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ENERGIES AND MIXING RATIOS OF TRANSITIONS IN ^{72}Ge †

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Abstract: The lower energy γ-rays of ^{72}Ge from the decay of 14 h ^{72}Ga have been studied using a 2 m curved-crystal spectrometer. Mixing ratios for the 601, 630, 894 and 1051 keV transitions were determined from the γ-γ directional correlations The E0 content of the 630 keV, $2^{+\prime} \rightarrow 2^{+}$ transition was found to be less than 2%. A spin of 3 for the 2065 keV level has been uniquely determined

E RADIOACTIVITY ^{72}Ga [from ^{71}Ga(n, γ)]; measured E_γ, $\gamma\gamma(\theta)$. ^{72}Ge deduced mixing ratios, spin Curved-crystal spectrometer and Ge(Li) detectors

1. Introduction

The level scheme of ^{72}Ge has been investigated by various authors [1-10]). It has been established that ^{72}Ge is a deformed nucleus, whose low lying level structure can be explained by a vibrational model. Recently, Camp [1]) and Rester *et al.* [2, 3]) have measured the γ-ray energies of transitions in ^{72}Ge occurring in the decays of 14.1 h ^{72}Ga and 26.0 h ^{72}As, using Ge(Li) detectors. However, some of their results, especially the low energy transitions, have large uncertainties. In the present work, a curved-crystal spectrometer was used to make precision energy measurements of many of the γ-rays below 900 keV. Two Ge(Li) detectors were used in the directional correlation measurements of the present study. The results from this system have much lower uncertainties than previous results [9, 10]) and allow one to determine the mixing ratios of the 1051, 894, 630 and 601 keV transitions. The E0 content of the 630 keV transition was determined for the first time by a method proposed by Anicin *et al.* [11])

2. Energy determination

The radioactive ^{72}Ga sources were prepared by neutron irradiation of natural gallium in the University of Michigan Ford Reactor. The γ-ray energies occurring in the β-decay of ^{72}Ga were measured with a 2 m Ge(02$\bar{2}$) curved-crystal spectrometer

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TABLE 1

Energies (in keV) of γ-rays in ^{72}Ge from the decay of ^{72}Ga

Present measurement	Camp [a])	Rester *et al.* [b])
289.313±0.066	289 5 ±0 2	289.3 ±0.3
336 632±0.042	336 6 ±0 2	336 3 ±0.3
381.242±0.080	381 2 ±0 2	381 2 ±0 2
428 417±0 177	428.4 ±0 2	428 3 ±0 3
479 228±0.098	479 6 ±0 3	479.1 ±0 3
587.440±0.240	587 4 ±0.3	587 9 ±0 4
600.948±0.028	600 9 ±0.01	600 85±0 03
629.956±0 036	629 9 ±0.1	629 86±0 04
786.438±0 083	786.5 ±0.1	786.4 ±0.1
810 195±0.088	810.2 ±0 2	810 24±0 09
834.026±0 034	833.95±0 05	834 02±0.03
894 254±0 094	894 2 ±0 1	894 22±0 05

[a]) Ref [1]). [b]) Ref [2])

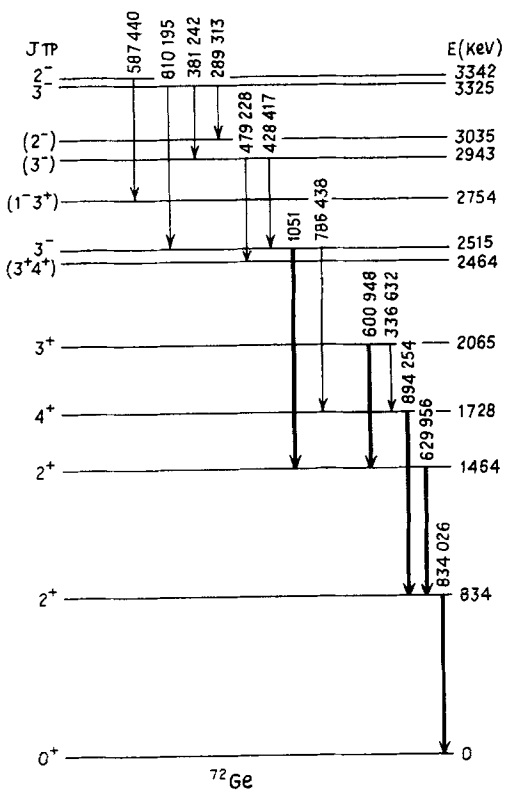

Fig. 1 An abbreviated level scheme for ^{72}Ge incorporating the curved-crystal energy measurements of this study The decay scheme is from refs. [1, 2]) The transitions in heavy lines are the ones used in the directional correlation measurements

described by Reidy and Wiedenbeck [12]). Because of the low intensity of the low energy γ-rays, only twelve transitions could be measured. These energy results are presented in fig. 1 and table 1. The results of Camp [1]) and Rester *et al.* [2]) are also presented in table 1 for comparison.

3. Gamma-gamma directional correlations

The directional correlation system and method of analysis have been described elsewhere [13]). The sign convention of the mixing ratios, δ, is that of Biedenharn and Rose [14]) and Dzhelepov *et al.* [16]).

In this work, the 601-630, 1051- 630, 630-834, 894-834, 601-630-834 and 1051-630-834 keV correlations were measured. The results and a comparison with previous results are presented in table 2. The 601-630 and 1051-630 correlations have not been measured previously. With the exception of the 601-630-834 keV correlation, all of the correlation coefficients determined in this work differ from previously published results [9, 10]) Earlier correlation measurements [9, 10]) used some combination of NaI(Tl), or NaI(Tl) and Ge(Li) detectors. The present measurements were made utilizing two large volume Ge(Li) detectors. This system enables one to gate the photopeaks of interest and to account for interfering correlations more precisely.

