Parity of the 2.10- and 1.08-MeV Levels in F^{18} †

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The linear polarization of the 2.10-MeV γ ray, de-exciting the F^{18} 2.10-MeV level, has been measured. This, together with the mixing ratio recently determined by Gorodetzky *et al.* for this transition, fixes the parity of the 2.10-MeV level in F^{18} as odd. Since the 1.08-MeV level in F^{18} is known to have the same parity as the 2.10-MeV level, its parity is also fixed as odd. The structure of these two levels is discussed. In an Appendix, the results are reported of a separate experiment in which the mixing ratios of the $2.10 \rightarrow 0$-MeV and $2.10 \rightarrow 0.94$-MeV transitions were measured.

INTRODUCTION

THE very simple structure of the nucleus F^{18} has encouraged a number of attempts[1] in recent years to explain the properties of its excited states in terms of two particles in the $(2s,1d)$ shell outside the closed O^{16} core. These calculations have succeeded very well in explaining the properties[2,3] of some of the low-lying states of F^{18}. They could not, however, explain the presence of the 1.08-MeV level. Furthermore, recent measurements[3] have shown that the transition between the 2.10- and 1.08-MeV states is $E2$ in character and that it is strongly enhanced compared to the Weisskopf single-particle estimate, indicating that both of these levels belong to the same configuration. Since the calculations using the $(s,d)^2$ configuration could not explain the properties of these two levels, they must arise from some type of excitation of the O^{16} core. In particular, configurations of the type $p^{-1}(2s,1d)^3$ would give rise to odd-parity states, whereas those of the type $p^{-2}(2s,1d)^4$ would give rise to states of even parity: To know the parity of the 1.08- and 2.10-MeV levels is to know which of these two configurations is involved.

EXPERIMENTAL METHOD

As discussed above, it was anticipated that the 2.10-MeV level in F^{18} arose from some type of excitation of the O^{16} core, thus a measurement of its parity would be a useful clue in the determination of its structure. The most direct method for determining the parity of this level at 2.10 MeV appeared to be a measurement of the linear polarization[4] of one of the gamma rays de-exciting it. I therefore attempted to make this measurement. Of the three established[2,5] decay modes of the 2.10-MeV level the decay to the 0.937-MeV level was expected to give rise to a gamma ray whose angular distribution was not markedly different from isotropy[3] (hence little or no information would be gained from an attempt to measure its linear polarization) and the decay to the 1.08-MeV level was to a state whose parity was also unknown.[2,3] This left the 2.10-MeV ground-state transition as the only possibility. Compton scattering has long been used as a basis for a polarization-sensitive detector.[4] In principle, then, a measurement (using a Compton polarimeter) of the polarization of the 2.10-MeV gamma ray which could be seen in the singles gamma-ray spectrum together with a measurement of its angular distribution would be sufficient to determine the parity of the 2.10-MeV level. Unfortunately, there are at least three[2,6] other transitions in F^{18} ($3.06 \rightarrow 0.94$, $3.13 \rightarrow 1.04$, and $3.13 \rightarrow 1.08$ MeV) which give gamma rays of about the same energy. This implied that it would be necessary to label the gamma rays as arising from the 2.10-MeV level in some other manner. The method which was adopted involved the detection of the protons populating the level in an annular surface-barrier detector at a backward angle. Besides labeling the gamma rays this also ensured that the 2.10-MeV level would be reasonably strongly aligned[7]—a necessary prerequisite. This meant a triple-coincidence experiment and consequently low coincidence counting rates, but the anticipated polarization[4] was quite large so that great statistical accuracy was not necessary. Furthermore, the Compton polarimeter was constructed so that scattering parallel to, and perpendicular to, the plane defined by the gamma ray and the beam axis was detected simultaneously in two different detectors.

As shown in Fig. 1, the polarimeter consisted essentially of a hollow cube of $\frac{1}{8}$-in.-thick Duraluminum with holes drilled in two opposite faces so that a 1.5-in.-diam by 3-in.-long NaI crystal which was the Compton scatterer could be inserted. Its front face was 9.6 cm from the target. The line defining the axis of this

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[1] References to theoretical and experimental work on F^{18} published before 1965 are given in Ref. 2 below. Recent theoretical investigations have been carried out by M. De Llano, P. A. Mello, E. Chacon, and J. Flores, Nucl. Phys. **72**, 379 (1965); T. T. Kuo and G. E. Brown, *ibid.* **85**, 40 (1966); and T. A. Hughes, R. Snow, and W. T. Pinkston, *ibid.* **82**, 129 (1966).

