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Spin Assignment for the F^{18} 1.131-MeV Level*

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Recent γ-ray angular-distribution results obtained by Poletti and Fossan using the differential-time-delay technique in the $O^{16}(He^3,p\gamma)F^{18}$ reaction are analyzed to show that the F^{18} 1.131-MeV level has $J=5$. Other evidence fixes its parity as even.

INTRODUCTION

RECENTLY, Poletti and Fossan[1] measured the magnetic moment of the F^{18} 1.131-MeV level using the differential-time-delay technique. They used the $O^{16}(He^3,p)F^{18}$ reaction to form the state and selected the γ rays from its decay by observing them in coincidence with the protons populating the 1.131-MeV level. These were detected in an annular counter centered at 180° to the incident beam. As an incidental outcome of the magnetic-moment measurement, Poletti and Fossan obtained the angular distributions, relative to the beam axis, of the two γ rays in the cascade F^{18} $1.131\rightarrow 0.937\rightarrow 0$. The angular distributions they obtained are characterized[1] by Legendre-polynomial coefficients: $A_2=+(0.30\pm0.02)$, $A_4=-(0.15\pm0.02)$ for the 0.937-MeV γ ray, and $A_2=+(0.27\pm0.02)$, $A_4=-(0.13\pm0.02)$ for the 0.194-MeV γ ray corresponding to the $1.131\rightarrow 0.937$ transition. These coefficients describe the angular distribution,

$$W(\Theta)=I_\gamma[1+A_2P_2(\cos\Theta)+A_4P_4(\cos\Theta)].$$

They have been corrected for the finite size of the γ-ray detector.

Poletti and Fossan pointed out that the γ-ray angular distributions, and thus the coefficients quoted above, are almost certainly attenuated due to the long lifetime of the 1.131-MeV level. For this reason they did not attempt to analyze these angular distributions to obtain information on the spin of the F^{18} 1.131-MeV level. It is the purpose of the present paper to point out that their results determine the spin of the 1.131-MeV level independently of the degree of this attenuation.

ANALYSIS OF THE ANGULAR DISTRIBUTIONS

The F^{18} ground state and 0.937-MeV level have $J^\pi=1^+$ and 3^+, respectively, and are connected by an $E2$ transition with negligible $M3$ contribution.[2] The nonzero terms in $P_4(\cos\Theta)$ for both members of the cascade, $1.131\rightarrow 0.937\rightarrow 0$, demand that the 1.131-MeV level has $J\geqslant 2$.[1] The lifetime[1] of the 1.131-MeV level would correspond to strengths for the $1.131\rightarrow 0.937$ transition of 3.8×10^7 and 8.8×10^8 Weisskopf units[3] if the transition were pure $E3$ or $M3$, respectively. Since these are completely unreasonable, the 1.131-MeV level has $J\leqslant 5$, and we have $J=2$, 3, 4, or 5 for this level. As was pointed out by Poletti and Fossan, the angular distributions they obtained are consistent with $J=5$ for the 1.131-MeV level and pure $E2$ for the $1.131\rightarrow 0.937$ transition. It will now be shown that the angular distributions are not consistent with $J=2$, 3, or 4 so that the 1.131-MeV level has $J=5$.

The basis of the method of analysis to be presented here is that, no matter how the angular distributions are attenuated, the attenuation for the 0.194- and 0.937-MeV γ rays will be the same. This follows from the fact that the attenuation is due almost totally to the long mean life, 225 ± 8 nsec,[1] of the 1.131-MeV level. Any further attenuation of the $0.937\rightarrow 0$ distribution due to the finite lifetime of the 0.937-MeV level, which has[4] $\tau=(6.8\pm0.7)\times10^{-11}$ sec, will be negligible. Thus, we can write the angular-distribution coefficients in the following way:

$$\begin{aligned}A_k(1)&=\rho_k(J_1)F_k(J_1J_2)Q_k,\\A_k(2)&=\rho_k(J_1)U_k(J_1J_2)F_k(J_2J_3)Q_k.\end{aligned}\tag{1}$$

$A_k(1)$ and $A_k(2)$ correspond to the $1.131\rightarrow 0.937$ and $0.937\rightarrow 0$ transitions, respectively, and Q_k describes the average attenuation of A_k due to environmental effects on the excited F^{18} nuclei. Note that Q_2 and Q_4 are not necessarily the same.

