The agreement between calculated and experimental values is shown in Table II. Of the eight cases calculated, six were accurate to within a factor of 2. This indicates that assumptions (1) and (2) listed above probably have at least an approximate validity. On the other hand, the agreement for In^{113} is poor. Whether this is due to shortcomings in assumption (1), or in (2), or both, cannot be determined from the present work. *P* waves and possibly also *D* waves should be of some importance at 25 kev, and a serious attempt to calculate capture cross sections must include them. This will of course require considerably more experimental data on resonance parameters than are presently available.

The conclusion indicated by the calculations in the present section is that, as far as resonance parameter systematics are concerned, nothing radical occurs in going from the electron-volt to the kiloelectron-volt region.

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Directional Correlation of Gamma Rays in Ge^{72}†

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Directional correlation measurements have been made on the 0.63–0.835 Mev, 2.20–0.835 Mev, 2.49 and 2.51–0.835 Mev, and 1.88–1.46 Mev gamma-gamma cascades in Ge^{72} following beta decay of 14.2-hour Ga^{72}. The level at 0.835 Mev has a spin and parity assignment of 2+ and proceeds to the 0+ ground state by pure electric quadrupole radiation. The 0.63-Mev transition proceeds from a 2+ level at 1.46 Mev to the 0.835-Mev level by radiation which is largely electric quadrupole with a small magnetic dipole admixture. The correlation data are consistent with spin assignments of 2 or 3 for the levels at 3.04, 3.32, and 3.34 Mev.

I. INTRODUCTION

The decay of Ga^{72} has been the subject of many investigations.[1] A portion of the decay scheme proposed by Kraushaar *et al.* is shown in Fig. 1. Important features of the level structure of Ge^{72} were confirmed by studies of the decay of As^{72}.[2]

The first excited state of $_{32}Ge_{40}{}^{72}$ has spin zero and even parity. This represents a departure from the usual 2+ first excited state found in even-even nuclei. The only other known exceptions (O^{16}, Ca^{40}, Zr^{90}, Pb^{208}) result when both neutrons and protons form closed shells. In view of this peculiarity it was felt that direct measurement of the spins and parities of some of the higher levels might be of value in establishing the relation of Ge^{72} to the systematics of other nuclei in this region.

II. EXPERIMENTAL METHOD

A conventional fast-slow coincidence circuit with a resolving time of 1×10^{-8} second was employed in the angular correlation measurements.[3] A 4-in.×5-in. NaI(Tl) crystal and DuMont 6364 photomultiplier were used to detect the 1.88-Mev gamma ray in the weak 1.88 Mev–1.46 Mev correlation. The detectors in all other cases consisted of 2-in.×2-in. NaI(Tl) crystals mounted on RCA 6342 photomultipliers. Energy selection was provided by differential analyzers.

The Ga^{72} sources were obtained from Oak Ridge National Laboratory as gallium chloride in a dilute HCl solution. No interfering activities were present in the source material.

The half-life of the 0.835-Mev level has been measured to be $(3.2\pm0.8)\times10^{-12}$ sec[4] and the half-life of the 1.46-Mev level is expected to be short. This, together with the fact that the source was in dilute solution, eliminates the possibility of attenuation of the correlation function due to extranuclear fields.

Data were taken in a double quadrant sequence. The real coincidence rate was normalized to correct for source decay and electronic drift. A least-squares fit of the data was made to the function

$$W'(\theta)=\alpha_0+\alpha_2P_2(\cos\theta)+\alpha_4P_4(\cos\theta).$$

The resultant expansion coefficients were then normalized and corrected for finite angular resolution by a collimated beam method.[5] This yielded a correlation function of the form

$$W(\theta)=1+(A_2\pm\sigma_2)P_2(\cos\theta)+(A_4\pm\sigma_4)P_4(\cos\theta).$$

The σ_2 and σ_4 are the root-mean-square errors as defined by Rose, Eq. (30).[6]

