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II–11 Quadrupole Interaction of Polarized ^{19}F (197 keV) Implanted into Zn Single Crystals*

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The spin precession of a polarized nucleus interacting with an electric field gradient (EFG) allows the measurement of the magnitude and sign of the nuclear quadrupole interaction.[1] As in all hyperfine interactions, one has to assume either the sign and magnitude of the nuclear moment or of the atomic field is known in order to determine the other quantity. In this case, $|Q(5/2+,\ ^{19}F)| = 0.11 \pm 0.02$ is known from previous work[2] and the sign can be taken from calculations by different authors.[3,4] The electric field gradient at the ^{19}F site in a metal can be treated as consisting of a contribution from the lattice[5] and a less well known contribution from the conduction electrons.[6] As their effect can be large and of opposite sense to the lattice contributions,[7,8] it is important to measure the sign of the interaction.

The experimental setup is shown in Fig. 1. Projectile Coulomb excitation and strong polarization were obtained by scattering a 45 MeV ^{19}F beam from the Stony Brook FN tandem accelerator at 60° from a 3.5 mg/cm² gold foil. Most of the orientation was preserved during the 5 ns flight in vacuum between target and single crystal catcher due to the large fractions of bare nuclei, helium-like and hydrogenic ions among the scattered ^{19}F.[9] The passage of the ^{19}F ions through a thin scintillator foil[10] (viewed by a photomultiplier) in front of the single crystal generates the time zero signals for the implantation process. This novel technique avoids heating and radiation damage of the single crystal by the direct beam and has inherently good timing properties.

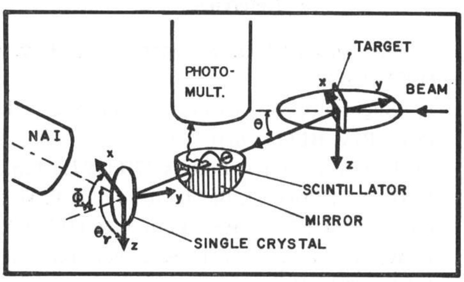

Fig. 1. Experimental geometry.

The coefficients describing the orientation of the excited $\frac{5}{2}^+$ state of F^{19} are calculated using first order perturbation theory. The angular correlation pattern at the catcher is, in the notation of ref. 1, given by:

$$W(\Omega_\gamma, t) = (4\pi)^{1/2} \sum_{k_1k_2N_1N_2} \left(\frac{2k_1+1}{2k_2+1}\right)^{1/2} \times A_{k_1k_2}a_{k_1N_1}(\theta, \Phi)G_{k_1k_1}\binom{\text{hard}}{\text{core}} \times G_{k_1k_2}^{N_1N_2}(t)Y_{k_2N_2}(\Omega_\gamma)\ . \quad (1)$$

The factor $\overline{G_{k_1k_1}\binom{\text{hard}}{\text{core}}}$ accounts for the attenuation of the angular correlation by the atoms in flight, and is calculated by averaging the hard core attenuation factor for each atomic species with the charge state fractions. Attenuation occurs independently in the flight between the target and scintillator and between the scintillator and catcher.

The $\hat{c}$-axis of the Zn crystal was oriented along the z axis of the coordinate system shown in Fig. 1. The general correlation function for an $I = \frac{5}{2}$ state is given by:

$$W(\theta_\gamma, \Phi_\gamma, t) = 1 + \sum_{n=1,2,3} a_n \sin(n\omega_0 t - \phi_n)\ . \quad (2)$$

For detectors in the plane, the a_1 coefficients are largest, and the phase shifts are $\approx 90°$, making detection of the sign of ω_0 difficult for small $\omega_0\tau$. For a detector placed 45° above the scattering plane ($\theta_\gamma = 135°$) the a_3 terms are largest and the phase shift is 0° for $\phi_\gamma = -135°$, allowing determination of the sign of the quadrupole interaction.

The theoretical coefficients and phases are given in Table I for an incident 45 MeV F^{19} projectile scattered from Au^{197} to a laboratory angle of 60°. The

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Table I. Theoretical and Measured coefficients and phases of eq. (2) for the detector 45° above the reaction plane ($\theta_\gamma = 135°$).

Φ_γ	a_3[a](theory)	a_3(exp)	ϕ_3[a](theory)	ϕ_3(exp)	$3\omega_0(\mu sec^{-1})$
−135°	+0.128	+0.064±0.01	0°	−24±15	21.7±2.5
−112.5°	+0.208	+0.080±0.01	+64°	+61±15	25.8±2.5

[a]Calculated for incident F^{19} energy of 45 MeV and scattering angle of 60°. Attenuation in flight has been taken into account. Values of a_n for $n \neq 3$ are less than 15% of a_3 in both cases.

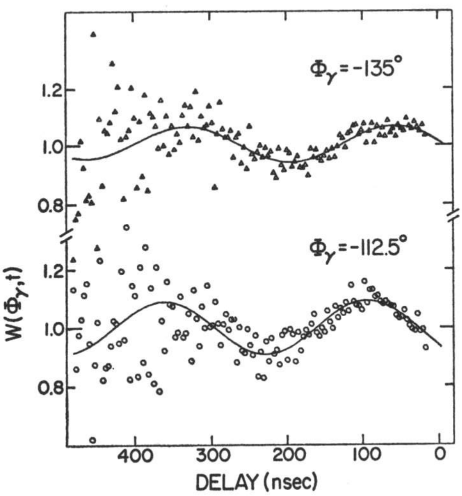

Fig. 2. Normalized time spectra taken with the counter 45° above the reaction plane ($\theta_\gamma = 135°$) for ^{19}F implanted into a single crystal of Zn with the $\hat{c}$ axis along the z axis. The upper spectrum is for $\Phi_\gamma = -135°$ and the lower spectrum is for $\Phi_\gamma = -112.5°$.

normalized time spectra taken with the detector placed 45° above the scattering plane are shown in Fig. 2, and the parameters extracted from least squares fits to the data are given in Table I.

The upper curve in Fig. 2 clearly starts as a positive sine and is shifted to the right relative to the lower curve, both facts indicating a positive quadrupole interaction. The observed frequency of $\omega_0 = +7.9 \pm 1.0\ \mu sec^{-1}$ can be coupled with a moment of $Q = -.11$ barns to give the field gradient at the fluorine site as $V_{ZZ} = -(0.31 \pm 0.08) \times 10^{18}$ volts/cm². If one calculates the lattice contribution to the field gradient at a substitutional site (assuming two positive charges on each Zn ion) and corrects with the Sternheimer factor $\gamma_\infty = -42$ for a F^- ion,[11] one gets an electric field gradient about twice as large as the measured value. Under these assumptions the lower measured electric field gradient might be the result of the shielding by the conduction electrons.

The magnitude of the observed oscillations is about 45% of the expected magnitude. This decrease could be due to more loss of orientation in flight than we have accounted for. However, it is more likely that some of the fluorine nuclei land at a different site in the crystal lattice and experience a different field gradient. Indications of a higher frequency oscillation are present in some of our spectra taken with different detector angles and crystal orientation, and further experiments are in progress to establish its presence.

The technique used in this experiment allows implantation of F^{19} into crystals where direct beam techniques could yield large backgrounds in the gamma detector. This additional flexibility in the choice of crystals allows measurements in crystals where reliable field gradient calculations can be performed, so that it should be possible to measure the sign of $Q(^{19}F, 5/2^+)$ and confirm the theoretical value.

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