In Eq. (1), J_1, J_2, and J_3 refer to the spins of the 1.131-, 0.937-, and 0-MeV levels of F^{18}, respectively; $\rho_k(J_1)$ is the statistical tensor describing the alignment of the initial state J_1; and the F_k and U_k describe the γ-ray transitions in the notation of Poletti and Warburton.[2] Taking the ratio of the two parts of Eq. (1) we have

$$A_k(1)/A_k(2)=F_k(J_1J_2)/U_k(J_1J_2)F_k(J_2J_3).\tag{2}$$

For $J_1=2$, 3, or 4 the $1.131\rightarrow 0.937$ transition is a dipole-quadrupole mixture since the measured lifetime is incompatible with a significant contribution of octupole radiation. Defining x as the amplitude ratio

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[1] A. R. Poletti and D. B. Fossan, Phys. Rev. **160**, 883 (1967).

[2] A. R. Poletti and E. K. Warburton, Phys. Rev. **137**, B595 (1965).

[3] D. H. Wilkinson, in *Nuclear Spectroscopy*, edited by F. Ajzenberg-Selove (Academic Press Inc., New York, 1960), Part B, p. 862 ff.

[4] T. K. Alexander, K. W. Allen, and D. C. Healey, Phys. Letters **20**, 402 (1966).

of *dipole to quadrupole* components, we have

$$\frac{A_k(1)}{A_k(2)}=\frac{F_k(223J_1)-2F_k(213J_1)x+F_k(113J_1)x^2}{[U_k(2J_13)+U_k(1J_13)x^2]F_k(2213)}, \quad (3)$$

where the $F_k(LL'J_2J_1)$ and $U_k(LJ_1J_2)$ are numerical constants defined and tabulated by Poletti and Warburton.[2] Equation (3) is a function of x only, for J_1 given. Plots of Eq. (3) for $J_1=2$, 3, and 4 and $k=2$ and 4 are shown in Figs. 1, 2, and 3 together with the values obtained by Poletti and Fossan for the ratios $A_2(1)/A_2(2)$ and $A_4(1)/A_4(2)$. It is seen that for all three spin values there is no value of x for which Eq. (3) has a solution for $k=2$ and 4 simultaneously. Thus, these spin values are excluded and the F^{18} 1.131-MeV level has $J=5$.

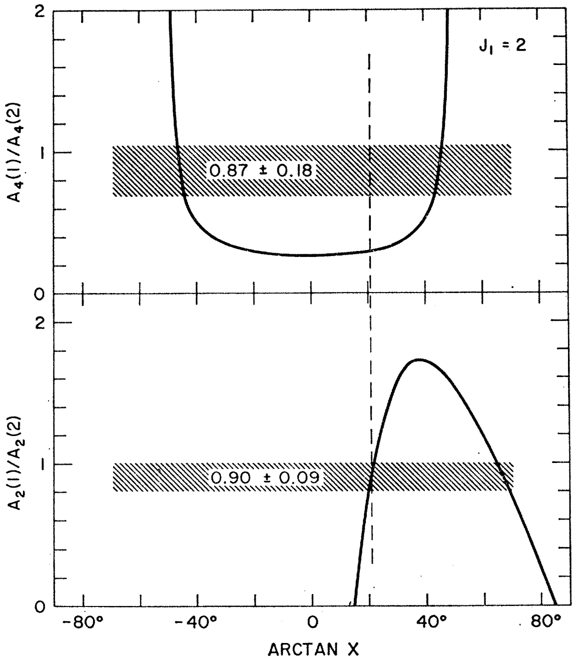

FIG. 1. The ratios $A_2(1)/A_2(2)$ and $A_4(1)/A_4(2)$ defined by Eq. (3) with $J_1=2$. The dipole-quadrupole mixing ratio x varies from $-\infty$ to 0 to $+\infty$ as arctan x varies from $-90°$ to 0° to $+90°$. Note that x is the reciprocal of the mixing ratio which is conventionally used. The $A_k(1)/A_k(2)$ determined by Poletti and Fossan (Ref. 1) are also shown.

