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# PREFERENTIAL POLAR EMISSION IN THE ALPHA DECAY OF DEFORMED $Cf^{249}$ AND $E^{253}$ *

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In 1953 Hill and Wheeler predicted that prolately deformed alpha-emitting nuclei should exhibit enhanced emission from the polar regions, or "tips", because of the lower Coulomb barrier in these regions.[1] Dabbs and co-workers have observed anisotropic angular distributions of alpha particles from oriented uranium and neptunium nuclei.[2] For $Np^{237}$ they determined the sign of the quadrupole coupling constant in neptunyl ion and showed that alpha particles are indeed emitted preferentially along the direction of the angular momentum vector, confirming the prediction of Hill and Wheeler. Pryce[3] has suggested that the quadrupole moment of $Np^{237}$ is negative, which would require a different interpretation of the orientation experiments, but this seems unlikely on the basis of the collective nuclear model. In this letter we describe orientation experiments on $Cf^{249}$ and $E^{253}$ which provide independent confirmation of the predications of Hill and Wheeler, that is to say, the L = 2 component in the main alpha group is appreciable and is in phase ($\delta > 0$) with the dominant L = 0 wave.

Neodymium ethylsulfate was chosen as the crystal most suitable for these experiments. The ions $Cf^{+3}$ and $E^{+3}$ are chemically analogous to $Dy^{+3}$ and $Ho^{+3}$, nuclei of which have been aligned in this lattice.[4,5] This salt can easily be cooled to 0.02°K, where fairly complete alignment of these

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nuclei could be expected. The alpha counters used in this experiment were similar to those described by Walter, Dabbs, and Roberts.[6] In each experiment care was taken to grow the radioactive ions only in a thin surface layer on a small spot on the crystal. Low temperatures were obtained by standard adiabatic demagnetization techniques, and the temperature was measured with mutual inductance coils.

At the lowest temperatures the angular distributions of alpha particles from both isotopes were highly anisotropic. In $E^{253}$, and in $Ho^{166}$,[5] it could be ascertained by the temperature dependence of the anisotropy that the alignment was nearly complete even at temperatures as high as $0.1^{\circ}K$. For $E^{253}$ the temperature dependence of the alpha particle intensity along the crystalline c axis for two runs is shown in Fig. 1. Data were also taken at $90^{\circ}$ to the c axis. These showed a change in counting rate on orientation of the $E^{253}$ nuclei of opposite sign and approximately half the magnitude as that along the c axis, indicating that the dominant anisotropic term in the angular distribution is proportional to $P_2$ ($\cos \theta$).

In the ethylsulfate lattice the dominant spin-Hamiltonian terms affecting nuclear orientation are expected to lead to "axial" nuclear alignment (states with $I_Z = \pm I$ would lie lowest) for both $Cf^{249}$ and $E^{253}$. Combining this with the observed enhancement of alpha particle intensity along the c axis on orientation, we find preferential alpha emission along the nuclear spin direction in both cases. Since the ground states of both $Cf^{249}$ and $E^{253}$ have spins greater than 1/2 and spin projections K equal to the spin, so that the nuclear spin is along the prolate axis,[7,8,9] alpha emission must take place preferentially from the tips of these prolately deformed nuclei. In both cases the direction of orientation can also be established from experiment, for $E^{253}$ from the temperature dependence of the anisotropy, and in $Cf^{249}$ from the sign of the anisotropy of the (following) 394-keV $\gamma$-ray and knowledge of its dipole character with $I \rightarrow I-1$ spin sequence.

In the case of $E^{253}$ we can with some confidence derive the hyperfine splitting constant A by fitting the shape of the anisotropy vs. 1/T curve in Fig. 1, since the curve appears to come close to the limiting $(T \rightarrow 0)$ value. An unusually large value is obtained, $|A_{253}| = 0.28 \pm 0.03\ \mathrm{cm}^{-1}$ value.