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

[3] J. W. Olness and E. K. Warburton, Phys. Rev. **151**, 792 (1966).

[4] L. W. Fagg and S. S. Hanna, Rev. Mod. Phys. **31**, 711 (1959).

[5] C. Chasman, K. W. Jones, R. A. Ristinen, and E. K. Warburton, Phys. Rev. **137**, B1445 (1965).

[6] Recent measurements [E. K. Warburton, J. W. Olness, and A. R. Poletti (to be published)] show that the 3.13-MeV level actually decays $(41\pm4)\%$ to the 1.04-MeV level and $(27\pm4)\%$ to the 1.08-MeV level.

[7] A. E. Litherland and A. J. Ferguson, Can. J. Phys. **39**, 788 (1961).

counter passed through the target and together with the beam determined a scattering plane. Two 3×3-in. NaI crystals "viewed" the central scatterer. The horizontal crystal had its axis in the scattering plane (detected parallel scattering) while the vertical crystal detected the perpendicular scattering. The duraluminum cube was carefully machined so that the distances of both of these detectors from the central scatterer were the same to within 0.02 in. The two 3×3-in. crystals were shielded from gamma radiation originating from the target by approximately 2 in. of lead. A lead block 2-in. thick with a 1.5-in.-diam hole in it ensured that the central crystal saw only γ rays originating from the target. Also shown in Fig. 1 is the position of the annular particle detector in relation to the polarimeter and target. This detector subtended an angle of $162.5°\pm5.5°$ at the target. This represents a solid angle of 2.9% of a sphere. The self-supporting target of SiO, approximately 100 μg/cm^2 thick was bombarded by He^3 of approximately 3.5-MeV energy.

The range of the Compton scattering angle was defined by setting voltage windows on the pulses from the horizontal and vertical crystals. These windows selected γ rays with energies of between 400 and 700 keV. For a 2.1-MeV γ ray incident on the central crystal this corresponded[4] to Compton scattering angles of between 59° and 89°. Gamma rays from the second excited state of N^{14} were used to calibrate and check the polarimeter. Their energies[8] were, respectively, 1.64 and 2.31 MeV. Since for a given Compton scattering angle the energy of the scattered quantum does not depend strongly on the energy of the incident gamma ray, the above window settings were left unchanged throughout the experiment and the calibration. A block diagram of the electronics is given in Fig. 2. Coincidences were determined between pulses corresponding to recoil electrons of energy greater than 600 keV detected by the center crystal and γ rays falling within the energy window set on either the horizontal or vertical crystals. A single-channel analyzer selected the protons detected in the annular detector corresponding to excitation of the 2.10-MeV level. Pulses corresponding to these protons were then put in triple coincidence with the double coincidences recorded in the polarimeter. The outputs from the horizontal and center and vertical and center crystals were summed in the passive adding circuit shown in the insert of Fig. 2. The triple coincidences then gated one or another of the two analog-to-digital converters (ADC) of a Technical Measurement Corporation (TMC) 16 384-channel analyzer allowing the summed pulses to be analyzed and stored. The advantage of adding the pulses corresponding to the detection of the recoil electron and the Compton-scattered γ ray is that in this way the full-energy peak is again obtained, there is no loss of resolution, and most spurious events can be rejected.

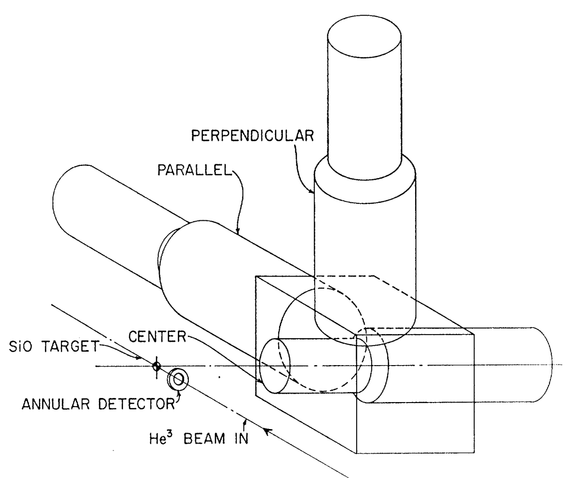

FIG. 1. Sketch, roughly to scale, of the Compton polarimeter used in the present experiment. The central NaI(Tl) crystal was 1.5-in. diam by 3-in. long, while the NaI crystals which detected scattering perpendicular and parallel to the reaction plane were 3×3 in. The center crystal was at an angle of 90° with respect to the beam axis with its front face 9.6 cm from the SiO target. The spatial relationship of the polarimeter, the target, and the annular detector is also shown.

