Electroexcitation of the Ground-State Rotational Band in ^{19}F

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Cross sections for the electroexcitation of the ground-state rotational band in ^{19}F have been measured over the momentum transfer range $0.5 \leq q \leq 2.5$ fm^{-1} and are compared to calculations based on the variation-after-projection, Hartree-Fock approximation. The data support the predicted predominance of $\vec{L}\cdot\vec{S}$ coupling for this band. The 5464-keV level is unambiguously identified as the $\frac{7}{2}^+$ member of the ground-state band.

The nucleus ^{19}F is an excellent example of a light, odd-A, strongly deformed nuclear system of sufficient size and complexity to exhibit properties of a many-body system, yet containing few enough nucleons to be amenable to realistic theoretical treatment. In this Letter we present a comparison of a large-basis Hartree-Fock calculation to the new high-resolution electron scattering results from the ground-state rotational band. These data add substantial new information through newly observed transitions and the addition of high-momentum-transfer data.

Electron scattering from ^{19}F has been previously reported by Hallowell *et al.*[1] for momentum transfers between 0.55 and 1.0 fm^{-1}, and by Oyamada *et al.*[2] for momentum transfer between 0.4 and 1.8 fm^{-1}. In these experiments, it was not possible to extract experimental transition rates for several members of the ground-state rotational band because of inadequate resolution. With the present data, form factors have been obtained at 45° and 90° over the momentum transfer range $0.5 \leq q \leq 2.5$ fm^{-1} for all levels of this band up to and including the $\frac{13}{2}^+$ level (with the exception of the $\frac{11}{2}^+$ level which could not be resolved). The data are used to identify unambiguously the $J^\pi = \frac{7}{2}^+$ level at 5464 keV as a member of the ground-state band.

The present experiment was performed at the Bates Linear Accelerator Center using the 400-MeV electron linac[3] and high-resolution, dispersion-matched magnetic spectrometer.[4,5] Spectral linewidths of 20–50 keV allowed clean separation of the levels of the ground-state band. Since the Teflon targets used in the experiment contained ^{12}C and ^{19}F in well-known quantities, absolute cross sections for both nuclei were calculated from the parameters of the experiment. The ^{12}C cross sections so measured agreed very well with the measurements of Sick and McCarthy.[6]

The measured differential cross sections, $d\sigma/d\Omega$, were reduced to squared form factors, $|F(q)|^2$, using the equation

$$\frac{d\sigma}{d\Omega} = \left[\frac{\hbar c Z \alpha \cos\frac{1}{2}\theta}{2E_i \sin^2\frac{1}{2}\theta}\right]^2 \frac{|F(q)|^2}{\eta}. \tag{1}$$

Here q is the momentum transfer, E_i is the incident electron energy, and $\eta \approx 1$ is the nuclear recoil factor. The quantities α, θ, and Z are the fine-structure constant, laboratory scattering angle, and atomic number, respectively. The squared form factors are plotted as a function of the "effective" momentum transfer, $q_{\text{eff}} = q[1 + (3\alpha Z)/(2E_i R)]$, where $R = \frac{5}{3}^{1/2}$ is the equivalent uniform radius. The squared form factor in Eq. (1) contains longitudinal (L), transverse electric (E), and transverse magnetic (M) components as follows:

$$|F(q)|^2 = |F_L(q)|^2 + (\tfrac{1}{2} + \tan^2\tfrac{1}{2}\theta)[|F_M(q)|^2 + |F_E(q)|^2]. \quad (2)$$

The data for the ground-state scattering are shown in Fig. 1, and data for the electroexcitation of the members of the $K^\pi = \frac{1}{2}^+$ rotational band in ^{19}F are presented in Fig. 2. The agreement with the data of Refs. 1 and 2 is very good for those states that were resolved in the earlier experiments.

