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Directional correlations of gamma rays in ^{131}I

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The γ radiation following the decay of $^{131}\mathrm{Te}^m$ to levels in ^{131}I has been studied. γ-γ directional correlation measurements have been made using two Ge(Li) detectors. The amplitude mixing ratios for 11 transitions have been determined. A discussion of possible spin assignments for several of the levels is presented.

[RADIOACTIVITY $^{131}\mathrm{Te}^m$ from $^{130}\mathrm{Te}(n,\gamma)$; measured $\gamma\gamma(\theta)$. ^{131}I deduced levels, J, γ mixing ratios. Enriched target, Ge(Li) detectors.]

I. INTRODUCTION

The decay of $^{131}\mathrm{Te}^m$ to levels in ^{131}I with a half-life of 30 h has been recently studied by several investigators.[1-3] The results of these investigations have led to a fairly well-established level scheme. Due to the complexity of the γ-ray spectrum, γ-γ directional correlation studies have not been reported. As a result the spins of most of the levels were unknown and the mixing ratios of the γ rays have not been determined. In the present study γ-γ directional correlation measurements have been made using two Ge(Li) detectors.

II. EXPERIMENTAL PROCEDURE

The sources used in the present study were obtained by irradiating samples of ^{130}Te (enriched to 99.5%) in the University of Michigan Ford nuclear reactor (thermal neutron flux $\approx 3\times 10^{13}$ neutrons/cm^2 sec) for periods of 3–4 days. The radioactive samples were set aside for a period of 4 h. in order that the short-lived activity $^{131}\mathrm{Te}^g$ might decay away. The sources used for the correlation measurements were then obtained by dissolving the radioactive Te in dilute nitric acid and placing a drop of the liquid in a Lucite holder.

The γ-γ directional correlation studies were performed utilizing a 29 and a 32 cm^3 Ge(Li) detector. The 29 cm^3 detector was held fixed and the 32 cm^3 detector was moved from 90 to 270° and back to 90° through the sequence of angles 90, 105, 120, 135, 150, 165, 180° and the supplementary angles in the 180–270° quadrant. The spectra were recorded in a 4096-channel Nuclear Data 50/50 multichannel pulse-height analyzer operating in the two parameter mode. The usual procedure involved setting digital gates for both the peak of interest and a portion of the adjacent Compton region. At least two complete runs were made for each correlation studied.

The data at each angle were corrected for the contribution due to the Compton distribution in the gate, chance coincidences, and source decay. In the case of the 81 keV transition the calculation of chance coincidences included a correction for the presence of the 80 keV transition following ^{131}I decay. All of the data obtained at each of the seven angles in the first quadrant were then added to the data from the supplementary angles in the second quandrant and a least squares fit to the correlation function was performed. The correlation coefficients were then corrected for the finite solid angles subtended by the detectors. No correction was made for attenuation due to the finite lifetimes of the states, since dilute sources were used and all but one of the states have half-lines of less than 1 nsec. In the case of the 1797 keV level ($T_{1/2}=6$ nsec) it would be expected that the correlation would be attenuated by a few percent. However, since in the analysis of the correlation data the uncertainties obtained in the coefficients were doubled, it was assumed that the attenuation effect could be ignored.

III. ANALYSIS AND RESULTS

The results of the γ-γ directional correlation measurements are summarized in Table I, which gives the corrected correlation coefficients and their standard deviations. These standard deviations reflect the goodness of fit to the correlation function. The 453-150 keV correlation had been previously studied by Ahmed[4] in an investigation of the decay of the ground state of ^{131}Te. He reported coefficients of $A_2 = 0.135 \pm 0.111$ and $A_4 = 0.005 \pm 0.015$. The present values are in agreement with this result. No other correlations reported in the present study were previously reported.