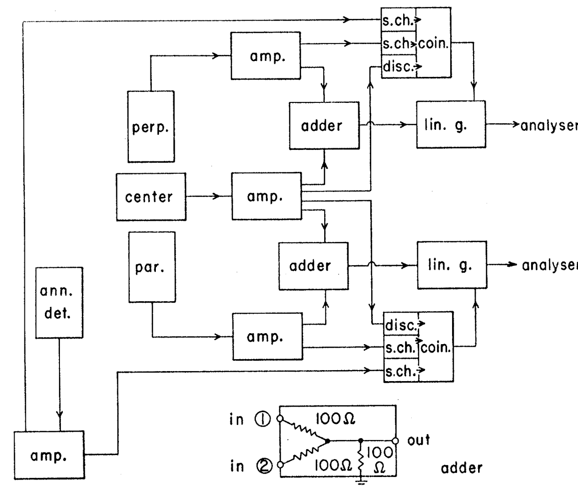

FIG. 2. Block diagram of the electronics. The three NaI(Tl) detectors and the annular detector were each connected to a double-delay line amplifier. Coincidences were established between pulses from the particle detector and the center and perpendicular NaI detectors and between the particle detector and the center and parallel detectors. These triggered linear gates which allowed added pulses from the perpendicular and center or parallel and center detectors to be analyzed. The simple adding circuits were passive resistive networks as shown in the inset at the bottom.

RESULTS

The counting period was divided into two roughly equal periods of about 16 h each, with the average beam current during the second period (0.25 μA) about twice that during the first. Between these two runs the SiO target was replaced by a carbon foil and the single

[8] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. 11, 1 (1959).

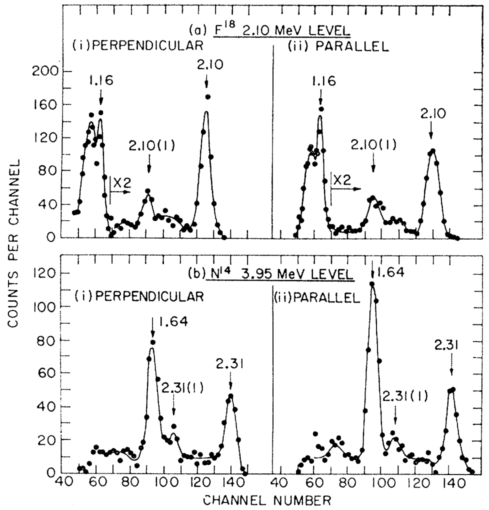

FIG. 3. The summed spectra obtained by the Compton polarimeter. Figure 3(a) shows the two spectra for the F^{18} 2.10-MeV level obtained by adding the spectra obtained in the two counting periods discussed in the text. Since the two spectra of Fig. 3(a) were recorded simultaneously, they can be directly compared: For the 2.10-MeV peak there are more counts recorded in the perpendicular detector than in the horizontal one. Figure 3(b) shows the two spectra obtained for the N^{14} 3.95-MeV level in the check run. For this case, the anisotropy is opposite to that for the F^{18} 2.10-MeV γ ray—more 1.64-MeV γ rays were scattered parallel to the reaction plane than perpendicular. The energies of the Compton-scattered γ rays are shown. The peaks labeled 2.10 (1) and 2.31 (1) are attributed to pair production in the central crystal and the subsequent detection of one of the annihilation quanta in one of the other crystals.

