Time-dependent quadrupole interactions in ^{129}I

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γ-γ time-differential directional correlation studies have been carried out on the $5/2^+$ (459.6 keV) $5/2^+$ (27.8 keV) $7/2^+$ cascade in ^{129}I using a ^{129}Te^{m+g} source in 4*N* HCl. The measurements reveal time-dependent electric quadrupole perturbation of the correlation. From the plot of $A_2(\bar{t})$ vs $\bar{t}$ (finite time resolution corrected), the obtained values of the relaxation parameter λ_2^{el} and the unperturbed $A_2(0)$ coefficient (solid angle corrected) are $(0.21 \pm 0.01) \times 10^9$ sec^{-1} and $-(0.068 \pm 0.002)$, respectively. The observed λ_2^{el} is consistent with that deduced from the theory of Abragam and Pound.

[RADIOACTIVITY ^{129}Te^{m+g} [from ^{128}Te (n,γ)]; measured γ-$\gamma(\theta,t)$; deduced $\lambda_2^{el}, A_2(0), \bar{G}_2(\infty)$.]

I. INTRODUCTION

Tellurium radicals are known to have ionic structure in HCl solution and generate strong electric field gradients due to electrons in covalent bonds. The field gradients are made time dependent due to the Brownian motion of the ions in the liquid. The interaction of these fields with the electric quadrupole moments of nuclei in their intermediate states is expected to cause time-dependent perturbation of the γ-γ angular correlation. In our earlier work[1] we carried out time-differential directional correlation measurements on the $\frac{5}{2}^+$ (360.3 keV) $\frac{7}{2}^+$ (57.6 keV) $\frac{5}{2}^+$ cascade using ^{127}Te^{m+g} source in HCl solution. A time-dependent electric quadrupole perturbation of the correlation was found. Similar time-differential perturbed angular correlation (PAC) measurements are performed on the (459.6–27.8 keV) γ-γ cascade using ^{129}Te^{m+g} activity in 4*N* HCl solution and are presented in this paper. This work has been undertaken to search for any quadrupole interaction similar to that observed in ^{127}I. Our data in this case also clearly indicate a time-dependent quadrupole perturbation of the correlation.

II. EXPERIMENTAL DETAILS

The ^{129}Te^{m+g} source of high specific activity was obtained from New England Nuclear, U.S.A. It was in the form of concentrated solution in 4*N* HCl. The radiometric purity of the source was >99%. The counting source was prepared by taking a few drops of this chloride solution in a perspex vial of dimensions 3 mm diam × 4 mm.

The timing coincidence spectrometer consisted of 2.54 cm diam × 1.27 cm NE111 plastic scintillator and 3.81 cm diam × 3.81 cm NaI(Tl) detector both coupled to XP-1021 photomultipliers. The fast output on the side of the plastic scintillator was further coupled to a constant fraction pulse height trigger. Aluminum absorbers of appropriate thickness were used in front of both the scintillators to cut off the conversion electrons and ~1.5 MeV β's feeding the 27.8 keV level in ^{129}I. The 459.6 keV gamma photopeak was gated in the NaI(Tl) detector whereas the upper ~75% of the Compton distribution of the 27.8 keV γ transition was gated in the plastic scintillator. The calibration of the TPHC-ADC system was carried out by observing the shift of the prompt resolution curve using a ^{60}Co source with the introduction of accurately calibrated GR874-L30 air dielectric coaxial delay lines and was found to be (0.62 ± 0.01) nsec/channel.

The full width at half maximum (FWHM) of the prompt curve at the above energy settings using a ^{60}Co source was 2.9 nsec with a slope ($\frac{1}{2}$) of 0.2 nsec. The delayed time coincidence spectra were recorded at 90°, 120°, 150°, 180°, 180°, 210°, 240°, and 270° and the data from the corresponding angles in the two quadrants were stored in the 256 channel subgroups of a 4096 channel analyzer. Simultaneously, the singles counts from both detectors were also recorded for normalization purposes.

Figure 1 shows the chance subtracted delayed time coincidence spectra recorded at 90°(I), 120°(II), 150°(III), and 180°(IV). The prompt part in the spectra arises due to the counter-to-counter scattering and other prompt γ-γ cascades. After normalizing with the gate counts, the data at each corresponding channel of the delayed region were analyzed by the weighted least squares method for obtaining $A_2(t)$ coefficients. The delayed region so chosen was well outside the prompt part.