Using extrapolated values of crystal field parameters we calculate an electronic ground state for einsteinium in the ethyl sulfate of

$$(5f)^{10}\ {}^5I_8\ [0.78\,|J_z{=}\pm 7\rangle \ + \ .54\,|J_z{=}\pm 1\rangle \ + \ .32\,|J_z{=}\mp 5\rangle]$$

(This is actually the lowest doublet; a singlet should lie very close in energy.) With $\langle r^{-3}\rangle$ average values for 5f electrons estimated from the results of Foglio and Pryce,[10] we calculate a nuclear magnetic moment of $|\mu| = 4.9$ n.m. for $E^{253}$. Using Nilsson wave functions for the 7/2 + (633) odd proton state we calculate a theoretical magnetic moment of 4.2 n.m. using the free-space $g_s$ factor and interpolating to a deformation of $\delta = 0.24$.

For $Cf^{249}$ the much larger statistical error precludes a detailed interpretation of the hyperfine structure constants. By estimating the crystal field parameters appropriate for $Cf^{+3}$ in an ethylsulfate lattice we have calculated an electronic ground state which is quite similar to that of $Dy^{+3}$ in this lattice. The spin Hamiltonian should have the form

$$\mathcal{H} = AS_zI_z + B[S_xI_x + S_yI_y] + P[I_z^2 - 1/3\ I\ (I+1)].$$

This state has $P < 0$ and $B = 0$. Thus the orientation should arise from A and P, both of which produce axial alignment in this case. It is not possible to resolve values of A and P independently, but if the orientation were due only to A alone or to P alone, a value of $A \sim .02\ \mathrm{cm}^{-1}$ or $P \sim -.002\ \mathrm{cm}^{-1}$ would be required. The orientation was not saturated down to $0.03^\circ$K (Fig. 1), at which temperature the coefficient of the $P_2$ term was + 0.6.

The $E^{253}$ decay scheme has been given by Asaro et al.[8] who estimate an L = 2 to L = 0 intensity ratio of 1:8 in the main alpha group. The estimate is based on the decay intensity to the first excited state together with the approximate branching relations of Bohr, Fröman, and Mottelson.[11] Using the intensities of partial waves from the analysis of Asaro et al. and taking L = 0 and L = 2 in phase we calculate a limiting ($T \rightarrow 0$) angular distribution for $E^{253}$ of

$$W(\theta) = 1 + 1.06\, P_2(\cos\theta) + 0.10\, P_4(\cos\theta)$$

for the L = 2,4 waves in phase, and

$$W(\theta) = 1 + 0.92\, P_2(\cos\theta) - 0.01\, P_4(\cos\theta)$$

for the L = 2,4 waves out of phase. The experimental value is

$$W(\theta) = 1 + (0.66 \pm 0.06)\, P_2 + (0.04 \pm 0.06)\, P_4$$

Thus we cannot experimentally decide the relative phase of the L = 2,4 waves. It is puzzling that the experimental coefficient of the $P_2$ term is lower than theoretical. Taken at face value the result would indicate a lower admixture of L = 2 in the ground transition that the Asaro estimate, but we are reluctant to draw this conclusion, since there could be systematic experimental effects such as scattering in the source or incomplete growth of the $E^{+3}$ atoms into the lattice sites.

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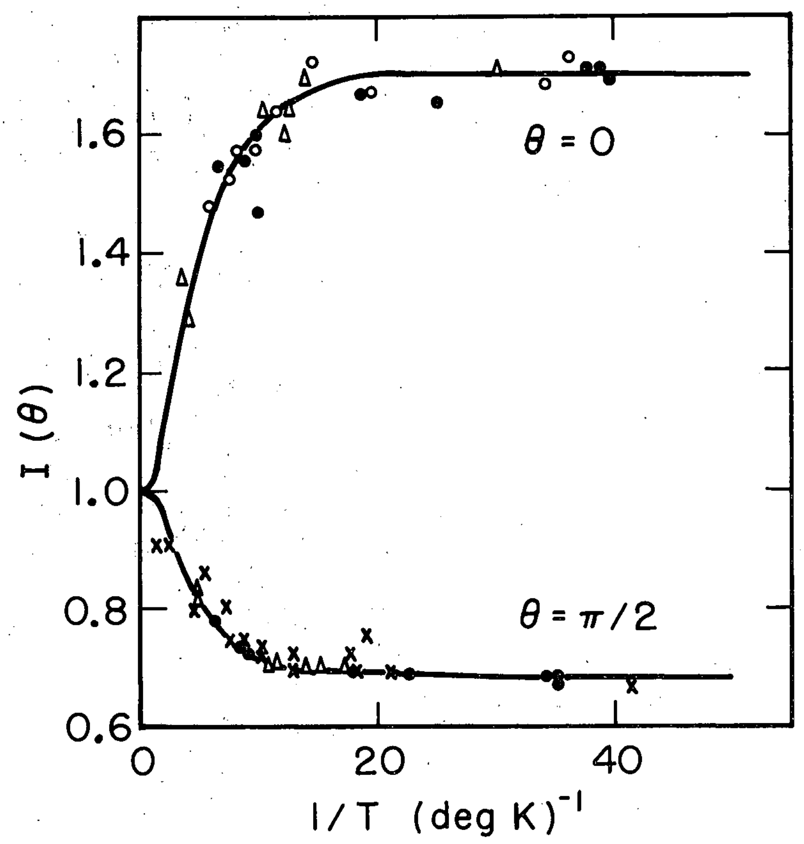