channel set on pulses corresponding to protons leading to the F^{18} 2.10-MeV level was adjusted slightly so that the pulses corresponding to protons leading to the 3.95-MeV level in N^{14} fell within the window. Nothing else was changed. This measurement, which occupied about 4 h, checked the isotropy of response of the polarimeter. As well as this, it enabled a calibration to be made: the 3.95-MeV ($J^\pi=1^+$) level in N^{14} decays[8,9] 96% to the 2.31-MeV level ($J^\pi=0^+$), so that the 2.31-MeV γ ray must be completely unpolarized, while the polarization of the 1.64-MeV γ ray feeding the 2.31-MeV level is characteristic of a pure $M1$ transition[10] and is thus known, provided the angular distribution of the 1.64-MeV γ ray is measured. A similar check run was also carried out after the second counting period. The isotropy of the response of the polarimeter could be checked with a higher statistical accuracy by removing the particle coincidence condition and observing the Compton scattering of the 2.31-MeV γ ray corresponding to the excitation of the first excited state of N^{14}. This γ ray is the most prominent peak in the singles γ-ray spectrum obtained when a carbon target is bombarded with He^3. This test was also carried out between the two counting periods mentioned above. The result of this test gave $N_{2.31}=0.984\pm0.025$, where N is the ratio (number of γ rays Compton-scattered parallel to the reaction plane) divided by (number of γ rays scattered perpendicular to the reaction plane). The response of the polarimeter is thus isotropic to better than 2.5%. The results of the triple coincidence polarization measurements were: for the N^{14} 1.64-MeV γ ray, $N_{1.64}=1.36\pm0.10$; for the N^{14} 2.31-MeV γ ray, $N_{2.31}=1.03\pm0.10$; and for the F^{18} 2.10-MeV gamma ray, $N_{2.10}=0.85\pm0.05$. These results are further illustrated in Fig. 3 which shows the spectra for the F^{18} runs from which the above numbers were extracted as well as the spectra for the N^{14} check run. The F^{18} spectra were obtained by adding together the results of the two 16-h runs mentioned earlier. The figure also shows qualitatively that for the F^{18} $2.10\rightarrow0.94$-MeV transition N is not significantly different from unity, as expected.

If the angular distributions of the F^{18} 2.10-MeV γ ray and the N^{14} 1.64-MeV γ ray were roughly the same and it could be shown that the 2.10-MeV transition were essentially dipole the above values of N would immediately suggest that the parity of the F^{18} 2.10-MeV level was odd. That this is indeed so will now be shown in more detail. Three previous investigations[2,3,11] had not been able to assign the mixing ratio for the F^{18} $2.10\rightarrow0$-MeV transition unambiguously. In each case two values were obtained: $x\sim0$ and $x\sim3$. In principle, however, a careful angular-distribution measurement could resolve the ambiguity. A separate experimental attempt was thus made to do this, but because of insufficient alignment it was unsuccessful. (Some new information, obtained in the process of analyzing this experiment, is given in the Appendix.) Recently, however, Gorodetzky *et al.*[12] in an angular-distribution experiment obtained a very strong alignment for the 2.10-MeV level. They have been able to show that the mixing ratio for the $2.10\rightarrow0$ transition is $x=-(0.03\pm0.05)$; i.e., the transition is essentially dipole. Their result completely eliminates the other solution, $x\sim3$, previously known.[2,3,11] They have also been able to establish that the spin of the 1.08-MeV level in F^{18} is zero,[12] as has Chagnon,[13] whose results also, to some extent, rule against the value $x\sim3$.

The angular distributions for the conditions of the polarization measurement for the F^{18} $2.10\rightarrow0$ and the N^{14} $3.95\rightarrow2.31$ γ rays were determined in a subsidiary experiment. They were characterized by $a_2=-(0.28\pm0.04)$ for the F^{18} 2.10-MeV γ ray and $a_2=-(0.64\pm0.03)$ for the N^{14} 1.64-MeV γ ray, where a_2 is the coefficient of the Legendre polynomial $P_2(\cos\theta)$ in the expansion $W(\theta)=A_0(1+a_2P_2(\cos\theta)+\cdots)$. The quantity $P=P(\theta=90°)$, which is the ratio: intensity of radiation polarized in the reaction plane divided by

[9] See, e.g., J. W. Olness, A. R. Poletti, and E. K. Warburton, Phys. Rev. (to be published).
[10] A. E. Litherland and H. E. Gove, Bull. Am. Phys. Soc. 3, 200 (1958).
[11] P. R. Chagnon, Nucl. Phys. 78, 193 (1966).
[12] S. Gorodetzky, R. M. Freeman, A. Gallmann, F. Haas, and B. Heusch (to be published); R. M. Freeman (private communication).
[13] P. R. Chagnon, Nucl. Phys. 81, 433 (1966).

