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DIRECTIONAL CORRELATIONS OF GAMMA RAYS IN ^{77}As †

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Abstract: Directional correlation measurements have been made for γ-transitions in ^{77}As following the decay of 11.30 h ^{77}Ge using two Ge(Li) detectors. Using the method of Chow *et al.*, mixing ratios of γ-transitions and the spins of seven levels have been deduced assuming only a ground-state spin of $\frac{3}{2}$. Levels for which spins were deduced are 216($\frac{3}{2}$), 264($\frac{5}{2}$), 475($\frac{9}{2}$), 632($\frac{5}{2}$), 1189($\frac{7}{2}$), 1458($\frac{3}{2}$) and 1528($\frac{5}{2}$) keV.

E | RADIOACTIVITY ^{77}Ge [from ^{76}Ge(n, γ)]; measured $\gamma\gamma(\theta)$. ^{77}As levels deduced J, γ mixing ratios.

1. Introduction

Previous investigators [1-4]) of directional correlations of γ-rays in ^{77}As following the decay of 11.30 h ^{77}Ge have used at least one NaI(Tl) detector in their experiments. In addition, no results for triple cascades in ^{77}As have been reported. The present work employs two Ge(Li) detectors and uses their improved resolution to obtain results for nineteen correlations, twelve of which have not been previously reported. Results for directional correlations of ten triple cascades have also been obtained. Using these results in the method of Chow, Gardulski, and Wiedenbeck [5]) and assuming only that the spin of the ground state of ^{77}As is $\frac{3}{2}$, the mixing ratios of the 367 and 416 keV transitions and the spins of the 216, 264 and 632 keV levels were deduced. It was then possible to deduce the spins of the 475, 1189, 1458 and 1528 keV levels and mixing ratios for several other γ-transitions.

2. Experimental procedures

Samples of GeO_2 enriched to 74 % in ^{76}Ge were irradiated in the thermal neutron flux ($\approx 3 \times 10^{13}$ n/cm$^2 \cdot$ sec) of the University of Michigan Ford Nuclear Reactor for periods of approximately 36 h. The samples were set aside for about eight hours to allow the 82 min ^{75}Ge to decay away and then dissolved in hydroflouric acid and placed in lucite holders.

The directional correlation studies utilized 29 and 32 cm^3 Ge(Li) detectors. The

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29 cm^3 detector was held fixed and the 32 cm^3 detector was moved from 90° to 270°, stopping at 15° intervals for 90 min. The spectra were recorded in a Nuclear Data 50/50 multichannel analyzer operating in the two-parameter mode. Digital gates were set for both the peak of interest and an adjacent Compton region.

Corrections were made to the data at each angle for chance coincidences, source decay and contributions due to Compton scattering. The data resulting from the seven angles in the first quadrant were then added to those from the second quadrant, and a least squares fit to the correlation function was performed following the method of Rose [6]. Geometric corrections to the correlation coefficients due to the finite angle subtended at the source by the detectors were obtained using the method of Camp and Van Lehn [7].

3. Analysis and results

The results of the γ-γ directional correlation measurements are given in table 1. A partial level scheme [8] is presented in fig. 1. Only transitions and levels studied in the present investigation are shown. A γ-spectrum taken with the 29 cm^3 detector is presented in fig. 2. Graphs of the normalized data and the correlation function

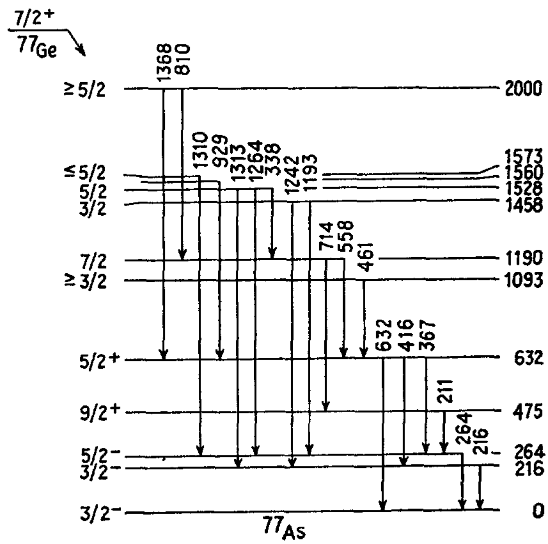

Fig. 1. Partial level scheme of ^{77}As [ref. [8]] with spins deduced in the present study.

$W(\theta)$ before making geometrical corrections are presented for the (367–264) keV correlation and the (558–264) keV first-third correlation in figs. 3 and 4, respectively. The sign convention of Krane and Steffen [9] for the mixing ratio δ of the γ-transitions is used throughout.

