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Effect of Static Quadrupole Interaction on γγ Delayed Angular Correlation in Ta^{181}

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We wish to report the results of some work in which the effect of a static quadrupole interaction on the angular correlation of the 133, 482 kilovolt gamma cascade in Ta-181 has been observed. Using a source of polycrystalline hafnium metal containing the activity, the differential anisotropy was measured as a function of the time interval between the formation and decay of the intermediate level by the method of delayed coincidence. The results display the general periodic features predicted by theory and allow the determination of the quadrupole coupling through the observation of the quadrupole precession period.

The theory of angular correlations perturbed as a result of quadrupole coupling of the intermediate state to crystalline field gradients at nuclear sites has been developed for the experimental situations most frequently encountered. The results of Abragam and Pound[1] pertinent to the present work are summarized on the first slide. The A_k's appearing in the correlation function $W(\theta, t)$ are the geometrical factors which depend upon the spins and multipolarities of the levels and radiations involved; the G_k's, containing the time dependence, are the attenuation coefficients which depend upon the details of the interaction through its effect on the population of the intermediate magnetic substates. Explicit expressions given for these are those of Abragam and Pound for a polycrystalline source of randomly oriented

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microcrystals having axial symmetry. Also shown on this slide are the pertinent features of the 133, 482 kilovolt cascade.

The differential anisotropy was obtained by recording delayed coincidence spectra at 90 and 180 degrees using a conventional fast-slow system. Fast pulses, shaped to one volt amplitude and 200 nano$_{\text{seconds}}$ duration were used to gate a 6BN6 time to pulse height converter, while the slows were processed in the usual way to provide selective gating of the multichannel analyzer used to record the delayed events. The detectors were sodium iodide crystals direct-coupled to RCA 6810A photomultipliers. This arrangement gives moderately good resolution, about 3.5 nanoseconds for gamma rays of these energies, and excellent linearity over a region of 170 nanoseconds. Source material was prepared by neutron irradiation of hafnium metal powder to produce a Hf-181 activity of about 3 millicurie/gram. Counting sources consisted of a small quantity of this material in thin-walled fluorethylene holders, the volume of the source being about $10^{-3}cm^3$ and the activity about 20 microcuries. Average microcrystal size was roughly $10^{-3}mm^3$ achieved by screening prior to irradiation.

Presented on slide two are the delayed coincidence curves for 90 and 180 degrees. Although the anisotropy of this cascade is quite large, about -0.4, the finite time resolution and the finite angular resolution of our apparatus smears out the fluctuations considerably, and several hours running is required to observe these over statistical fluctuations. The data shown, corrected for accidentals, represent that collected in six days of two-hour runs made alternately at each angle. The true to chance ratio for the source used in these runs was about 80 at time t = 0.

On the third slide, the anisotropy computed from the data of the previous slide is shown along with similar data obtained with a liquid source for comparison. Correction for the angular resolution has been made here, but the results are not corrected for the finite time resolution. The solid curve represents the theory of Abragam and Pound for axially symmetric field gradients and has been modified here to account for the time resolution. The precession period corresponds to a quadrupole coupling of 333 $\pm$ 15 Mc/sec. Departure from this theory is characterized by what appears to be a time-dependent background plus a smearing out of the fluctuations with increasing time. Most apparent is the well defined knee appearing between the first and second peak. Some work reported recently by Matthias, Schneider, and Steffen[2] appears to offer a reasonable explanation for the deviations observed here. They have investigated the behavior of the attenuation factors for electric interactions of lower than axial symmetry, the departure from axial symmetry being characterized by the parameter

$$\eta = \frac{V_{xx} - V_{yy}}{V_{zz}}$$

where the V's are the principal components of the field gradient. The dotted curve represents their results for $\eta = 0.4$ with our resolution folded in. We have not yet attempted a fit through the adjustment of η, but are anxious to do this as well as to extend the comparison out past the second peak as soon as this information becomes available. A second effect considered is that of a finite frequency distribution due to a dispersion in the value of the field gradient from nucleus to nucleus. For a normal distribution, this is shown to lead to a general smearing out of the peaks with some skewing in the direction of increasing time. Each of these effects leads to a non-periodic behavior in the attenuation factors and in this connection it is important to point out that the uncertainty in $\Delta \nu_Q$ reported is that due to counting statistics only.