(intensity of radiation polarized perpendicular to the reaction plane) for $\theta=90°$, is given theoretically for a dipole-quadrupole mixture by[2,4,14]

$$P=\left[\frac{1+a_2+a_4+[4x/(1+x^2)]\rho_2(a)F_2(12ba)}{1-2a_2-\frac{1}{4}a_4-[4x/(1+x^2)]\rho_2(a)F_2(12ba)}\right]^{1-2\sigma}, \qquad (1)$$

where σ is 0 for a $M1/E2$ mixture and 1 for an $E1/M2$ mixture, x is the mixing ratio whose phase is as defined by Litherland and Ferguson,[7] $\rho_2(a)$ is the statistical tensor describing the alignment of the state, and $F_2(12ba)$ is the interference term of the angular distribution for a mixed dipole-quadrupole transition from state a to state b. Its definition is given, e.g., by Poletti and Warburton.[2] For the N^{14} 1.64-MeV γ ray (pure $M1$) Eq. (1) reduces to $P=(1+a_2)/(1-2a_2)$, while for the F^{18} 2.10-MeV γ ray, if $a_2=-0.28$,

$$P=\left[\frac{0.3012+2.3946x-0.2151x^2}{0.6525+1.8708x-0.4661x^2}\right]^{1-2\sigma}. \qquad (2)$$

The relationship between P and N is given by[4,14]

$$P=(1-NR)/(N-R), \qquad (3)$$

where R is the particular value of the ratio N obtained for a γ ray completely polarized in the reaction plane. The value of P calculated from the angular distribution of the N^{14} 1.64-MeV transition together with $N_{1.64}$ measured previously allowed the polarimeter to be calibrated for a 1.64-MeV γ ray; i.e., $R_{1.64}=0.65\pm0.06$. This value of R was then extrapolated to the appropriate value for $E_\gamma=2.10$ MeV by using the same general dependence of R on incident gamma-ray energy as is given by McCallum.[14] This gave $R_{2.10}=0.72\pm0.07$, where the error involved in the extrapolation has been taken into account. This together with the value $N_{2.10}=0.85\pm0.05$, quoted above gave

$$P_{2.10}=3.0_{-1.3}^{+6.0}. \qquad (4)$$

That is, to one standard deviation in both N and R, the lower limit for P is 1.7, while for two standard deviations the lower limit for P is 1.2, so that, conservatively, there is less than a 1% chance of P being less than 1.2. The comparison between Eq. (2), which expresses P as a function of the mixing ratio (x) for the $2.10\rightarrow0$ transition (as well as the parity of the 2.10-MeV level), and the value of P given by Eq. (4) is shown in Fig. 4. The dashed curves are a plot of Eq. (2) for even parity for the 2.10-MeV level ($M1/E2$ transition) while the solid curves are for odd parity ($E1/M2$). The value of the mixing ratio obtained by averaging all the known measurements of this quantity, as discussed in the Appendix, is $x=+(0.01\pm0.03)$. This, together with the polarization P measured in the present work, defines the region shaded in the figure. Since this includes only

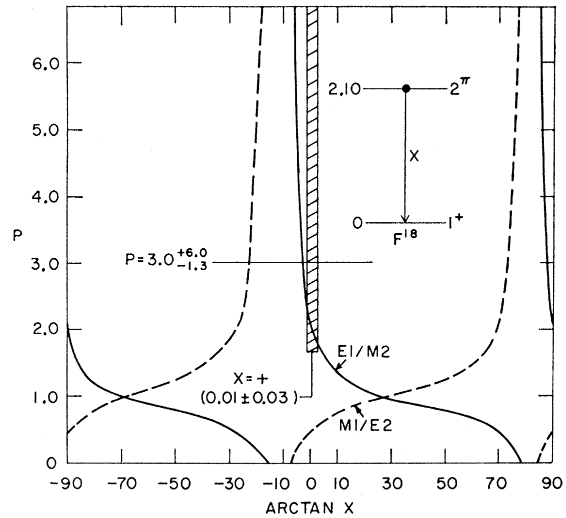

FIG. 4. A plot of the relation between P, the polarization observed at 90° with respect to the beam direction, and arctan x, where x is the mixing ratio for the ground-state transition from the 2.10-MeV level in F^{18}. The shading indicates the allowed region for P as determined in the present experiment and arctan x as obtained by averaging all the known measurements of this quantity (see Appendix). The lower limit for P corresponds to one standard-deviation error in both N and R (see text). To two standard deviations, the lower limit for P is 1.2. (See Appendix.) The measurement of Gorodetzky *et al.* (Ref. 12) was crucial in that it eliminated the other previously known region of arctan x at about +75°.

the solid line, I conclude that the 2.10-MeV level of F^{18} has odd parity and that the transition to the ground state is, within experimental errors, pure electric-dipole radiation. Since the 1.08-MeV level has already been shown[3] to have the same parity as the 2.10-MeV level, the present experiment also fixes the parity of the 1.08-MeV level of F^{18} as odd.