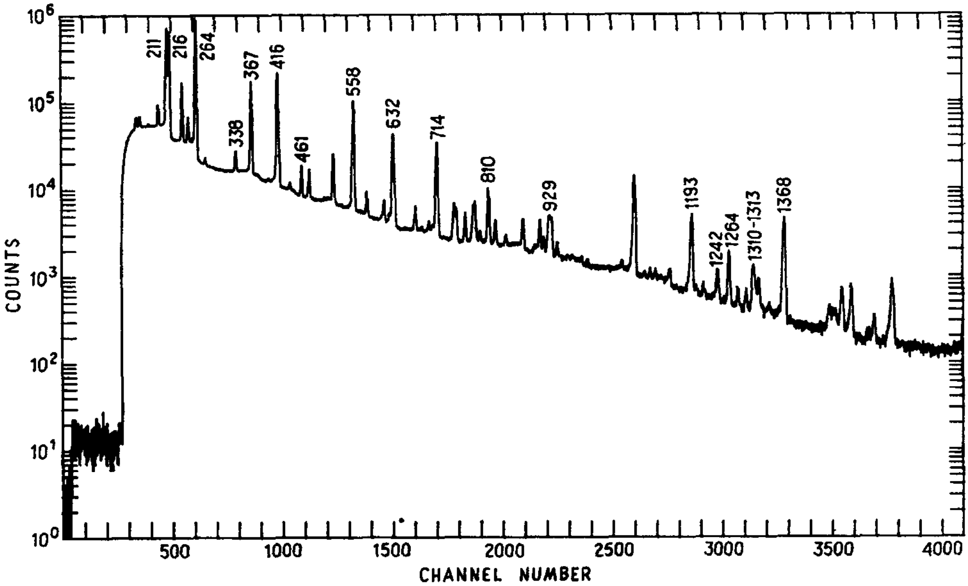

Fig. 2. Gamma-ray spectrum following the decay of 11.30 ^{77}Ge to levels in ^{77}As. Only transitions used in the correlations are labeled.

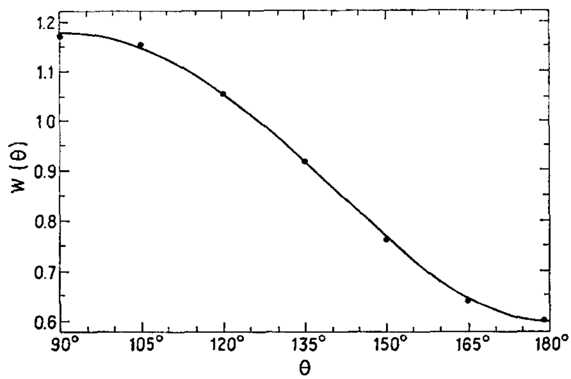

Fig. 3. Normalized data values and the correlation function $W(\theta)$ (before geometric corrections) *versus* the angle θ between the detectors for the (367–264) keV correlation. Errors of the data values are less than 0.3 %.

3.1. ANALYSIS OF THE 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 depends only on the spins of the intermediate levels and is a solution of a polynomial of fourth order in δ. This method was used to determine the mixing ratios of the 367 and

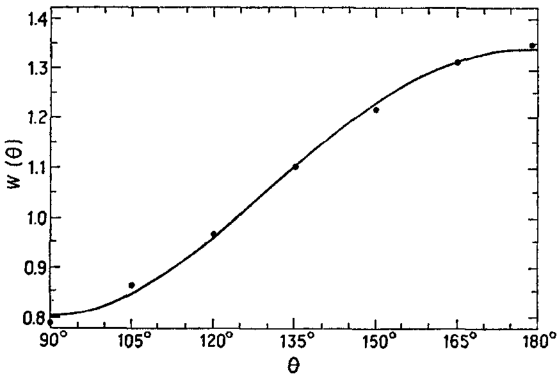

Fig. 4. Normalized data values and the correlation function $W(\theta)$ (before geometric corrections) *versus* the angle θ between the detectors for the (558–264) keV correlation. Errors of the data values are less than 0.4 %.