However, these effects are estimated to produce a change of less than five percent in $\Delta\nu_Q$ and, moreover, can be corrected for here. This value of the quadrupole coupling corresponds to interaction frequency of 50 ± 2 Mc/sec which is in agreement with that of Ousseph and Canavan[3] who obtain 56.5 ± 5 from their work with single crystals.

At present, we are attempting to better the time resolution of our apparatus through the use of faster photomultipliers plus the use of a fast organic scintillator in the 482 kilovolts channel where integral discrimination is sufficient. It is hoped that this will permit detection of some of the secondary peaks predicted by theory but unattainable under present conditions, and present a more detailed picture of the effect of interactions of these types on gamma-gamma angular correlations.

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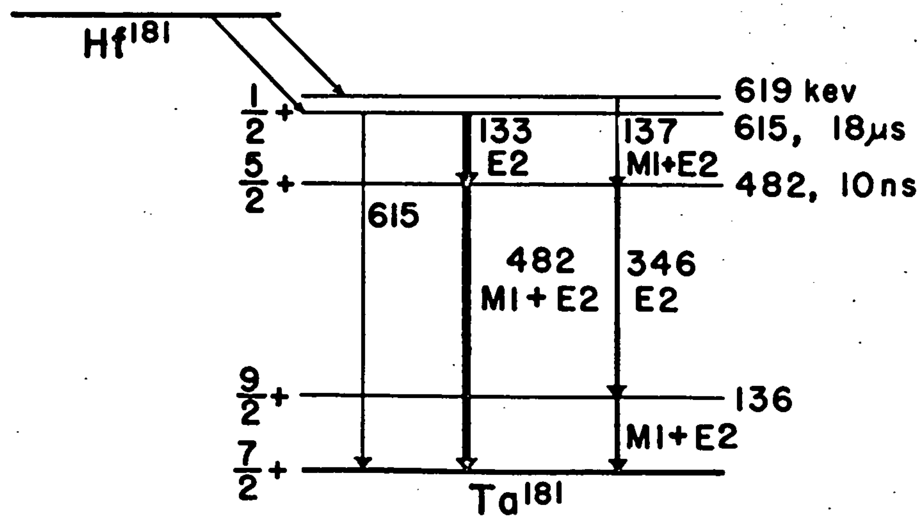
1 - A. Abragam and R. V. Pound, Phys. Rev. 92, 493 (1953)