DISCUSSION

The properties of the 1.08- and 2.10-MeV states of F^{18} can now be stated in some detail: The spin of the 1.08-MeV level has been determined by Chagnon[13] and by Gorodetzky *et al.*[12] as $J=0$, while the same workers as well as Olness and Warburton[3] have determined the spin of the 2.10-MeV level to be $J=2$. The mean lifetime[3,15] of the 2.10-MeV level is $t_m=4.1\pm1.6$ psec while for the 1.08-MeV level $t_m=30\pm3$ psec.[15] The mixing ratios for the two possibly mixed transitions from the 2.10-MeV level have also been determined (see below and Refs. 12, 13). For the transition to the 0.937-MeV level, a weighted average of five measurements gives $x=+(0.00\pm0.06)$, while for the transition to the ground state the weighted average is $x=+(0.01\pm0.03)$. The lifetime of the 2.10-MeV level together with the observation of a definite $P_4(\cos\theta)$ term in the $2.10\rightarrow1.08$ transition[3,12,13] implies that the 2.10- and 1.08-MeV levels have the same parity,

[14] G. J. McCallum, Phys. Rev. **123**, 568 (1961).

[15] T. K. Alexander, K. W. Allen, and D. C. Healey, Phys. Letters **20**, 402 (1966); T. K. Alexander (private communication to J. W. Olness and E. K. Warburton).

while the present work has determined their parity as odd. With this information, four transition strengths can be calculated. The $E2$ transition from the 2.10- to the 1.08-MeV level is enhanced over the single-particle Weisskopf estimate[16]: $|M(E2)|^2=20\pm7$ Weisskopf units while three $E1$ transitions involving these levels are all highly hindered compared to the single-particle estimates.[16] The hindrance factors are, for the indicated transitions, $(1.4\pm0.5)\times10^4$ $(2.10\to0.937)$, $(7.2\pm2.4)\times10^4$ $(2.10\to0)$, and $(2.7\pm0.3)\times10^4$ $(1.08\to0)$. These transition strengths together with the determination of the parity of the 2.10- and 1.08-MeV levels give some clue to their identity.

The configuration most likely to give rise to these low-lying odd-parity states in F^{18} appears to be that obtained by promoting a particle from the $1p_{1/2}$ shell to the $(2s,1d)$ shell to form the $1p_{1/2}^{-1}(2s,1d)^3$ configuration. It would thus be hoped that some understanding of the low-lying negative-parity states of F^{18} could be obtained by considering them as arising from the coupling of a $1p_{1/2}$ hole to the low-lying even-parity states of F^{19} (or Ne^{19}). For F^{19} the three lowest states of this configuration are the ground state, 0.198-, and 1.56-MeV states with spins $\frac{1}{2}$, $\frac{5}{2}$, and $\frac{3}{2}$, respectively. Coupling a $p_{1/2}$ hole to the two lowest states would give rise to levels of spin 0, 1, 2, and 3. We can identify the spin-zero state as the 1.08-MeV level, the spin-2 state as the 2.10-MeV level, and assume that the spin 1 and 3 states are pushed up in energy at least above 3.1 MeV, since all of the other seven states in F^{18} below this energy can be explained as arising from the $(2s,1d)^2$ configuration.[1,2] This simple picture would imply that the enhancement in the speed of the $E2$ transition from the 2.10- to the 1.08-MeV level should be comparable to that for the F^{19} $0.198\to0$ and Ne^{19} $0.238\to0$ transitions.[17] All three of these transitions are indeed significantly enhanced over the $E2$ Weisskopf single-particle estimate.[16] The enhancement factors, using the recently measured[18] lifetimes of the transitions in F^{19} and Ne^{19} are 20 ± 7 (F^{18}), 6.71 ± 0.09 (F^{19}), and 13.30 ± 0.30 (Ne^{19}). The ratio of the enhancement for the F^{18} transition to those for the F^{19} and Ne^{19} transitions are $F^{18}/F^{19}=2.9\pm0.7$ and $F^{18}/Ne^{19}=1.6\pm0.5$. The enhancement of the F^{18} transition is then significantly greater than that for the F^{19} transition and is comparable with that for the Ne^{19} transition. This comparison can be made somewhat more quantitative. Since the $E2$ transition $p_{1/2}^{-2}(2s,1d)^3(J=2)\to p_{1/2}^{-1}(2s,1d)^3(J=0)$ can arise only from the $(2s,1d)^3$ part of the wave function, the reduced matrix elements for the three $E2$ transitions which we have been considering are connected. Using the relations [19,20] $\Gamma(E2=8.02\times10^{-8}E_\gamma{}^5\lambda^2(E2)$, $\lambda(E2)=\lambda_0+T_3\lambda_1$, where $\lambda_0\lambda_1$ are independent of the isotopic spin of the nucleus and T_3 the Z component of the isotopic spin is $(N-Z)/2$, the quantity λ_0 can be calculated from the known lifetimes[19] for the mass 19 $(\frac{5}{2}\to\frac{1}{2})$ transition. In this way it is found that $\lambda_0=17.35\pm0.23$ where it is assumed[20] that the phases of $\lambda(E2)$ are the same for Ne^{19} and F^{19}. The $E2$ width of the F^{18} 2.10-MeV level for the transition to the 1.08-MeV level is then

