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Polarization Measurements of the Gamma-Ray Transitions from the 1.459-MeV Level in ^{19}F

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Linear-polarization and angular-distribution measurements have been made on the three transitions from the 1.459-MeV level in ^{19}F using inelastic proton scattering. The mixing ratios were determined to be $-0.1<\delta_{M2/E1}<0.0$ for the $1.459\rightarrow0.197$-MeV transition, $0.30<\delta_{E2/M1}<0.38$ for the $1.459\rightarrow0.110$-MeV transition, and $|\delta_{M2/E1}|<0.06$ for the $1.459\rightarrow0$-MeV transition. The results indicate that the level in question cannot be explained as a $p_{1/2}$ proton hole coupled to the pure ground-state rotational band as has been accepted in the past.

I. INTRODUCTION

The nucleus ^{19}F has been the subject of several recent theoretical[1-4] and experimental[5-8] investigations, and the detailed properties of the low-lying states of this nucleus are now fairly well understood. In particular, Benson and Flowers[1] successfully explained the low-lying positive-parity levels in ^{19}F by shell-model calculations as three nucleons coupled to an ^{16}O core, and the authors attempted further to explain the negative-parity levels as a $p_{1/2}$ proton hole coupled to the ground-state rotational band in ^{20}Ne.

The crucial test for this "one-band" model for the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states in ^{19}F comes from the observation that the $E2$ strength for the transitions $1.459\rightarrow0.110$ and $1.346\rightarrow0.110$ MeV in ^{19}F should be the same as the $1.630\rightarrow0$-MeV transition in ^{20}Ne if the odd-parity states in ^{19}F indeed arise from the coupling of a proton hole to the ground-state rotational band of ^{20}Ne. The $E2$ strength of the transitions can be obtained by measurement of the mixing ratio and the lifetime of the states.

The mixing ratio in question can be determined by a linear polarization measurement of the γ ray. Such a measurement is difficult, however, because of the background from three other γ rays of nearly equal energy. As soon as a polarimeter based on germanium detectors became available, Lam, Litherland, and Simpson[8] were able to resolve the γ rays and measure the mixing ratios, but their single-crystal polarimeter did not have a large enough asymmetry ratio to prove or disprove the prediction of Benson and Flowers. Recently in our laboratory, a polarimeter constructed with two planar germanium detectors has been built. This polarimeter has an improved asymmetry ratio which is suitable for an experi-

TABLE I. Branching ratios for the γ-ray transitions from the 1.459-MeV level in ^{19}F from this work and previous work.

Energy (keV)	Transition (keV)	Branching (this work) (%)	Branching (previous) (%)
1236	1346→110	···	···
1262	1459→197	10.2±1	11 ±0.5 [a] 10.9±2 [b]
1349	1459→110	69.7±1	68 ±3 [a] 66.6±3 [a]
1459	1459→0	20.0±1	21 ±1 [a] 22.5±2 [b]

[a] Reference 8. [b] Reference 7.

ment to resolve this question.[9]

II. EXPERIMENTAL METHODS

In the present experiment the angular distribution and linear polarization of the γ radiation deexciting the 1.459-MeV state were measured. These two measurements determine both the statistical tensor describing the orientation of the γ-emitting state and the mixing ratios of the γ radiation.[10]

The polarimeter consisted of two planar detectors, each with dimensions $25\times13\times10$ mm^3 and separated by 5.7 mm. A description of the polarimeter used in this experiment and its calibration procedure has been given elsewhere.[9] The polarimeter was placed approximately 10 cm from the target, at an angle of 90° with respect to the beam direction.

The reaction $^{19}F(p, p'\gamma)^{19}F^*$ was used in the experiment. A 3-μA proton beam at 2.78 MeV bombarded a 70-$\mu g/cm^2$-thick CaF_2 target. The angular distribution was measured with a 32-cc GeLi detector with 3-keV resolution, and a third GeLi detector served as a monitor.