The spins and parities of the ground state, 834, 1728, 2065 and 2514 keV levels have been determined [5, 6, 8–10]). The directional correlation measurements of Monahan and Arns [9]) limited the spin of the 2065 keV level to 1 or 3. They assign a spin of 3 on the basis that there is no observed transition to the ground state from this level. The analysis of the present 601-630 keV correlation, using $\delta(630) = 10.3 \pm 1.3$ from the present 630-834 keV correlation, is only consistent with a 3(D, Q)2(M1, E2)2 sequence and a mixing ratio $\delta(601) = 46^{+\infty}_{-25}$

The mixing ratio of the 894 keV transition was determined from the 894-834 keV transitions to be $\delta(894) = -0.039 \pm 0.009$, using the fact that the 834 keV transition is pure E2. This mixing ratio yields an octupole content $0.0009 \leqq O(894) \leqq 0.0023$, compared to the single particle estimate $(M3/E2) = 9.4 \times 10^{-5}$. The anomaly of the large enhancement of M3 over E2 mode mentioned in the previous work [9]) is considerably reduced.

The 1051-834 keV correlations yields two possible mixing ratios, $\delta(1051) = 8^{+24}_{-4}$ or $\delta(1051) = 0.30^{+0\ 12}_{-0\ 10}$. For either mixing ratio, the partial coefficient $A_2(1051) = 0.503 \pm 0.120$. This partial coefficient together with the mixing ratio, $\delta(630) = 10.3 \pm 1.3$, and the conversion coefficients $\alpha_T(E2) = 0.119 \times 10^{-2}$ and $\beta_T(M1) = 0.841 \times 10^{-3}$ obtained from the tables of Hager and Seltzer [15]) are used in the method of Anicin *et al.* [11]) to determine from the 1051-630-834 keV correlation

$$T(E0)/T(E2_\gamma) \leqq 0.042$$

for the 630 keV $2^{+\prime} \rightarrow 2^+$ transition. The E0 content of the 630 keV transition can also be determined from the 601-630-834 keV correlation Using the conversion coef-

TABLE 2

Directional correlation results for ^{72}Ge

Cascade (keV)	Spin sequence	A_{22}	A_{44}	$\delta(\gamma)$	Ref
894-834	4^+(Q, O)2^+(Q)0^+	0.125±0.005	−0 005±0 007	$\delta(894) = -0\,039 \pm 0\,009$	present
		0.046±0 016	−0.012±0.013		[9]
630-834	2^+(D, Q)2^+(Q)0^+	−0 002±0.009	0.311±0.012	$\delta(630) = 10\,3 \pm 1\,3$	present
		−0 075±0.012	0 225±0.018		[9]
		−0 145±0 040	0 314±0.065		[10]
601-630	3^+(D, Q)2^+(D, Q)2^+ [a]	0 089±0 006	−0.027±0 008	$\delta(601) = 46^{+\infty}_{-25}$ [b]	present
1051-630	3^-(D, Q)2^+(D, Q)2^+ [a]	0.121±0.028	−0 038±0 038	$\delta(1051) = 0\,30^{+0\,12}_{-0\,10}$ [c]	present
				or $= 8^{+24}_{-4}$	
601-630-834	3^+(D, Q)2^+(E0, M1, E2)2^+(Q)0^+ [d]	0 047±0.006	−0.020±0 008	$\delta(601) = 38^{+\infty}_{-24}$ [b]	present
		0 045±0 050	−0.092±0.075		[9]
1051-630-834	3^-(D, Q)2^+(E0, M1, E2)2^+(Q)0^+ [d]	0 064±0 006	−0.006±0.008	$\delta(1051) = 0\,31 \pm 0\,06$ [c]	present
		−0 039±0.055	−0 069±0 084		[9]

[a]) $\delta(630) = 10\,3 \pm 1\,3$ was used in the analysis

[b]) The weighted average value of these two values is $\delta(601) = 42^{+\infty}_{-18}$

[c]) The weighted average value of these two values is $\delta(1051) = 0.31 \pm 0.05$

[d]) The weighted average E0 content $T(E0)/T(E2_\gamma) \leqq 0.02$ was used in the analysis.

ficients given above and the $\delta(630)$ and $\delta(601)$ determined in this experiment in the method of Anicin *et al.* [11]) one obtains

$$T(\mathrm{E0})/T(\mathrm{E2}_\gamma) \leqq 0.023.$$

The weighted average value $T(\mathrm{E0})/T(\mathrm{E2}_\gamma) \leqq 0.02$ indicates that the 630 keV transition has no more than a 2 % E0 content. This is consistent with what is expected from a deformed quadrupole vibrator. The E0 content of the 630 keV transition can now be used to determine $U_{22}(630) = 0.210 \pm 0.018$ and $U_{44}(630) = 0.275 \pm 0.012$. These U_{22} and U_{44} are used in the analysis of the 601-630-834 and 1051-630-834 keV correlations to determine $\delta(601) = 38^{+\infty}_{-24}$ and $\delta(1051) = 0.31 \pm 0.06$. Combining these results with the 601-630 and 1051-630 keV correlation results one obtains the weighted average values, $\delta(601) = 42^{+\infty}_{-18}$ and $\delta(1051) = 0.31 \pm 0.05$.

These results indicate that the 601 keV transition is $\mathrm{E2} + (0.06^{+0.11}_{-0.06})\%$ M1. This indicates that the 2065 keV level is a vibrational state. They also indicate that the 1051 keV transition is $\mathrm{E1} + (8.8^{+2.7}_{-2.4})\%$ M2. Consequently, the 2514 keV level does not appear to be a vibrational state.

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