Comment on Rotational Bands in ^{19}F†

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A recent suggestion that the 4.385-MeV $\frac{7}{2}^+$ state in ^{19}F is in the ground-state rotational band and that the 5.473-MeV $\frac{7}{2}^+$ state is in an excited band appears to be contradicted by γ-decay data and by data from the $^{16}O(^6Li, ^3He)^{19}F$ reaction – both of which assign the 5.473-MeV state to the ground-state band.

Recently, Dixon *et al.*,[1] assigned $J^\pi = \frac{9}{2}^+$ to a state at $E_x = 6592$ keV in ^{19}F, and $J = \frac{11}{2}$ (parity uncertain) to a state at $E_x = 7937$ keV. They then used these assignments, together with the known[2] assignment of $\frac{7}{2}^+$ for the state at 5464 keV to suggest that states at 3907 keV ($\frac{3}{2}^+$), 4549 keV ($\frac{5}{2}^+$), 5464 keV ($\frac{7}{2}^+$), 6592 keV ($\frac{9}{2}^+$), and 7937 keV ($\frac{11}{2}$) form a $K^\pi = \frac{3}{2}^+$ rotational band. There are no observed $E2$ transitions connecting these states,[1] but very strong $E2$'s could be present without being detected. (A 20 W.u. in-band $E2$ would correspond[1] to less than a 1% decay branch for these states.) The principal evidence[1] that these states form a band is that their excitation energies lie on a straight line when plotted as a function of $J(J+1)$. The identification of these states as members of an excited $\frac{3}{2}^+$ rotational band appears to contradict existing γ-decay data,[3] as well as information on three-particle transfer.[4] We review the situation below and then present evidence which suggests a different band assignment.

The available information is as follows:

(1) The 5464-keV $\frac{7}{2}^+$ state decays[3] to the $\frac{3}{2}^+$ state at 1554 keV with a strongly enhanced $E2$ [$B(E2) = 41 \pm 21\ e^2\,\mathrm{fm}^4$]. This large $B(E2)$ is suggestive of an in-band transition. The fact that the 1554-keV state is in the ground-state band is then strong evidence that the 5464-keV state is also a member of the ground-state band.

(2) The configuration of the states in the ground-state band is largely[5,6] $(sd)^3$. The configuration of the $\frac{3}{2}^+$ state at 3907 keV is most likely[7,8] $(sd)^7(1p)^{-4}$ or $(sd)^5(1p)^{-2}$. Recent shell-model calculations[6] of ^{19}F which include a full *sd* shell basis and an inert ^{16}O core predict two low-lying $\frac{7}{2}^+$ states, but only one low-lying $\frac{3}{2}^+$ state. Thus, both the low-lying $\frac{7}{2}^+$ states (at 4378 and 5464 keV) can be accounted for as $(sd)^3$ states, whereas the $\frac{3}{2}^+$ state at 3907 keV cannot be. Calculations[7] that assume a ^{12}C core, however, do reproduce this second $\frac{3}{2}^+$ state, and suggest a 7p-4h or 5p-2h configuration for it. This would put the $\frac{3}{2}^+$ 3907-keV state in a band different from both of the low-lying $\frac{7}{2}^+$ states.

(3) The large $B(E2)$ observed for the 5464-keV $\frac{7}{2}^+$ decay to the first $\frac{3}{2}^+$ state is accounted for by the $(sd)^3$ calculations.[6] The calculated $B(E2)$ value is $18.4\ e^2\,\mathrm{fm}^4$. The $B(E2)$ for the decay of the other low-lying $\frac{7}{2}^+$ state to the first $\frac{3}{2}^+$ state is calculated[6] to be small.

(4) In a recent study[4] of the $^{16}O(^6Li, ^3He)^{19}F$ reaction, the $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, $\frac{9}{2}^+$, and $\frac{13}{2}^+$ members of the ground-state band (all of whose identifications now appear firm) were strongly populated relative to other states of the same J^π. Furthermore, the $\frac{7}{2}^+$ state at 5464 keV was a factor of 10 stronger than the $\frac{7}{2}^+$ state at 4378 keV – again suggesting that the 5464-keV state is the $\frac{7}{2}^+$ member of the ground-state band.