III. EXPERIMENTAL RESULTS

Table I is a list of the γ rays studied with their measured branching ratios, and those obtained by previous workers. As can be seen, they are in excellent agreement with those of the other workers. Figure 1 shows a typical pulse-height spectrum taken by the 32-cc GeLi detector with the γ transitions indicated. The angular distributions were analyzed by fitting the areas under peaks with the method of least squares to the equation

$$W(\theta)=\sum_i a_i P_i(\cos\theta).$$

The results of the angular-distribution measurements are shown in Table II and Fig. 2. As can be seen from the table, our results are in better agreement with the work of Lam, Litherland, and Simpson[8] than with that of Poletti, Becker, and McDonald.[7]

Figure 3 shows the polarimeter sum spectra

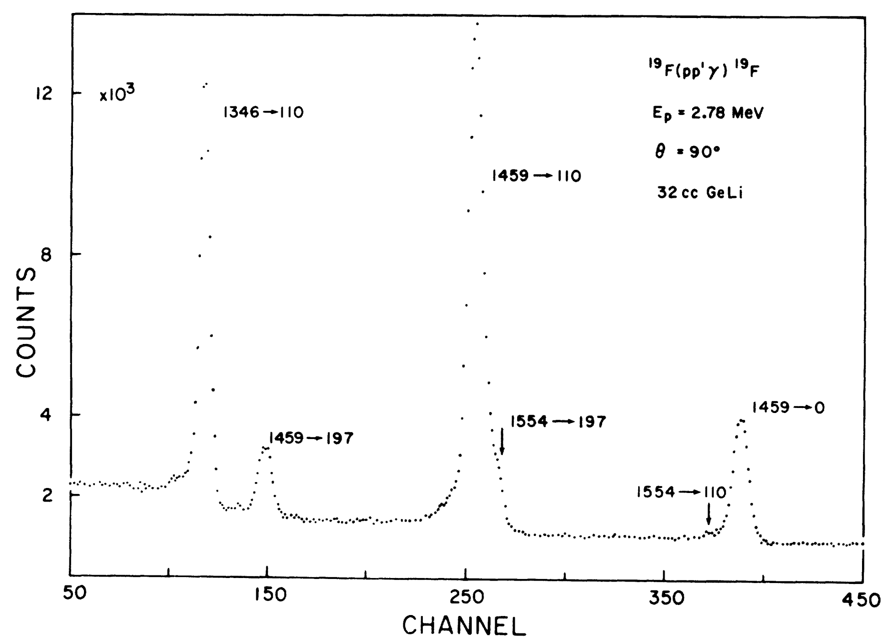

FIG. 1. Pulse-height spectra from which the angular distributions are determined. The energies shown are in keV. This shows that the 1459-keV level is strongly excited relative to the 1554-keV level.

TABLE II. Angular-distribution coefficients obtained for transitions in ^{19}F. The values have not been corrected for finite detector size.

Energy (keV)	Transition (keV)	This work A_2	This work A_4	Other A_2	Other A_4
1236	1346 → 110	0.314 ± 0.01	−0.093 ± 0.01	0.374 ± 0.012	−0.022 ± 0.016 [a]
1262	1459 → 197	−0.073 ± 0.02		−0.015 ± 0.017 [a]	
				−0.12 ± 0.05 [b]	
1349	1459 → 110	−0.438 ± 0.004		−0.396 ± 0.013 [a]	
				−0.48 ± 0.01 [b]	
1459	1459 → 0	−0.256 ± 0.005		−0.167 ± 0.019 [a]	
				−0.30 ± 0.03 [b]	

[a] Reference 7.

[b] Reference 8.

taken with the polarimeter at 0 and 90° to the reaction plane. The data were fitted by the method of least squares to a Gaussian line shape plus a step function on a quadratic background in order to extract the areas under the peaks. In the analysis of the 1.459 → 0.110-MeV transition, the small contribution from the 1.554 → 0.197-MeV transition must be considered; therefore this peak was fitted with a doublet. The polarizations of the γ rays are given by the equation

$$P=(1-NS)/(N-S),$$

where N is the ratio of the intensities of γ rays preferentially scattered parallel to the reaction plane and those scattered perpendicular to the reaction plane, and S is the asymmetry ratio of the polarimeter.