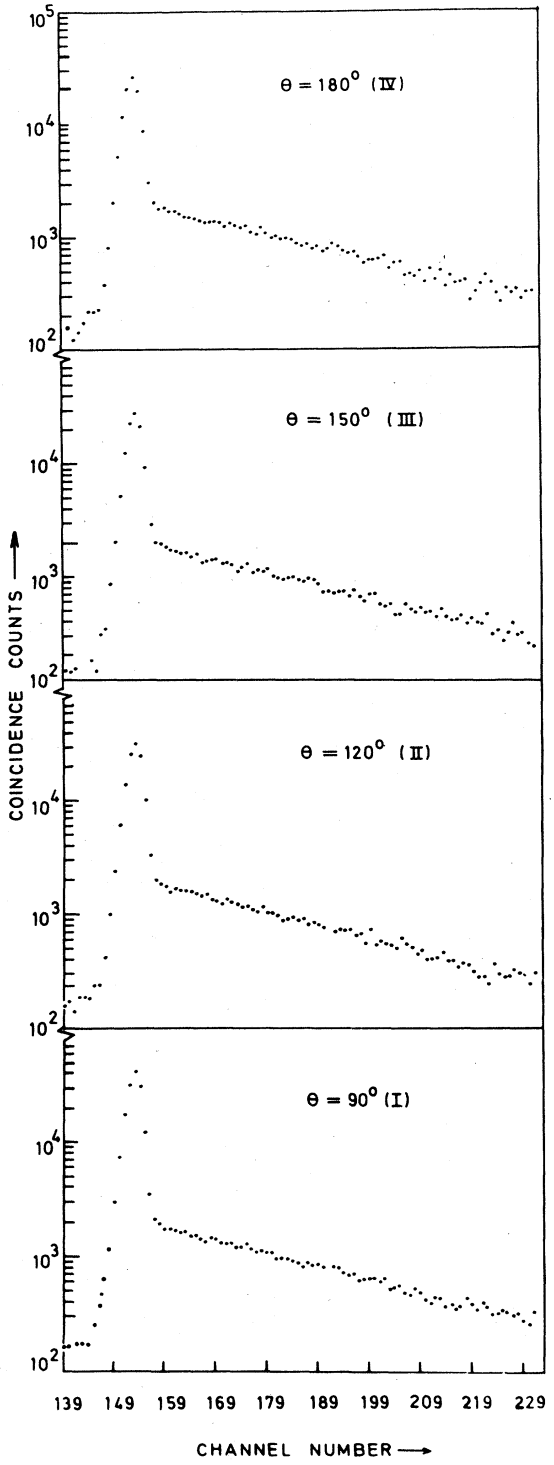

FIG. 1. The chance subtracted delayed time coincidence spectra recorded at $\theta = 90°$ (I), 120° (II), 150° (III), and 180° (IV) for the (459.6–27.8) keV γ-γ cascade in ^{129}I.

The main contribution to the (459.6–27.8) keV γ-γ cascade appears to come from the $\frac{5}{2}^+ \xrightarrow{1083.9\ \gamma} \frac{5}{2}^+ \xrightarrow{27.8\ \gamma} \frac{7}{2}^+$ interfering cascade. This was estimated to be $\leq 1\%$ and hence no correction was applied. The contributions from other γ rays coincident with the 27.8 keV γ ray are negligible because of their weak photon intensities.

The differential nonlinearity (DNL) curve for the system was also recorded. The nonlinearity was estimated to be $< 1\%$ and hence no correction was applied.

An estimate of self-absorption for the 27.8 keV γ ray within the thickness of the liquid $^{129}Te^{m+g}$ source employed for the present measurements was also made.[2] It was found to be $\sim 0.4\%$ and hence no correction for this effect was applied to the cascade anisotropy.

The solid angle correction factor (Q_2) for the correlation geometry and at the energy settings mentioned above was determined experimentally by the method given in Ref. 3. The instrumental angular resolution curve was obtained by recording 511-511 keV coincidences using a ^{22}Na source. The correction factor (Q_2), obtained by direct numerical integration over the experimental resolution curve, is 0.816 ± 0.002.

III. RESULTS

After applying finite time resolution correction[4] to the $A_2(t)$ coefficients, a plot of $A_2(\bar{t})$ vs $\bar{t}$ is shown in Fig. 2, which exhibits the exponential behavior of the perturbation. The $A_2(\bar{t})$ values were least squares fitted to the equation

$$A_2(\bar{t}) = A_2(0) \exp(-\lambda_2^{el} \bar{t}) , \tag{1}$$

yielding λ_2^{el} (the relaxation parameter) $= (0.21 \pm 0.01) \times 10^9$ sec^{-1} and the solid angle uncorrected unperturbed expansion coefficient $A_2(0) = -0.056 \pm 0.002$. After solid angle correction, $A_2(0) = -(0.068 \pm 0.002)$. This is compared with the earlier results in Table I. Using our λ_2^{el} and known $\lambda_0 [T_{1/2} = 16.8 \pm 0.2$ nsec (Ref. 5)] and using the relation

$$\bar{G}_2(\infty) = \frac{\lambda_0}{\lambda_2^{el} + \lambda_0} \tag{2}$$

for a time-dependent perturbation, the integral attenuation coefficient $\bar{G}_2(\infty) = 0.16 \pm 0.01$ is obtained. This value of $\bar{G}_2(\infty)$ is quite small and is, therefore, indicative of a strong perturbation of the correlation.