$$\begin{aligned}\Gamma(E2)&=(8.02\times10^{-8})(1.02)^5(6/5)(0.5)(17.35)^2\\&=(0.16\pm0.002)\times10^{-4}\text{ eV},\end{aligned}$$

where

$$0.5=(2J_i+1)(2J_f+1)\begin{Bmatrix}j_f J_f j\\ J_i j_i 2\end{Bmatrix}$$

(j_f, J_f, j, J_i, and j_i are, respectively, $\frac{1}{2}$, 0, $\frac{1}{2}$, 2, $\frac{5}{2}$), and $6/5=(2J_i+1)_{19}/(2J_i+1)_{18}$. The factor 0.5 arises from the decoupling necessary to calculate transition probabilities in a two-particle system;[21] 6/5 is a statistical weight factor. The agreement of this prediction with experiment is not good, the experimental value is[3] $\Gamma(E2)=(0.5\pm0.2)\times10^{-4}$ eV. Since the lifetime of the 2.10-MeV level falls at the limits of the two techniques[3,15] used to measure it, there is still the possibility that the lifetime quoted above could be in error by perhaps a factor of 2 if, for instance, systematic errors—relatively more important near the limits of the techniques—were underestimated. This could bring theory and experiment into closer agreement. The inhibition of the $E1$ transitions from the 1.08- and 2.10-MeV levels can be to some extent understood on the basis of the isobaric-spin $E1$ selection rule[22] in self-conjugate nuclei. Any further explanation of these inhibitions will not be attempted at the present time.

APPENDIX

In an attempt, which was not successful, to determine unambiguously the mixing ratio of the $2.10\to0$ transition, some information was gained on the possible ranges of the mixing ratios for the $2.10\to0$ and $2.10\to0.94$ transitions. In particular, the $2.10\to0.94$ transition was found, within experimental errors, to be dipole in nature. This result verifies the conclusion of Chagnon.[13] The method[2,7] used involved detection of the protons leading to the F^{18} 2.10-MeV level in an annular detector placed at 180° with respect to the target and the determination of the angular distribution of the coincident γ rays de-exciting the level. The edges

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

[17] Recent measurements [E. K. Warburton, J. W. Olness, and A. R. Poletti (unpublished)] give the excitation energy of the first-excited state of Ne^{19} as 238.0 ± 0.5 keV.

[18] J. A. Becker, J. W. Olness, and D. H. Wilkinson, Phys. Rev. (to be published).

[19] E. K. Warburton and W. T. Pinkston, Phys. Rev. **118**, 733 (1960).

[20] A. R. Poletti, E. K. Warburton, and D. Kurath, Phys. Rev. (to be published).

[21] A. de-Shalit and I. Talmi, *Nuclear Shell Theory* (Academic Press Inc., New York, 1963), p. 522.

[22] L. A. Radicati, Phys. Rev. **87**, 521 (1952); M. Gell-Mann and V. Telegdi, *ibid.* **91**, 169 (1953).

TABLE I. Angular-correlation results.