A. Triple cascades

It has been shown by Chow, Gardulski, and Wiedenbeck[5] that if correlation coefficients are obtained for the first-second, second-third, and first-third correlations in a triple cascade, then the mixing ratio of the second transition will depend only on the spins of the intermediate levels and the experimental correlation coefficients and may be readily determined by a graphical method. Using this method a range of values for the mixing ratios of the 102, 201, 241, 783, and 822 keV transitions were determined for all of the possible spin sequences that are allowed by the multipolarities of the transitions as deduced from the reported conversion coefficients.[1,3] Because all of the associated levels are fed by the $\frac{11}{2}-$ metastable state of ^{131}Te, all half-integer spin values from $\frac{7}{2}$ to $\frac{15}{2}$ were examined in the analysis of the data. These mixing ratios were then used to determine the mixing ratios of the preceding and succeeding transitions for the various spin sequences. By requiring that the mixing ratio of a γ ray treated as a second transition be consistent with the value obtained when it is treated as a first or third transition, it was possible to exclude many of the spin sequences. By further requiring that the mixing ratios obtained be consistent with the values deduced from the reported conversion coefficients,[1,3] many of the remaining sequences were eliminated.

The results of this analysis are presented in Table II. Column 3 gives the values of δ, the mixing ratio, and the uncertainties deduced from the data of the present investigation. These values follow the sign convention of Krane and Steffen.[6] Column 4 gives the values of $|\delta|$ deduced from the reported conversion coefficients.[3]

The 335-794-852 triple cascade was also analyzed. Since the results of this analysis eliminated only a few of many possible spin sequences, these results are not presented.

B. Simple correlations

The remaining correlations were analyzed as simple correlations in the conventional manner. The results of this analysis are presented in Table III. The mixing ratio for the 150 keV transition was deduced from the reported conversion coefficient[3] to be $|\delta| \leq 0.45$. The values of $\delta(150)$

TABLE I. γ-γ directional correlation coefficients in ^{131}I.

Cascade [E (keV)]	A_2	A_4
81-103	0.050± 0.027	−0.088± 0.036
81-201	0.056± 0.089	0.036± 0.120
81-241	−0.019± 0.026	0.017± 0.035
102-201	0.190± 0.030	−0.096± 0.041
102-241	0.009± 0.029	−0.067± 0.039
102-783	−0.120± 0.035	0.089± 0.048
102-822	0.215± 0.013	0.053± 0.018
201-774	−0.063± 0.023	−0.008± 0.031
201-822	0.087± 0.018	−0.001± 0.025
241-774	0.216± 0.024	−0.006± 0.033
241-783	0.110± 0.016	0.005± 0.021
335-794	−0.136± 0.019	0.063± 0.025
335-852	−0.407± 0.036	0.005± 0.048
453-150	0.154± 0.030	−0.069± 0.041
783-774	0.078± 0.044	0.094± 0.060
794-852	0.185± 0.020	−0.005± 0.027
822-774	−0.145± 0.036	−0.083± 0.049
910-150	0.095± 0.016	−0.067± 0.022
1126-774	−0.028± 0.025	−0.075± 0.033
1206-774	0.184± 0.093	−0.109± 0.124

TABLE II. Mixing ratios of transitions in ^{131}I deduced from triple cascades.

E_γ (keV)	Sequence	δ [a]	$\|\delta\|$ [b]
81	$\frac{7}{2}(D,Q)\frac{9}{2}$	0.169± 0.352	<0.54
	$\frac{9}{2}(D,Q)\frac{11}{2}$	−0.029± 0.138	
	$\frac{11}{2}(D,Q)\frac{9}{2}$	−0.195± 0.345	
	$\frac{13}{2}(D,Q)\frac{11}{2}$	−0.039± 0.164	
102	$\frac{9}{2}(D,Q)\frac{11}{2}$	0.00 ± 0.040	<0.38
	$\frac{11}{2}(D,Q)\frac{13}{2}$	0.033± 0.007	
201	$\frac{11}{2}(D,Q)\frac{9}{2}$	−0.035± 0.035	<0.13
	$\frac{13}{2}(D,Q)\frac{11}{2}$	−0.060± 0.009	
241	$\frac{11}{2}(D,Q)\frac{13}{2}$	−0.263± 0.007 or −0.028± 0.022	<0.24
	$\frac{13}{2}(D,Q)\frac{11}{2}$	0.236± 0.004	
774	$\frac{9}{2}(D,Q)\frac{7}{2}$	3.8 ± 3.4	Any value
	$\frac{11}{2}(D,Q)\frac{7}{2}$	0.00 ± 0.21	<0.21
783	$\frac{11}{2}(D,Q)\frac{9}{2}$	3.51 ± 0.11	
	$\frac{13}{2}(D,Q)\frac{11}{2}$	−0.025± 0.025 [c] 3.63 ± 0.22 [d]	
822	$\frac{9}{2}(D,Q)\frac{11}{2}$	0.100± 0.150	
	$\frac{11}{2}(D,Q)\frac{9}{2}$	−0.043± 0.068	