TABLE 1

The γ-γ directional correlation coefficients in ^{77}As

Cascade [E(keV)]	A_{22}	A_{44}
211–264	-0.175 ± 0.003	-0.028 ± 0.004
416–216	0.005 ± 0.003	-0.003 ± 0.004
462–216	-0.005 ± 0.026	-0.020 ± 0.035
558–216	-0.014 ± 0.004	-0.039 ± 0.006
929–216	0.050 ± 0.033	-0.095 ± 0.044
1242–216	0.170 ± 0.065	0.139 ± 0.088
1313–216	0.101 ± 0.038	0.043 ± 0.052
1368–216	0.030 ± 0.024	-0.025 ± 0.032
367–264	-0.393 ± 0.003	-0.032 ± 0.004
558–264	0.388 ± 0.012	-0.034 ± 0.016
1193–264	0.643 ± 0.004	0.051 ± 0.006
1264–264	-0.494 ± 0.045	0.103 ± 0.059
1310–264	-0.471 ± 0.042	0.050 ± 0.056
1368–264	0.119 ± 0.018	0.001 ± 0.025
338–416	0.061 ± 0.014	-0.089 ± 0.018
338–558	0.089 ± 0.026	-0.001 ± 0.035
558–367	-0.108 ± 0.007	-0.019 ± 0.009
810–367	-0.043 ± 0.031	0.008 ± 0.042
1368–367	0.059 ± 0.062	-0.035 ± 0.083
461–416	0.087 ± 0.031	-0.112 ± 0.043
558–416	0.205 ± 0.003	-0.010 ± 0.004
810–416	0.253 ± 0.018	-0.062 ± 0.025
929–416	0.057 ± 0.056	0.095 ± 0.077
1368–416	0.043 ± 0.024	-0.035 ± 0.032
558–632	0.238 ± 0.014	-0.049 ± 0.019
810–558	0.446 ± 0.031	-0.008 ± 0.042
810–632	0.150 ± 0.029	-0.033 ± 0.039
1368–632	0.053 ± 0.032	-0.041 ± 0.042
810–714	0.217 ± 0.035	0.003 ± 0.047

TABLE 2

Mixing ratios deduced in the present study

E_γ (keV)	Sequence [a]	δ
211	$\frac{9}{2}$(Q, O)$\frac{5}{2}$	0.100 ± 0.007
		3.77 ± 0.09 [b]
264	$\frac{5}{2}$(D, Q)$\frac{3}{2}$	-2.26 ± 0.02
		-0.128 ± 0.004
338	$\frac{5}{2}$(D, Q)$\frac{7}{2}$	-0.129 ± 0.016
		12.0 ± 2.0
367	$\frac{5}{2}$(D, Q)$\frac{5}{2}$	-0.290 ± 0.009
416	$\frac{5}{2}$(D, Q)$\frac{3}{2}$	0.087 ± 0.019
558	$\frac{7}{2}$(D, Q)$\frac{5}{2}$	-1.1 ± 0.4
632	$\frac{5}{2}$(D, Q)$\frac{3}{2}$	0.064 ± 0.015
		-4.4 ± 0.3
714	$\frac{7}{2}$(D, Q)$\frac{9}{2}$	0.26 ± 0.08
		6.0 ± 3.0
1193	$\frac{3}{2}$(D, Q)$\frac{5}{2}$	0.90 ± 0.06
		0.61 ± 0.04
1264	$\frac{5}{2}$(D, Q)$\frac{5}{2}$	-0.6 ± 0.3

The sign convention of Krane and Steffen [9]) is used for δ.

[a]) Dipole, quadrupole and octupole radiation are denoted by D, Q and O, respectively.

[b]) The value for the lifetime of the 475 keV level makes this value for $\delta(211)$ unlikely.

416 keV transitions. Correlations were studied to determine $\delta(558)$ also, but statistical errors were too large to produce conclusive results.

Mixing ratios for the 367 and 416 keV transitions were determined for all possible spin assignments for the 216, 264 and 632 keV levels with the assumption that the spin of the ground state is $\frac{3}{2}$. The value $\frac{1}{2}$ was ruled out for the spin of the 216 level because the (1242–216) and (1313–216) keV correlations were not isotropic. Requiring that $\delta(367)$ produce real values for both $\delta(264)$ and $\delta(558)$ eliminated many possibilities. Further, requiring that $\delta(416)$ produce the same real value for $\delta(558)$ as that produced by $\delta(367)$ eliminated all but one sequence of spin assignments. The criterion for consistency was agreement within two standard deviations, but the deduced spin sequence produces agreement within one standard deviation. The results are presented in fig. 1 and in table 2.

3.2. ANALYSIS OF THE SIMPLE CORRELATIONS

The first-second correlations were analyzed in the usual manner and incorporated the above results. Spins were eliminated whenever they produced an imaginary value for the mixing ratio of one of the γ-transitions. The spin $\frac{7}{2}$ was eliminated for the 475 keV level because the lifetime of that level (116 μs, ref. [10])) precludes dipole transitions to the $\frac{3}{2}$ ground state and the 264 keV level with spin $\frac{5}{2}$. Results are presented in fig. 1 and in table 2. Mixing ratios of transitions between levels for which more than one spin sequence is possible are not shown; $\delta(216)$ and $\delta(1242)$ cannot be deduced from the present data.