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Fig. 1. Plot of the alpha particle intensity from $E^{253}$ oriented in NES, at 0° and 90° from the crystalline c axis, versus reciprocal absolute temperature. Solid angle corrections have been made (assuming a $P_2$ (cos θ) distribution) to the data, which are from four separate runs. The theoretical curves are based on the spin Hamiltonian $AS_zI_z$ with $S_z = \pm 1/2$ with A and $F_2$ in the angular distribution function $I(\theta) = 1 + B_2(T)F_2P_2(\cos\theta)$ adjustable.

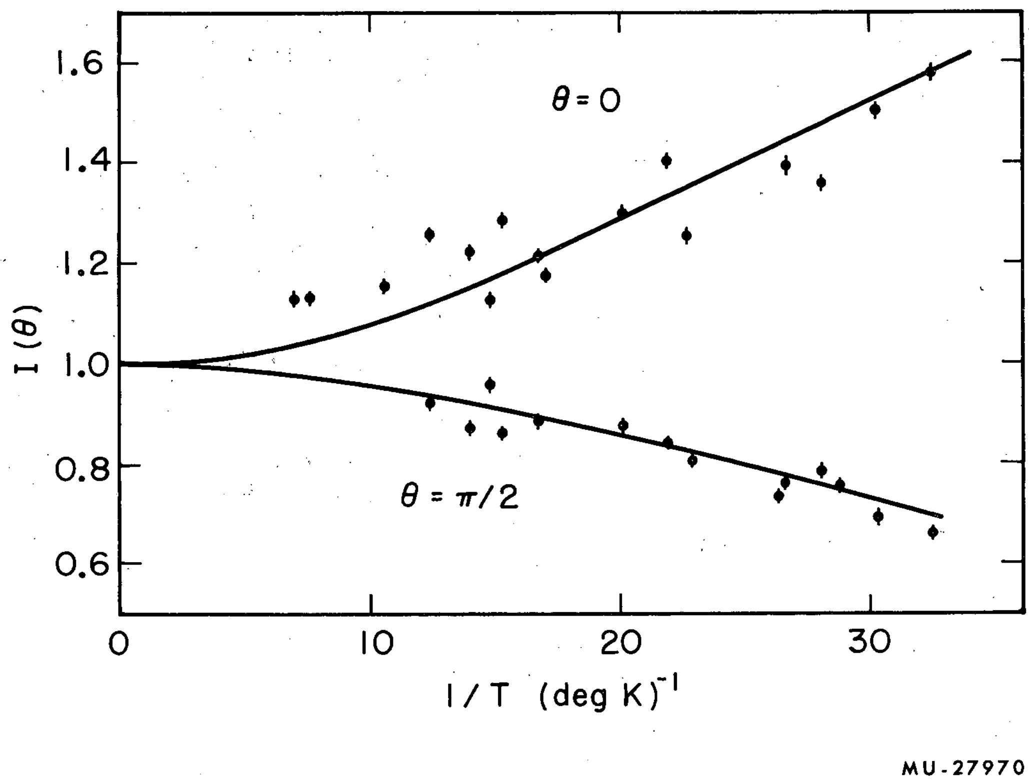


Fig. 2. Alpha particle intensity from $Cf^{249}$ oriented in NES, vs $T^{-1}$. The theoretical curves are based on the spin Hamiltonian $AS_zI_z$, with $S_z = \pm 1/2$, but quadrupole coupling would fit the data equally well.