If we assume that the 1.346 → 0.110-MeV transition in ^{19}F is a pure $E2$ transition, we have a "built-in" calibration of the polarimeter. Using the angular-distribution coefficients listed in Table II, one can compute[11] the polarization of this transition and find $P=3.09^{+0.32}_{-0.22}$, which is in agreement with the measured polarization (Table III).

The polarimeter data were not corrected for finite-solid-angle effects,[12] since these corrections are insignificant for a two-section polarimeter using small, closely spaced crystals. In addition, the high sensitivity of a two-section polarimeter makes the relative correction negligible. For the 1.459 → 0.110-MeV transition these corrections would be approximately $\frac{1}{10}$ of the statistical error.

Figure 4 is a graph of the statistical tensor vs mixing ratio for the transitions from the 1.459-MeV level. The mixing ratio may be determined from the overlapping areas of those graphs.[10] In Table IV, column 2 shows the mixing ratios determined from the polarization and angular-distribution measurements. The results presented in Table IV were determined analytically,[13] and they agree with those obtained from the overlapping areas of Fig. 3.

For the three γ transitions originating from the 1.459-MeV level, one can deduce the mixing ratio of the two other γ transitions from the ratio of the angular-distribution coefficients, if the mixing ratio of one γ transition is known. The known mixing ratio and the angular-distribution coefficients determine the statistical tensor describing

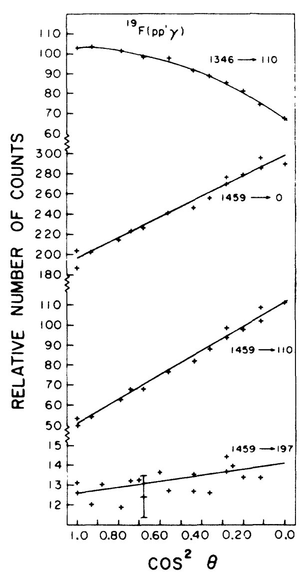

FIG. 2. Results of the angular-distribution measurement. The errors for the 1346 → 110, 1459 → 0.0, and 1459 → 110-keV transitions are approximately the size of the vertical bars on the data points.

TABLE III. Results of the polarization measurements. The energies are in keV.

Energy	Transition	N_0/N_{90}	P	P (Ref. 8)
1236	1346 → 110	0.714 ± 0.018	$3.84^{+0.58}_{-0.45}$	
1262	1459 → 197	0.936 ± 0.087	$1.27^{+0.55}_{-0.27}$	
1349	1459 → 110	1.069 ± 0.015	$0.77^{+0.05}_{-0.04}$	0.54 ± 0.20
1459	1459 → 0	0.761 ± 0.030	$3.34^{+0.89}_{-0.61}$	$2.3^{+1.6}_{-0.8}$