CONCLUSIONS

If the 1.131 → 0.937 transition were $M2$, its strength would be 103 Weisskopf units.[3] This is completely unreasonable, so that this transition must be $E2$ and the 1.131-MeV level has even parity. Assuming 100 Weisskopf units as the strongest possible $M3$ transition, and using the measured lifetime[1] of the 1.131-MeV level, a limit on the amplitude ratio of $M3$ to $E2$ radiation in the $1.131\rightarrow0.937$ transition of $|x|<3.4\times10^{-4}$ is obtained. Therefore, this transition as well as the $0.937\rightarrow0$ transition[2] is essentially pure $E2$. Thus, the $1.131\rightarrow0.937\rightarrow0$ cascade satisfies the conditions for a monotonic sequence,[5] and the angular distributions

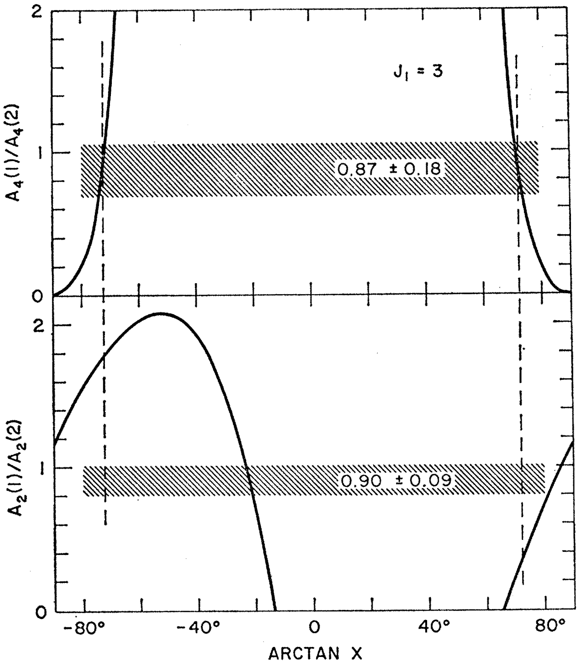

FIG. 2. The $A_k(1)/A_k(2)$ ratios defined by Eq. (3) with $J_1=3$. See the caption of Fig. 1 for further details.

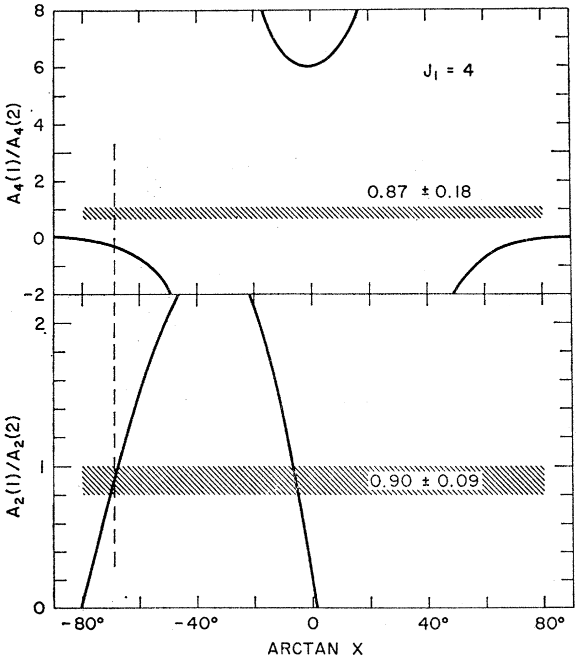

FIG. 3. The $A_k(1)/A_k(2)$ ratios for $J_1=4$. See the caption of Fig. 1 for further details.