Distorted-wave calculations have now been carried out for the $^{16}O(^6Li, ^3He)^{19}F$ reaction to all these low-lying positive-parity states. The details of the distorted-wave analysis and the results for the ground-state band have already been presented.[9] Those results are summarized in Table I. Results are also presented for the lowest state of each $J^\pi = \frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+, \frac{7}{2}^+$ that does not belong to the ground-state band. It can be seen that the ratio of experimental to theoretical cross section is roughly constant for the $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{9}{2}^+$ members of the ground-state band. This is to be expected, since these states can be reasonably well represented as different J projections from a single intrinsic state of $(sd)^3$ configuration.[5,10] In a simple picture of the $^{16}O(^6Li, ^3He)^{19}F$ reaction on an inert ^{16}O core, these are the only states in ^{19}F that should be populated. In that simple picture, other states would be populated only through 2p-2h and 4p-4h admixtures in the ^{16}O ground-state wave function. The ratio $\sigma_{\mathrm{exp}}/\sigma_{\mathrm{DW}}$ for states not within the ground-state band is significantly smaller than for states within the ground-state band, usually by an order of magnitude. Thus, the observed spectroscopic strengths for the $\frac{7}{2}^+$ states, 0.27 for the 5.47-MeV state and 0.030 for

TABLE I. Comparison of cross sections in the $^{16}O(^{6}Li, ^{3}He)^{19}F$ reaction leading to states within and outside of the ground-state rotational band.

J^{π}	Ground-state band members E_x (MeV)	σ_{max} (mb/sr)	σ_{exp}/σ_{DW}	Ground-state band nonmembers E_x (MeV)	σ_{max} (mb/sr)	σ_{exp}/σ_{DW}	$\sigma_{exp}/\sigma_{DWBA}$ (for ground-state band nonmember) / $\sigma_{exp}/\sigma_{DWBA}$ (for ground-state band member)
$\frac{1}{2}^+$	0.00	0.106	0.35	5.34 [a,b]	≲0.005 [b]	≲0.030	≲0.085
$\frac{3}{2}^+$	1.56	0.279	0.38	3.92	0.012	0.025	0.067
$\frac{5}{2}^+$	0.20	0.682	0.33	4.55 [c,d]	≲0.059 [d]	≲0.063	≲0.19
$\frac{7}{2}^+$	5.47	0.318 [e]	0.27	4.39	0.037	0.030	0.11
$\frac{9}{2}^+$	2.78	1.16	0.32				

[a] J^{π} has not yet unambiguously been assigned for 5.34-MeV state.
[b] The 5.34-MeV state is a member of a probable doublet. The combined cross section for the two members of the doublet is given.
[c] The parity of 4.55-MeV state is not yet completely unambiguous.
[d] The 4.55- and 4.56-MeV states are not completely resolved. The cross section given is for both states.
[e] Further work on the $^{16}O(^{6}Li, ^{3}He)^{19}F$ reaction reveals that of the 0.347 mb/sr listed for the 5.47-MeV state in Ref. 4, 0.029 mb/sr arises from the 5.49-MeV state.

the 4.39-MeV state, appear to present a strong argument for placing the 5.47-MeV state in the ground-state band. It is observed, however, that the strength of the 5.47-MeV state is somewhat smaller than the strengths of the other members of the ground-state band. This result would indicate more mixing between the $\frac{7}{2}^+$ states than for states of other J^{π}. This is consistent with theoretical expectations.[5,8,10]

These results, coupled with the lifetime measurements,[3] then lead to the conclusion that the 5.47-MeV state (and not the 4.39-MeV state) is to be identified with the $\frac{7}{2}^+$ member of the ground-state band.

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