Theoretical transition densities were calculated by a variation-after-projection, Hartree-Fock approximation[7] (VPHF) using the two-body interaction of Saunier and Pearson.[8] Theoretical form factors were then generated from these transition densities in the distorted-wave Born approximation.[9] The dashed curves show predicted longitudinal squared form factors, while the solid curves show the predictions when the transverse contributions are included in the final VPHF calculations. The theory predicts negligibly small transverse electric contributions for all these transitions.

The agreement of the theory with the data is very good in the range of momentum transfer of Refs. 1 and 2 ($q \leq 1.8$ fm^{-1}). In this range the scattering is sensitive primarily to the overall size and shape of the transition density, and this seems to be well predicted by the theory. However, the theory is in poor agreement with the new data for $q \geq 1.8$ fm^{-1}. The discrepancy appears in all the form factors within this rotation-

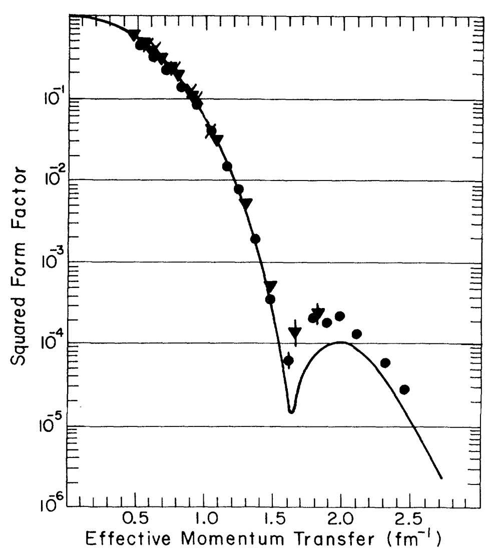

FIG. 1. Squared form factors for elastic scattering in ^{19}F. Solid circles, present data; crosses, data of Ref. 1; inverted triangles, data of Ref. 2; solid line, VPHF calculation.

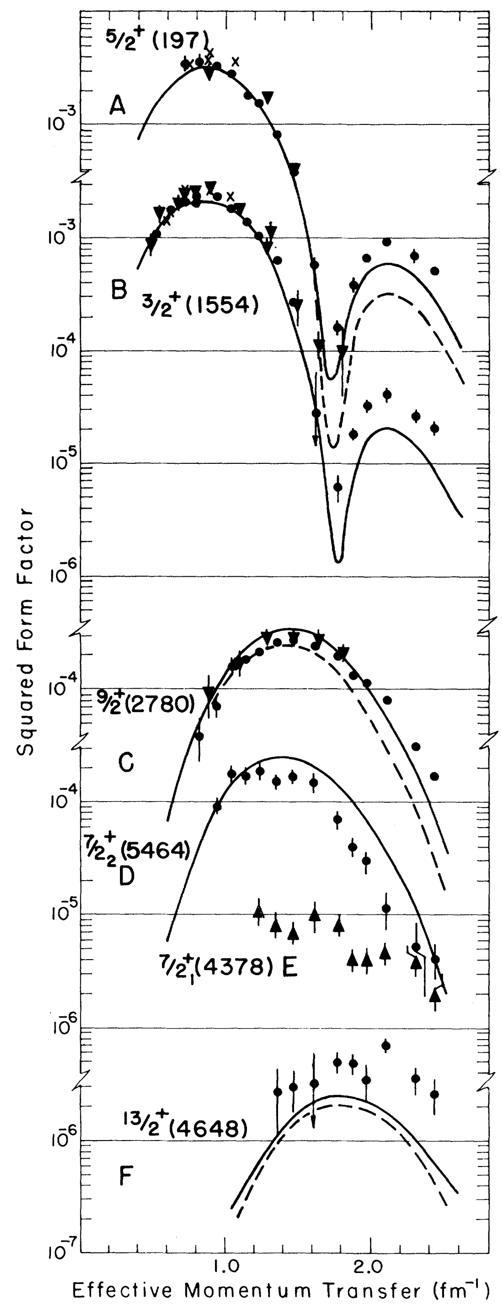

FIG. 2. Squared form factors for inelastic scattering in ^{19}F. Circles and triangles, present data; crosses, data of Ref. 1; inverted triangles, data of Ref. 2; solid line, VPHF calculation including both longitudinal and transverse magnetic components; in B and D the magnetic components are predicted to be negligibly small; dashed line, VPHF calculation including longitudinal components only.