Transition (MeV)	A_2/A_0	A_4/A_0	x
$2.10 \to 0$	-0.29 ± 0.04	$+0.04\pm0.05$	-0.02 ± 0.06 or $+(3.0\pm0.5)$[a]
$2.10 \to 1.08$	$+0.62\pm0.06$	$+0.12\pm0.07$	Pure $E2$[b]
$1.08 \to 0$	$+0.04\pm0.06$	0.0[c]	Pure $E1$[d]
$2.10 \to 0.94$	-0.06 ± 0.06	$+0.06\pm0.07$	$+0.03\pm0.08$
$0.94 \to 0$	$+0.37\pm0.06$	$+0.04\pm0.07$	$\|x\| \leq 0.005$[e]

[a] This value is eliminated as a solution by Gorodetzky *et al.* (Ref. 12) and is ruled against to some extent by Chagnon (Ref. 13).
[b] From Refs. 3, 12, and 13.
[c] From Refs. 12 and 13, this correlation must be isotropic. The value of A_4/A_0 obtained for this correlation was $A_4/A_0=-0.11\pm0.05$, indicating some miscentering. All other values of A_4/A_0 quoted in the table were normalized to this value.
[d] From the odd-parity assignment of the present work together with the spin-zero assignments to the 1.08-MeV state of Refs. 12 and 13.
[e] From the lifetime of the 0.94-MeV state and the spins of the levels involved (see Refs. 3 and 15).

of the annular detector subtended angles of 171° and 175.5° at the target. The beam energy which was used was 3.5 MeV while the self-supporting SiO target was approximately 100 μg/cm^2 thick. The γ-ray detector was a 3×3-in. NaI(Tl) crystal with its front face 15 cm from the target. The scattering chamber enabled all angles between 0° and 90° to be reached by the NaI detector. Its design was such that for angles from 90° to 20° the attenuation, by the walls of the scattering chamber, of the intensity of a 870-keV γ ray was 1.5%, while because of the beam catcher, the attenuation at 0° was 3%. The biggest possible source of error in the determination of the angular distributions arose from the miscentering of the beam spot (i.e., the deviation of the beam spot from the axis about which the NaI crystal rotated). In the present experiment it was not possible to determine the effect of this on the coefficients A_2/A_0 and A_4/A_0 to better than $\Delta(A_2/A_0)=\pm0.02$ and $\Delta(A_4/A_0)=\pm0.06$, respectively. The statistical errors quoted for A_2/A_0 in Table I have been increased to take account of this while the values of A_4/A_0 which are quoted have been normalized to the angular distribution of the $1.08 \to 0$ transition, which must be isotropic.[12,13] The errors quoted for A_4/A_0 take account of this normalization. The method used to extract the angular distributions of the quartet of lines at 0.94, 1.02, 1.08, and 1.16 MeV has been described previously by Olness and Warburton.[3] The results of the analysis of the five angular distributions are given in Table I. From the table it can be seen that it was not possible to determine the mixing ratio for the $2.10 \to 0$ transition uniquely. Gorodetzky *et al.*[12] have, however, been able to eliminate the value 3.0 ± 0.5 while the low value -0.02 ± 0.06 reported in the present work is in good agreement with, and has comparable errors to, the recent measurements by Gorodetzky[12] *et al.* and Olness and Warburton.[3]

TABLE II. Mixing ratios for two transitions from the F^{18} 2.10-MeV level.

Transition (MeV)	Mixing ratio	Reference
$2.10 \to 0$	$+0.04\pm0.18$ or $3.0\ \pm0.5$	2
	$+0.04\pm0.04$ or 1.78 ± 0.35	3[a]
	$+0.07\pm0.18$ or 2.65 ± 0.65	13
	-0.03 ± 0.05 [b]	12
	-0.02 ± 0.06 or $3.0\ \pm0.5$	Present work
	$+0.01\pm0.03$ [b]	Average
$2.10 \to 0.94$	0.00 ± 0.14 or 6_{-2}^{+9}	3
	-0.09 ± 0.14 [b]	13
	$+0.03\pm0.08$ [b]	Present work
	$+0.00\pm0.06$ [b]	Average

[a] Using $J_{1.08}=0$. [b] Not allowed.

The different measurements of this quantity are given in Table II which also lists the weighted average value $x=+0.01\pm0.03$ for this transition. The $2.10 \to 0.94$ mixing ratio was determined uniquely and is in good agreement with the measurements of Chagnon[13] and Gorodetzky *et al.*[12] The averaged value is $x=+0.00\pm0.06$. The reason for the failure in the present experiment to eliminate the high value of x for the $2.10 \to 0$ transition is that the 2.10-MeV level was not sufficiently strongly aligned: $P(0)=0.38\pm0.03$ and $P(1)=0.31\pm0.03$. Much stronger alignments were obtained by Gorodetzky *et al.*[12] and by Chagnon.[13]

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