[a] Sign convention of Krane and Steffen (Ref. 6).

[b] Reference 3. The uncertainties of the conversion coefficients have been doubled in our calculation of the mixing ratio.

[c] If $\delta(241) = -0.028 \pm 0.022$.

[d] If $\delta(241) = -0.263 \pm 0.007$.

TABLE III. Mixing ratios [sign convention of Krane and Steffen (Ref. 6)] of transitions in ^{131}I deduced from simple correlations.

Cascade [E (keV)]	Sequence	δ_1	δ_2
453-150	$\frac{3}{2}(D,Q)\frac{5}{2}(D,Q)\frac{7}{2}$	-17.7 ± 17.3 2.9 ± 3.0	-0.32 ± 0.14 0.21 ± 0.25
	$\frac{5}{2}(D,Q)\frac{5}{2}(D,Q)\frac{7}{2}$	-1.1 ± 1.3 >0.54 or <-19	-0.33 ± 0.12 0.25 ± 0.21
910-150	$\frac{7}{2}(D,Q)\frac{5}{2}(D,Q)\frac{7}{2}$	1.39 ± 1.14 >5.9 or <0.03	-0.33 ± 0.13 0.21 ± 0.25
	$\frac{9}{2}(Q,O)\frac{5}{2}(D,Q)\frac{7}{2}$	0.92 ± 0.94 <-10.6 or >0.49	-0.34 ± 0.12 0.18 ± 0.28
1126-774	$\frac{11}{2}(D,Q)\frac{9}{2}(D,Q)\frac{7}{2}$	0.00 ± 0.20 or <-18 or >3.9	3.8 ± 3.4
	$\frac{9}{2}(D,Q)\frac{11}{2}(Q,O)\frac{7}{2}$	-0.070 ± 0.160 or <-12.6 or >4	0.00 ± 0.21

shown in column 4 are those which result in a solution for the mixing ratio of the other transition in the sequence. The value of the mixing ratio of the 774 keV transition is taken from Table II. All of the results presented in Table III were obtained by allowing the correlation coefficients to assume a range of minus to plus two standard deviations.

IV. DISCUSSION

A partial level scheme of ^{131}I is presented in Fig. 1. Only those levels and transitions studied in the present investigation are shown.

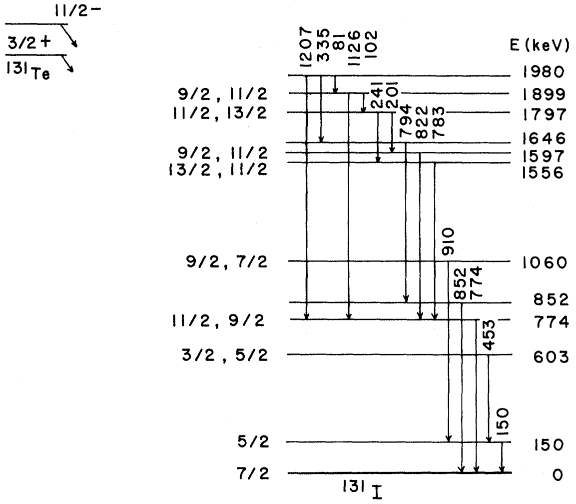

FIG. 1. Partial level scheme of ^{131}I deduced from present study. In the cases of the 774, 1556, 1597, 1797, and 1899 keV levels there are only two possible spin sequences. These two possibilities are the sequences which appear in the same column of spin values.