al band and indicates a general deficiency in these calculations when the momentum transfer corresponds to radial distances less than about 1.5 fm. Since similar discrepancies result when other two-body interactions are used,[10] the probable causes for this lack of agreement are the finite basis in configuration space and the approximations inherent in the VPHF method. A density-dependent interaction would probably compensate for these shortcomings. Inclusion of this effect is known to improve agreement between theory and experiment under similar circumstances.[11] Since the present calculation is performed in configuration space rather than coordinate space, the introduction of a density dependence in the interaction would be very difficult.

In Fig. 2 it is evident that the form factors for the $(\frac{7}{2}^+)_2$ (5464 keV) level (curve D) are somewhat smaller than predicted by the VPHF. A possible explanation of this discrepancy is the fragmentation of the $C4$ strength from the ground state between the $(\frac{7}{2}^+)_2$ and the $(\frac{7}{2}^+)_1$ state (data set E in Fig. 2). It is interesting to note that adding the strength of the $(\frac{7}{2}^+)_1$ state to the $(\frac{7}{2}^+)_2$ state would significantly improve the agreement with the theory. The fact that data sets C and D are of the same order of magnitude and are an order of magnitude larger than data set E clearly identifies the $(\frac{7}{2}^+)_2$ level as a member of the ground-state rotational band rather than the previously assigned $(\frac{7}{2}^+)_1$ level.[12] This assignment is in agreement with that of Fortune *et al.*[13] based on the reaction $^{17}O(\alpha, d)^{19}F$.

One of the salient features of the VPHF calculation is that the predominant underlying structure of the $\frac{1}{2}^+$ band appears to be almost pure $\vec{L}\cdot\vec{S}$ coupling. The levels in this band appear to be the result of coupling an $S_{1/2}$ quasiparticle to a 0^+, 2^+, 4^+, 6^+ sequence of states. In this case the following relations, based on pure $\vec{L}\cdot\vec{S}$ coupling, are expected to approximate the experimental results:

$$B(CL;\tfrac{1}{2}^+\to J_+)\approx[(L+1)/L]B(CL;\tfrac{1}{2}^+\to J_-), \tag{3}$$

$$B(M(L-1);\tfrac{1}{2}^+\to J_-)\approx 0, \tag{4}$$

$$B(M(L+1);\tfrac{1}{2}^+\to J_+)\approx(4\pi/9)(2L+1)(2L+3)B(M1;\tfrac{1}{2}^+\to\tfrac{1}{2}^+)B(CL;\tfrac{1}{2}^+\to J_+), \tag{5}$$

where $J_\pm = L\pm\frac{1}{2}$, and all $B(L)$ strengths are in units of $e^2\cdot\mathrm{fm}^{2L}$. A consequence of Eq. (3) is

$$|F(CL,q;\tfrac{1}{2}^+\to J_+)|^2\approx[(L+1)/L]\,|F(CL,q;\tfrac{1}{2}^+\to J_-)|^2. \tag{6}$$

Table I illustrates these relationships in the VPHF calculation for ^{19}F.

The experimental results for the $\frac{5}{2}^+$ and $\frac{3}{2}^+$ rotational levels (data sets A and B, respectively, in Fig. 2) indicate a strong $M3$ strength in the $\frac{1}{2}^+\to\frac{5}{2}^+$ transition. This can be seen by examining the relative magnitudes of these two states. In the region of the second maxima, where Eq. (6) fails, the relative magnitudes can be explained if the magnetic component is strong in the $\frac{5}{2}^+$ level and weak in the $\frac{3}{2}^+$ level. This is in fact predicted by Eqs. (4) and (5) when $\vec{L}\cdot\vec{S}$ coupling is predominant.