IV. DISCUSSION

The results of the present time-differential PAC measurements in $^{129}Te^{m+g}$ decay and those of our earlier work[1] in $^{127}Te^{m+g}$ decay both show a time-

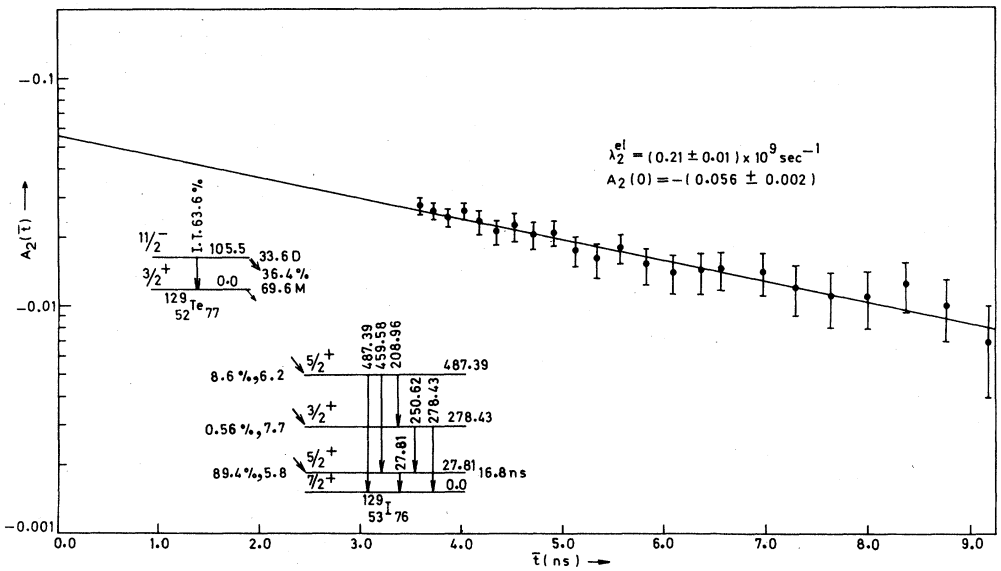

FIG. 2. Plot of $A_2(\bar{t})$ (uncorrected for solid angle) vs $\bar{t}$ from time-differential measurements in ^{129}I for a concentrated $^{129}Te^{m+g}$ source in 4*N* HCl. The relevant decay scheme (Ref. 15) is also shown as an insert.

dependent quadrupole perturbation of the correlations. The source forms used in these measurements are similar. The time-dependent interactions seemingly arise as a result of the rapidly fluctuating electric field gradients due to the Brownian motion of the complex tellurium chloride ions. These fields interact with the nuclear electric quadrupole moments of the first excited states[Q(57.6 keV level in ^{127}I) = −0.71 b and Q(27.8 keV level in ^{129}I) = −0.68 b].

Abragam and Pound[12] have shown that for time-dependent electric quadrupole interactions in the liquid sources, the relaxation parameter λ_2^{el} is given by

$$\lambda_2^{el} = \left(\frac{3}{80}\right)\left(\frac{eQ}{\hbar}\right)^2 \left\langle \left(\frac{\partial^2 V}{\partial Z^2}\right)^2 \right\rangle_{\tau_c} \times \frac{k(k+1)[4I(I+1) - k(k+1) - 1]}{I^2(2I-1)^2} . \quad (3)$$

TABLE I. A_2 coefficients ($A_4 \approx 0$ within experimental error) for the (459.6–27.8) keV γ-γ cascade in ^{129}I.

Reference	Source form	Detectors used	Integral A_2
6	Te metal	NaI-NaI	−0.160 ±0.033
7		NaI-NaI	−0.0489±0.0090
8	HNO_3 solution	NaI-NaI	−0.0148±0.0029
9	HNO_3 solution	NaI-NaI	+0.056 ±0.018
10	HNO_3 solution (dilute)	NaI-Si(Li)	−0.033 ±0.011
		Ge(Li)-Si(Li)	−0.035 ±0.017
		Detectors used	Differential $A_2(0)$
10	Te in Ni matrix	NaI plastic	−0.028±0.007
11	Te metal; ZnTe powder; aqueous solution of K_2TeO_3	NaI plastic	Isotropic
Present work	4*N* HCl solution	NaI-NE 111 plastic	−0.068±0.002

Here, the coupling factor $eQ\langle(\partial^2 V/\partial Z^2)\rangle/\hbar = 2\pi\Delta\nu_Q$, where $\Delta\nu_Q$ is the electric quadrupole interaction frequency. τ_c represents the correlation time for the ions in the liquid. Substituting $\tau_c \approx 2\times10^{-11}$ sec (Refs. 13 and 1) for the concentrated $4N$ HCl solution, $\Delta\nu_Q = 3000$ MHz (Ref. 14) and $I = \frac{5}{2}$ for the 27.8 keV level in ^{129}I in Eq. (3), λ_2^{el} (theory) $= 0.40\times10^9$ sec^{-1} has been obtained. This is roughly in agreement with our λ_2^{el} (expt) $= (0.21\pm0.01)\times10^9$ sec^{-1}. The difference in the two values could perhaps arise due to the uncertainties involved in the estimation of τ_c and $\Delta\nu_Q$. In any case, our differential correlation measurements clearly indicate the presence of time-dependent electric quadrupole interactions in the HCl solution.

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