The spin and parity of the ground state and first excited state have been well established in previous studies.[4,7] The 603 keV level has been previously[7] assigned a spin of $\frac{5}{2}$ in analogy to states in ^{127}I and ^{129}I. The present data are consistent with either an assignment of $\frac{3}{2}$ or $\frac{5}{2}$ for this level. The spin of the 1060 keV level has been previously suggested to be $\frac{5}{2}$, $\frac{7}{2}$, or $\frac{9}{2}$. The fact that this level is not fed in the ground state decay of ^{131}Te ($J = \frac{3}{2}+$) would favor an assignment of either $\frac{7}{2}$ or $\frac{9}{2}$. The correlation data of the present study are consistent with either assignment.

The fact that the 774 keV level is fed by the $\frac{11}{2}$-metastable state of ^{131}Te suggests a spin of $\frac{7}{2}$, $\frac{9}{2}$, $\frac{11}{2}$, or $\frac{13}{2}$. The strong γ transition from the 774 keV level to the $\frac{7}{2}$ ground state excludes the value of $\frac{13}{2}$. The 201-822 keV and 241-783 keV correlation data are not consistent with a spin value of $\frac{7}{2}$ for the 774 keV level. Therefore, this level is either $\frac{9}{2}$ or $\frac{11}{2}$. This is consistent with the fact that no feeding of this level from the $\frac{3}{2}+$ ground state of ^{131}Te has been observed and the fact that no transition from the 774 keV level to the $\frac{5}{2}$ level at 150 keV has been observed.

The results of the triple cascade analysis require that if the 774 keV level is $\frac{9}{2}$, then the 1556 and 1597 keV levels are both $\frac{11}{2}$, and if the 774 keV level is $\frac{11}{2}$, then the 1556 keV level is $\frac{13}{2}$ and the 1597 keV level is $\frac{9}{2}$. The fact that no transition from the 1597 keV level to the $\frac{7}{2}+$ ground state has been observed would seem to favor the assignment of $\frac{11}{2}$ to both these levels. However, the dissimilar branching of these two levels[3] tends to favor the assignment of $\frac{13}{2}$ to the 1556 keV level and $\frac{9}{2}$ to the 1597 keV level.

In the analysis of the triple cascade data for the 1797 keV level all half-integer values from $\frac{7}{2}$

through $\frac{15}{2}$ were studied. The only spin values which are consistent with the correlation data are $\frac{11}{2}$ or $\frac{13}{2}$. If the 1556 and 1597 keV levels are both $\frac{11}{2}$, then the 1797 keV level must be $\frac{13}{2}$. If the 1556 keV level is $\frac{13}{2}$ and the 1597 keV level is $\frac{9}{2}$, then the 1797 keV level must be $\frac{11}{2}$.

All half-integer spin values from $\frac{7}{2}$ through $\frac{15}{2}$ were studied in the analysis of the 1889 and 1980 keV levels. The results of these studies require that the 1889 keV level be $\frac{11}{2}$ if both the 1556 and 1597 keV levels are $\frac{11}{2}$ or $\frac{9}{2}$ if the 1556 keV level is $\frac{13}{2}$ and the 1597 keV level is $\frac{9}{2}$. The fact that no transition from the 1899 keV level to the $\frac{7}{2}+$ ground state has been observed[3] tends to favor the assignment of $\frac{11}{2}$ for the 1899 keV level. The correlation data are consistent with a spin assignment of $\frac{7}{2}$, $\frac{9}{2}$, $\frac{11}{2}$, or $\frac{13}{2}$ for the 1980 keV level.

Discussions of the systematics of the odd mass iodine nuclides have been previously published by Beyer, Berzins, and Kelly[2] and by Beyer and Kelly.[3] These papers also contain comparisons of the experimental results to recent theoretical calculations. Their results and the results of the present study indicate that the theoretical calculations cannot even qualitatively account for the observed level structure of ^{131}I.

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