Similar effects are seen in the excitation of the $(\frac{7}{2}^+)_2$, $\frac{9}{2}^+$, and $\frac{13}{2}^+$ states. In all these cases inclusion of $M5$ or $M7$ strength improves the agreement with the data. Unfortunately, it is not possible to compare to the excitation of the $\frac{11}{2}^+$ state at 6499 keV since it cannot be separated from the $\frac{3}{2}^+$ state at 6497 keV.

The present work indicates that the VPHF calculation gives a good quantitative description of the longitudinal transition strengths and low-q form factors for the ground-state rotational band in ^{19}F. The calculations predict that the basic structure of this band is determined by $\vec{L}\cdot\vec{S}$ coupling. The ratios of the longitudinal form factors as predicted by Eq. (6) seem to be reasonably

TABLE I. Intraband electromagnetic transition strengths to the ground state in ^{19}F from the VPHF calculation.

Initial state	$C\lambda$ or $M\lambda$	$B(\lambda)$ ($e^2\cdot\mathrm{fm}^{2\lambda}$)	$B(\lambda)$ (W.u.)[a]	$B(\lambda)$ (M.u.)[b]
$3/2^+$	$C2$	21.5	7.12	7.12
$5/2^+$	$C2$	20.3	6.74	6.74
$7/2^+$	$C4$	1.59×10^3	9.84	9.84
$9/2^+$	$C4$	1.25×10^3	7.74	7.74
$13/2^+$	$C6$	1.53×10^4	1.49	1.49
$1/2^+$	$M1$	6.45×10^{-2}	3.27	3.52
$5/2^+$	$M3$	44.0	47.8	5.7
$9/2^+$	$M5$	1.22×10^4	224.0	10.0
$13/2^+$	$M7$	3.25×10^5	88.4	2.1

[a] Weisskopf units.
[b] Moszkowski units (Ref. 14).

well verified by the present experiment. However, as Eqs. (4) and (5) indicate, the transverse strengths would provide a much more stringent test for the theoretical predictions. These cannot be extracted unambiguously from the present forward-angle data, although for $q \geq 1.8\ \mathrm{fm}^{-1}$, the data do provide supportive evidence for the existence of large $M3$, $M5$, and $M7$ strengths predicted by the theory.

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Proposed $E1$-$M1$ Interference Experiment in Hydrogenic Ions to Measure Spin Polarization

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It is shown that in the Stark quenching of a spin-polarized beam of metastable hydrogenic ions, a measurable right-left asymmetry can be produced in the emitted radiation which is proportional to the degree of spin polarization. The effect, which has previously been observed in absorption in neutral cesium and thallium, is due to interference between spontaneous magnetic dipole and induced electric dipole decay modes. Asymmetry measurements offer a simple means of determining the degree of spin polarization in the heavier hydrogenic ions.

There has been much recent interest in the radiation asymmetries in atomic transitions caused by interferences between electric-field-induced electric dipole ($E1$) and magnetic dipole ($M1$) transitions.[1-4] In analogy with the theory of molecular optical activity,[5] the electric field destroys the atomic inversion symmetry and weakens the parity selection rule. Consequently, both $E1$ and $M1$ transitions become simultaneously allowed. The interference effect has now been observed in absorption in the weak $M1$ transitions of cesium[2] and thallium.[3]

The purpose of this Letter is to point out that the $E1$-$M1$ interference term should produce an *easily observed* asymmetry in emission in the electric-field quenching of a spin-polarized hydrogenic ion beam (such as Ne^{9+}) in the metastable $2s_{1/2}$ state. The asymmetry is with respect to a mirror reflection of the total intensity through the plane containing the applied–electric-field vector and the spin-polarization vector.[1,2] The particular significance for hydrogenic ions is that there is no other simple way of measuring the degree of spin polarization for these fundamental systems. For example, it would be interesting to look for spin-polarization effects following the