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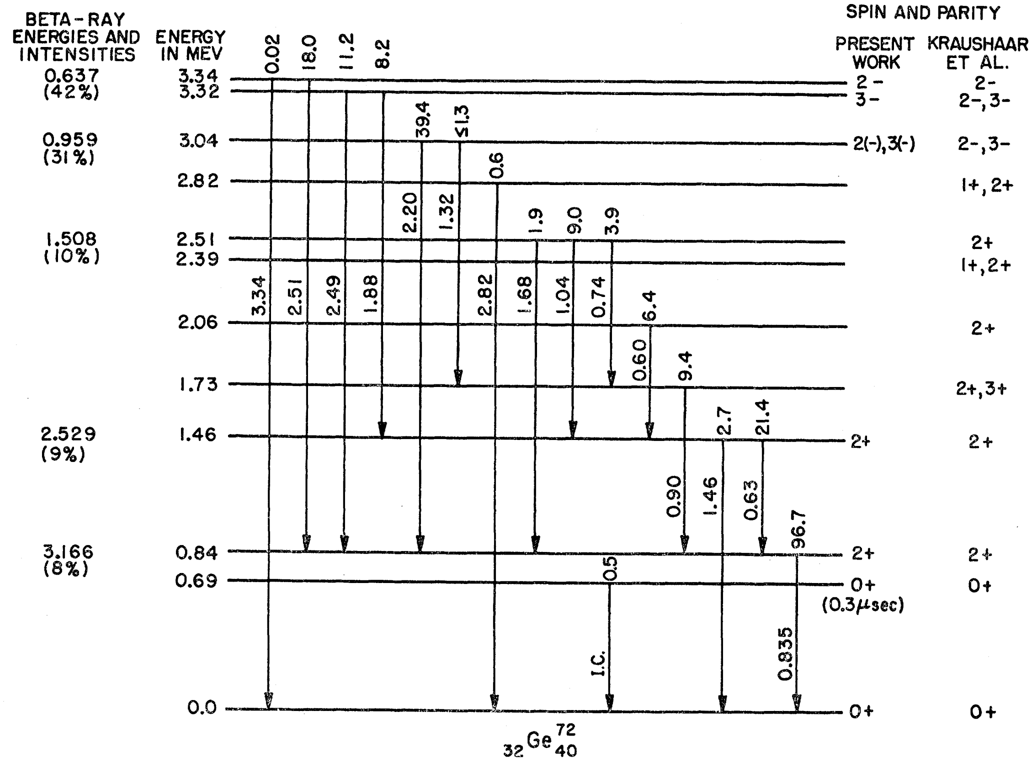

FIG. 1. Partial decay scheme of Ga^{72} according to Kraushaar *et al.*[1] Energies are given in Mev and intensities in percent. Some of the uncertain gamma rays and transitions involving the 0+ first excited state have been omitted. The spin and parity assignments of Kraushaar *et al.* are based on relative intensity considerations.

III. RESULTS

0.63 Mev–0.835 Mev Correlation

This correlation was measured by accepting all coincidences in a narrow portion of the scintillation photopeak for each of the gamma rays. However, owing to the complexity of the decay scheme, a fair percentage of these coincidences result from other interfering cascades. It was found that coincidences between the 0.835-Mev gamma ray and the Compton distribution of higher energy gamma rays resulted in $20.5\pm2.1\%$ of the total real coincidences. Similarly, coincidences between the 0.63-Mev gamma ray and interfering Compton distributions were found to comprise $23.4 \pm2.5\%$ of the total coincidences. The interfering correlations were measured and subtracted from the main correlation function. The resulting expansion coefficients were found to be $A_2=-0.145\pm0.040$ and $A_4=+0.314 \pm0.065$. It should be noted that the corrected expansion coefficients still contain contributions from coincidences between the 0.835-Mev gamma ray and the weak 0.60-Mev and 0.74-Mev gamma rays.