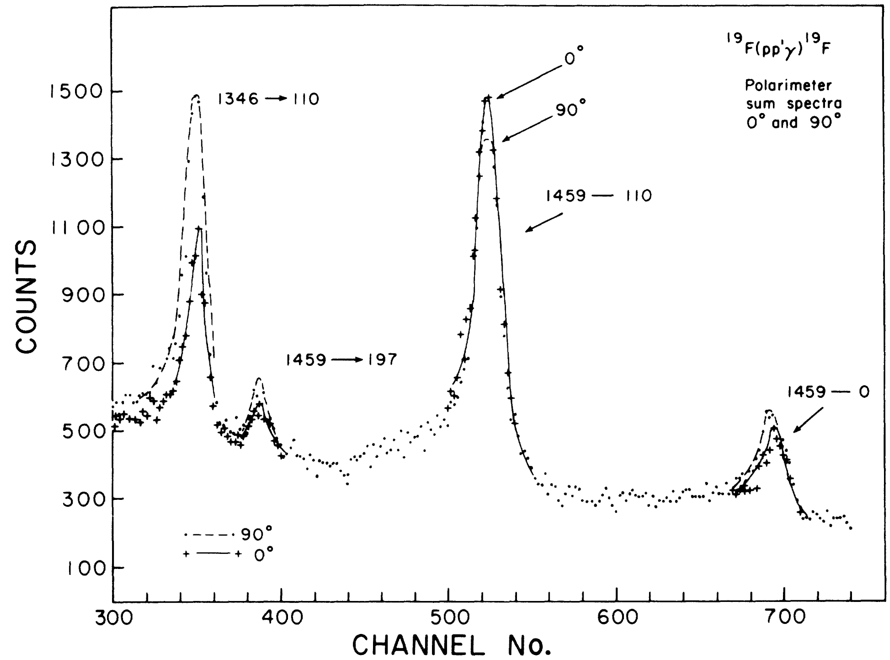

FIG. 3. Polarimeter line spectra at 0 and 90°. The crosses are data taken at 0° relative to the reaction plane, the dots at 90° relative to the reaction plane. The curves shown are drawn to aid the eye only, and are not used in the analysis of the data. Energies are in keV.

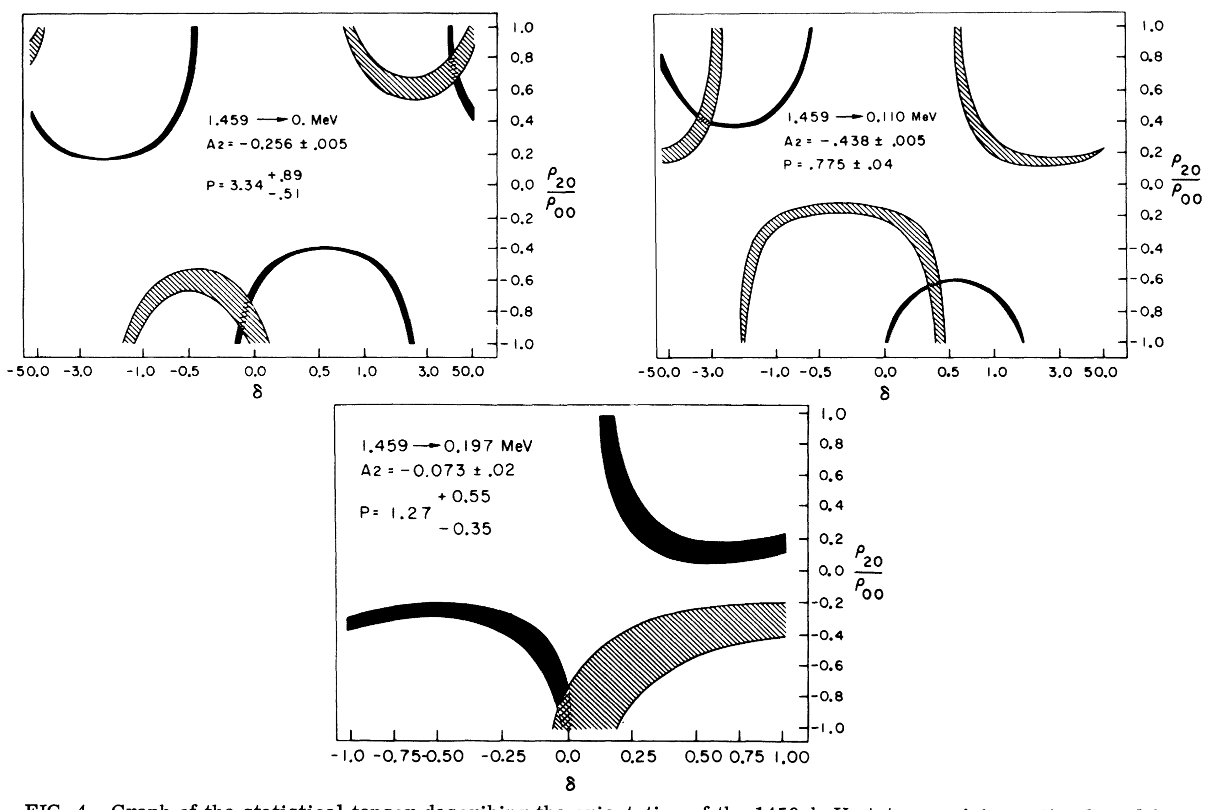

FIG. 4. Graph of the statistical tensor describing the orientation of the 1459-keV state vs mixing ratio plotted for the values of polarization and angular distribution obtained in the experiment. Our results were obtained analytically (see Ref. 14) and agree with those obtained from the overlapping areas of the graph.

