, G. F. R. Allen, A. M. Baxter, B. W. J. Gillespie, and J. A. Kuehner, Can. J. Phys. 49, 594 (1971).

[12]R. W. Zurmühle, P. F. Hinrichsen, C. M. Fou, C. R. Gould, and G. P. Anastassiou, Nucl. Instrum. 71, 311 (1969).

[13]D. J. Church (unpublished).

[14]S. Hinds, H. Marchant, and R. Middleton, as quoted in Ref. 3.

[15]E. R. Flynn, O. Hansen, and O. Nathan, Nucl. Phys. A228, 189 (1975).

[16]E. C. Halbert, J. B. McGrory, B. H. Wildenthal, and S. P. Pandya, in *Advances in Nuclear Physics,* edited by M. Baranger and E. Vogt (Plenum, New York, 1970), Vol. 4.

[17]A. A. Pilt and D. J. Millener (private communication).

[18]J. C. Merdinger, E. Bozek, C. Gehringer, and Z. Stachura, Phys. Lett. 59B, 38 (1975).