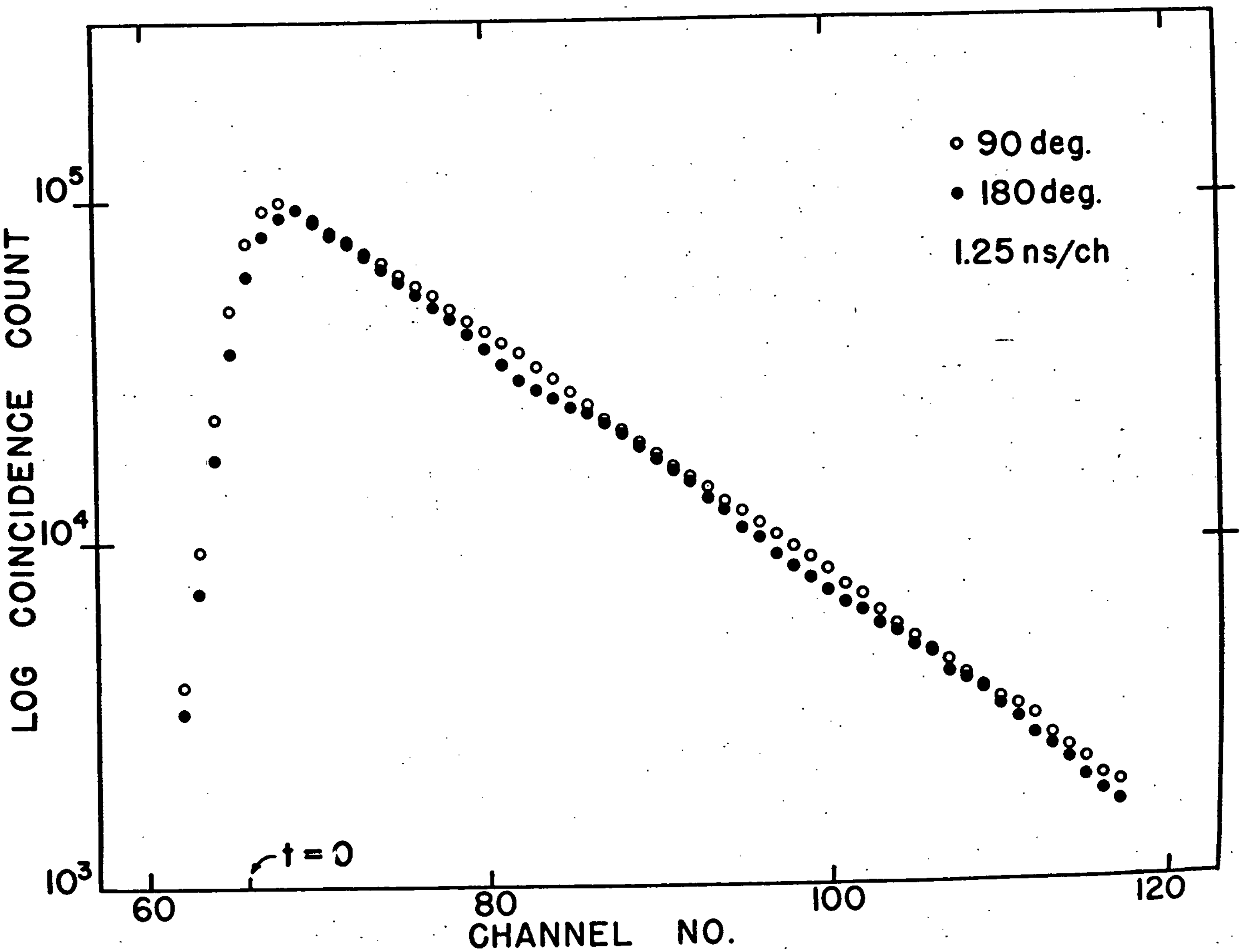
2 - E. Matthias, W. Schneider and R. M. Steffen, Phys. Let. 4, 41 (1963)

3 - P. J. Ousseph and F. L. Canavan, Bull. Am. Phys. Soc. 7, 543 (1962)