4. Discussion

Previous results of directional correlation studies in ^{77}As are presented in table 3. In general, the results of the present work agree best with those of Van der Kooi and Van den Bold [2]). Disagreement between present and previous results for the (367–264), (558–416) and (558–632) keV correlations is probably due to the much better resolution of the Ge(Li) detectors used in the present study compared to the poorer resolution of NaI(Tl) detectors, at least one of which was used in all previous investigations. The complex γ-spectrum allows for competing cascades to attenuate the correlations if the resolution of the detectors is not sufficient. Comparison of the Ge(Li) spectrum (fig. 2) in the present work with a typical NaI(Tl) spectrum [e.g. fig. 2 in ref. [2])] shows the improvement in resolution.

Spin assignments made in the present investigation agree with those currently accepted [8]). Recently, Betts *et al.* [11]) deduced the spin and parity of the 2000 keV level to be $\frac{9}{2}^+$ using data from the reaction ^{76}Ge(^{3}He, d). The present study is not in disagreement with those results.

Several different models have been proposed for odd-*Z* nuclei in this mass region with varying degrees of success. The model of Kisslinger and Sorensen [12]) uses the

TABLE 3

Previously measured directional correlation coefficients in ^{77}As

Cascade [*E*(keV)]	A_{22}	A_{44}	Refs.
(211–264)	−0.190±0.004	−0.009±0.004	[1])
	−0.173±0.005	−0.011±0.008	[2])
	−0.175±0.003	−0.028±0.004	present work
(416–216)	−0.031±0.007	0.017±0.009	[1])
	0.003±0.015	0.024±0.029	[2])
	0.005±0.003	−0.003±0.004	present work
(367–264)	−0.321±0.009	−0.007±0.012	[1])
	−0.360±0.012	−0.023±0.019	[2])
	−0.393±0.003	−0.032±0.004	present work
(558–367)	−0.035±0.020	0.068±0.020	[1])
	−0.14 ±0.05	−0.05 ±0.07	[2])
	−0.108±0.007	−0.019±0.009	present work
(558–416)	0.163±0.016	0.052±0.024	[1])
	0.16 ±0.04	−0.01 ±0.05	[2])
	0.123±0.006	−0.003±0.010	[4])
	0.205±0.003	−0.010±0.004	present work
(558–632)	0.085±0.027	0.065±0.030	[1])
	0.13 ±0.05	−0.28 ±0.10	[2])
	0.13 ±0.06	0.11 ±0.07	[3])
	0.238±0.014	−0.049±0.019	present work
(810–558)	0.37 ±0.13	−0.03 ±0.16	[2])
	0.446±0.031	−0.008±0.042	present work

quasiparticle random-phase approximation with pairing plus quadrupole force as a residual interaction. While this model agrees with experiment in other mass regions, it predicts a ground-state spin of $\frac{1}{2}$ and two levels with spins $\frac{5}{2}$ and $\frac{3}{2}$ near 250 keV for ^{77}As. Kisslinger and Kumar [13]) modified this model by assuming the entire effect of the static quadrupole is given by the anharmonicity of the doubly even system and correctly predict the $\frac{3}{2}^-$ ground state. They also suggest $\frac{5}{2}^-$ and $\frac{1}{2}^-$ levels near 150 keV.

Scholz and Malik [14]) account for the low-lying $\frac{9}{2}^+$ and $\frac{5}{2}^+$ levels using a Coriolis coupling model with a residual interaction of the pairing type and indicate a positive deformation of the nucleus. The $\frac{3}{2}^+$ and $\frac{5}{2}^+$ levels predicted by this model to be about 1 MeV above the $\frac{9}{2}^+$ level may be the 1458 and 1528 keV levels which have these spins indicated by the present work. Betts *et al.* [15]) propose that the model correctly predicts the $\frac{9}{2}^+$ 2000 keV level.

Imanishi *et al.* [16]) consider the motion of an unpaired quasiparticle moving in a Nilsson orbit to be coupled by a Coriolis force to the rotational motion and predict the lower odd-parity levels.

Paradellis and Hontzeas [17]) note that doubly even nuclei in this mass region do not exhibit the characteristic spectra of a deformed nucleus and object to the model of Scholz and Malik on that basis. They consider each nucleus to consist of a doubly even vibrating core and an extra-core proton quasiparticle. The interaction Hamiltonian for the quasiparticle core includes a dipole and a quadrupole term. They correctly predict the low-lying $\frac{9}{2}^+$ and $\frac{5}{2}^+$ levels in ^{75}As and also predict $\frac{3}{2}^+$ and $\frac{5}{2}^+$ levels about 1 MeV above the $\frac{9}{2}^+$ level. These results should also be applicable to ^{77}As which has a similar level structure.

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