TABLE IV. Mixing ratios for transitions from the 1.459-MeV level. Note the mixing ratio is $E2/M1$ for the 1.459→0.110-MeV transition, but is $M2/E1$ for the other two transitions.

Transition (MeV)	δ from P and A_2	δ [$0.30<\delta(1.459\to0.110)<0.38$] (see text)	δ [$\delta(1.45\to0)=0$]	Transition (MeV)	δ (accepted)	δ (other)
1.459→0.197	$-0.39<\delta<0.06$	$-0.10<\delta<-0.01$	$-0.06<\delta<0.0$	1.459→0.197	$-0.1<\delta<0.0$	$-0.22<\delta<0.0$ [a]
1.459→0.110	$0.30<\delta<0.38$	$0.30<\delta<0.38$	$0.22<\delta<0.26$	1.459→0.110	$0.30<\delta<0.38$	$0.11<\delta<0.30$ [a]
						$0.17<\delta<0.37$ [b]
						$0.13<\delta<0.33$ [c]
1.459→0.0	$-0.10<\delta<-0.06$	$0.02<\delta<0.04$	0.0	1.459→0.0	$\lvert\delta\rvert<0.06$	$\lvert\delta\rvert<\lvert0.03\rvert$ [a]

[a]Reference 8. [b]Reference 7. [c]Reference 6.

the orientation of the level, and the mixing ratio of the other two γ transitions are now a function of the angular distribution alone. Such a technique is applied here, and column 3 in Table IV shows the mixing ratio for the transitions based on the mixing ratio for the 1.459→0.110-MeV transition being $0.30<\delta<0.38$ and the measured ratio of the angular-distribution coefficients. Column 4 shows the result of a similar computation on the basis of a pure $E1$ transition for the ground-state transition. Column 5 gives our conclusions based on the results presented in columns 2–4. Column 6 shows the results obtained by other workers. The previous values for the 1.459→0.110-MeV transition have rather large uncertainties and seem to barely overlap the present result. Using the known mean lifetime of 1.459-MeV state,[7] 0.084 ± 0.020 psec, and the present measurement of mixing and branching ratio, we obtain $33<\Gamma_{E2}<71$ W.u. for the 1.459→0.110-MeV transition. The error is mostly due to the 25% uncertainty in the lifetime measurement.

IV. DISCUSSION

The "one-band" theory of Benson and Flowers forbids all $M1$ transitions between levels of ^{19}F formed by coupling a $p_{1/2}$ proton hole to different $|^{20}\mathrm{Ne}\ K=0JM\rangle$ states. The present result for the $M1$ strength disagrees with this prediction as did the results of previous experiments. The "one-band" model also predicts the $E2$ strength of the 1.459→0.110-MeV transition to be the same as the $2^+\to0^+$ transition in ^{20}Ne. Our more accurate measurement of the $E2$ strength is significantly different from the results of previous experiments[6-8] and from the theoretical value of 18 W.u. Since the theory predicts the $E2$ strength for the 1.346→0.110-MeV transition with great accuracy,[1,7,14] one concludes that the 1.459-MeV level cannot be explained as a $p_{1/2}$ proton hole coupled to the pure ground-state rotational band in ^{20}Ne, and that mixing of a higher rotational band is needed.

The present result for the mixing ratio for 1.459→0-MeV transition is in agreement with the general observation that $M2$ transitions in the $2s$-$1d$ nuclei have a strength less than 2 W.u. A better measurement of the lifetime of the 1.459-MeV level in ^{19}F would be of interest in order to make a better comparison with the theory. The present experiment demonstrates the usefulness of a two-section polarimeter based on germanium detectors for unraveling complex decay schemes.

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