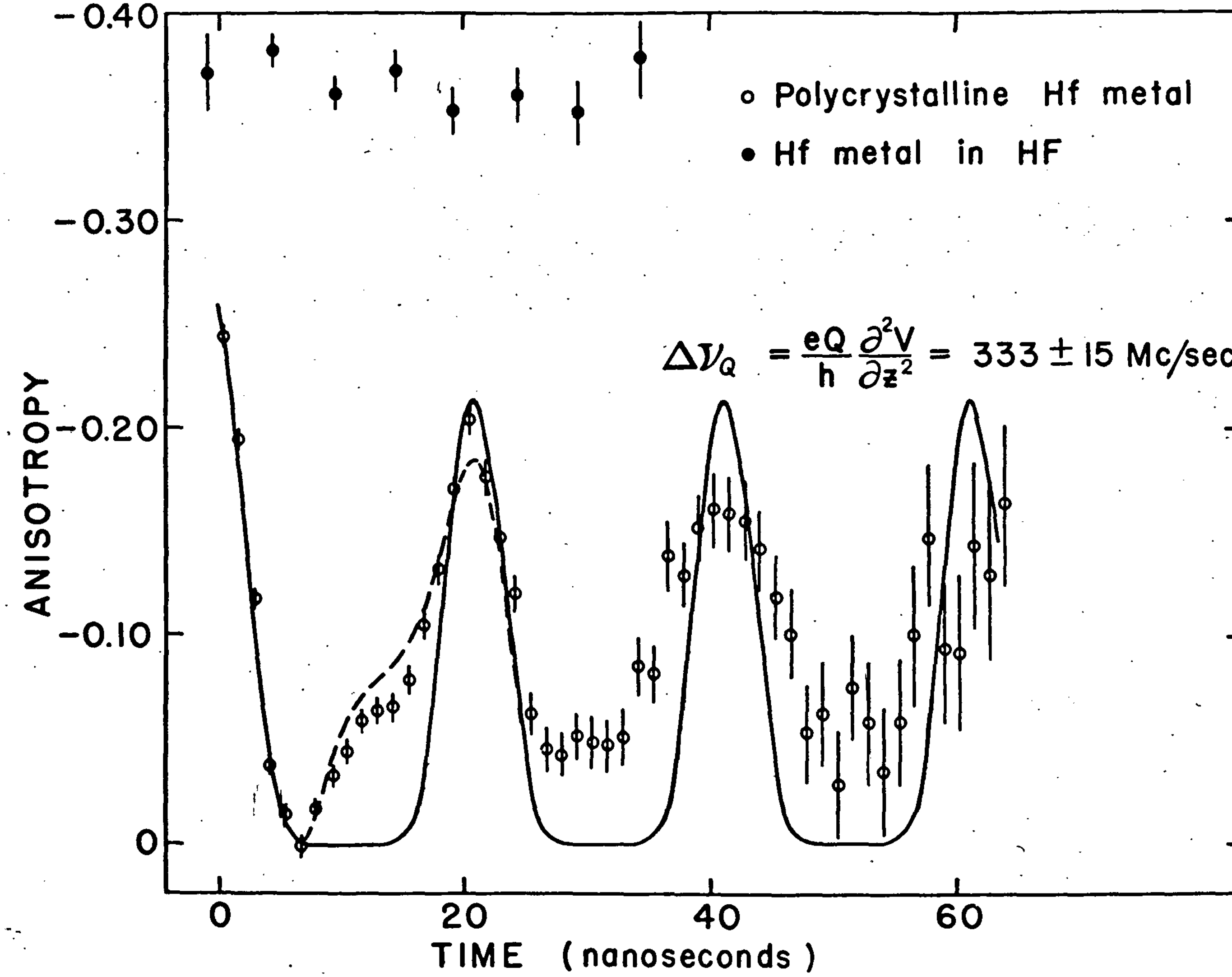
$$W(\theta,t) = \sum_k A_k G_k(t) P_k(\cos\theta)$$

$$I=\frac{5}{2}\begin{cases} G_2(t) = \frac{1}{5}\left[1 + \frac{13}{7}\cos\omega_0 t + \frac{10}{7}\cos 2\omega_0 t + \frac{5}{7}\cos 3\omega_0 t\right] \\ G_4(t) = \frac{1}{9}\left[1 + \frac{15}{7}\cos\omega_0 t + \frac{18}{7}\cos 2\omega_0 t + \frac{23}{7}\cos 3\omega_0 t\right] \\ \omega_0 = \frac{eQ}{\hbar}\frac{\partial^2 V}{\partial^2 z}\left[\frac{3}{2I(2I-1)}\right] \end{cases}$$





90 deg.
180 deg.
1.25 ns/ch
LOG COINCIDENCE COUNT
10^5
10^4
10^3
t = 0
60
80
100
120
CHANNEL NO.


-0.40
-0.30
-0.20
-0.10
0
ANISOTROPY
0
20
40
60
TIME (nanoseconds)
○ Polycrystalline Hf metal
● Hf metal in HF
$\Delta\nu_Q = \frac{eQ}{h}\frac{\partial^2 V}{\partial z^2} = 333 \pm 15$ Mc/sec