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[5] J. Weneser and D. R. Hamilton, Phys. Rev. **92**, 321 (1953); S. Raboy and V. E. Krohn, *ibid.* **98**, 24 (1955).

of the two members of the cascade must be identical. This is in agreement with experiment.[1]

In summary, the F^{18} 1.131-MeV level has $J^\pi=5^+$ and decays by $E2$ emission to the 0.937-MeV level. It has a mean lifetime[1] of 225±8 nsec, which corresponds to an $E2$ strength of 4.62±0.16 Weisskopf units. These properties have recently been discussed by Poletti and Fossan.[1]

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Determination and Distorted-Wave Born-Approximation Analysis of the Neutron Polarization in the $C^{12}(He^3,n)O^{14}$ Reaction*

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Nine angular distributions of the neutron polarization produced in the $C^{12}(He^3,n)O^{14}$ (ground-state) reaction were determined for He^3 energies from 2.24 to 3.70 MeV. High polarizations were found at all energies, the extreme values being −0.87 at 2.39 MeV and 50°, and +0.72 at 3.70 MeV and 40°. Below 3.2 MeV, the neutron yield at 0° and the differential cross sections exhibit compound-nuclear effects. Above this energy, the 0° yield curve is structureless, and the cross section shows pronounced $l=0$, diproton stripping patterns. Also, the three polarization distributions between 3.30 and 3.70 MeV are similar. An attempt was made to fit the 3.70-MeV (He^3,n) cross section and neutron polarization distributions with a distorted-wave Born-approximation (DWBA) analysis. Prior to this analysis, He^3 elastic-scattering data were obtained over the region from 3.6 to 3.8 MeV, and optical-model parameters for the incident channel were extracted. Considering the possible compound-nuclear effects which were neglected in the fitting procedure, reasonable results were achieved with the DWBA code. One striking result was that the predicted polarization is insensitive to the He^3 spin-orbit strength.

I. INTRODUCTION

RECENTLY, (He^3,n) reactions have been studied with considerable interest, since such reactions lead to levels of proton-rich nuclei which otherwise are difficult to populate. In order to examine the reaction mechanisms involved, polarization measurements, in conjunction with differential cross-section data, are particularly useful. Angular distributions of the outgoing neutron polarization, determined for several incident He^3 energies, help establish the importance of compound nucleus and direct-reaction contributions. If the reaction proceeds via double stripping, the transferred diproton has predominantly an intrinsic spin $S=0$. The same feature applies to a (t,p) double-stripping reaction, where a dineutron is transferred. On the other hand, in (He^3,p) reactions the transfer of a neutron-proton cluster is complicated by the fact that neither $S=0$ nor $S=1$ is strongly preferred. The treatment of (He^3,n) or (t,p) polarization data also has certain theoretical advantages compared to deuteron stripping polarizations, where an incoming particle of spin 1 and the D-state admixture to the deuteron wave function have to be taken into account. Although a large number of (d,n) and (d,p) polarization measurements have been performed,[1,2] no (He^3,n) or (t,p) polarization determinations have been reported to date. In fact, the only reported polarization measurements for two-nucleon transfer reactions are the (He^3,p) proton polarization measurements by Simons *et al.*[3] The scarcity of (He^3,n) and (He^3,p) polarization data is partly due to the low cross section of these reactions and partly due to the emphasis previously given to single-nucleon stripping studies.

The present paper reports the measurement of nine angular distributions of the neutron polarization for the $C^{12}(He^3,n)O^{14}$ [ground state (g.s.)] reaction in the He^3

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[1] W. Haeberli, in *Proceedings of the Conference on Direct Interactions and Nuclear Reaction Mechanisms, Padua, 1962*, edited by E. Clementel and C. Villi (Gordan and Breach Science Publishers, Inc., New York, 1963), p. 580.

[2] D. W. Miller, in *Proceedings of the Second International Symposium on Polarization Phenomena of Nucleons* (Birkhäuser Verlag, Basel and Stuttgart, 1966), p. 410.

[3] D. G. Simons and R. Detenbeck, Phys. Rev. **137**, B1471 (1965); D. G. Simons, Bull. Am. Phys. Soc. **11**, 301 (1966).