Metzger has shown that the 0.835 level has a spin of 2 by studying the angular distribution of resonance radiation from this level.[4] It was found that the present experimental data could not be fit by sequences of the form $4(Q)2(Q)0$, $3(D,Q)2(Q)0$, or $1(D,Q)2(Q)0$. The data are in agreement with a $2(D,Q)2(Q)0$ sequence in which the $2(D,Q)2$ transition (0.63-Mev gamma ray) is mostly quadrupole with a small dipole admixture. The experimental coefficients correspond to a quadrupole intensity for the 0.63-Mev transition of $Q\geqslant0.975$. If reasonable values are assumed for the maximum contribution from the interfering 0.60 Mev–0.835 Mev and 0.74 Mev–0.835 Mev cascades, the amended coefficients still demand a quadrupole intensity of $Q\geqslant0.90$.

2.49 and 2.51 Mev–0.835 Mev Correlation

Hedgran and Lind have successfully resolved the 2.51- and 2.49-Mev gamma rays and assigned a relative intensity of 8 to 5.[7] The directional correlation was measured by accepting the full-energy peak of the combined 2.49-Mev and 2.51-Mev gamma rays in one differential analyzer and the 0.835-Mev gamma ray in the other. The experimental expansion coefficients were found to be $A_2=+0.163\pm0.031$ and $A_4=-0.133 \pm0.046$. As has been pointed out,[1] the relative weakness of the ground-state transition (although assigned an energy of 3.34 Mev, the crossover gamma ray may originate from the other level) precludes the possibility of a spin 1 assignment for the levels at 3.32 Mev and 3.34 Mev. Assuming reasonable errors for the relative intensities of these cascades, all possible combinations of spins 2, 3, or 4 were considered as assignments for the 3.32-Mev and 3.34-Mev levels. The experimental data were found to be consistent only with spin 2 for

[7] A. Hedgran and D. Lind, Arkiv Fysik 5, 177 (1952).

one level and spin 3 for the other (in either order), with spin 3 for both levels, or with spin 3 for one level and spin 4 for the other. Relative intensities require that the ground-state transition be quadrupole radiation. Hence it must originate from a state of spin 2 and the correlation data then require a spin of 3 for the other state.

2.20 Mev–0.835 Mev Correlation

A portion of the real coincidences accepted in this correlation was due to the Compton and escape peaks of the 2.49-Mev and 2.51-Mev gamma rays. A fair estimate of the contribution ($23.7\pm2.4\%$) was obtained by moving the window of the differential analyzer from the 2.20-Mev photopeak to the valley between it and the 2.50-Mev photopeak and comparing coincidence rates. Although the assumptions involved are crude, the resultant coefficients are not very sensitive to the actual contribution. After correction for the interfering cascades, the experimental coefficients were found to be $A_2=+0.250\pm0.024$ and $A_4=-0.008\pm0.032$. These are in excellent agreement with the theoretical coefficients for a $2(D)2(Q)0$ sequence. The experimental coefficients will also fit a $3(D,Q)2(Q)0$ sequence with $0.23\leqslant Q\leqslant0.32$ for the mixed transition.

1.88 Mev–1.46 Mev Correlation

This correlation was measured by accepting the full-energy peak of each gamma ray in separate differential analyzers. There were no interfering cascades. The resultant coefficients, $A_2=+0.010\pm0.051$ and $A_4=-0.055\pm0.074$ are consistent with sequences of the form $1(D,Q)2(Q)0$, $2(D,Q)2(Q)0$, or $3(D,Q)2(Q)0$. (The spin of the 1.46-Mev level has been assumed to be 2 from the results of the 0.63 Mev-0.835 Mev correlation.) The absence of a strong crossover transition eliminates the first possibility.

IV. DISCUSSION

The ground-state nuclear angular momentum of Ga^{72} has been shown to be 3.[8] An odd-parity state is to be expected. Kraushaar *et al.* have summarized the log*ft* values of the five known beta transitions to Ge^{72}.[1] The spins inferred from the beta decay are in excellent agreement with values obtained above from angular correlation measurements.

Van Patter has recently summarized the systematics of even-even nuclei in this region.[9] The energy ratio E_2/E_1 of the second to the first excited state was shown to be less than 2 over the range $30\leqslant N\leqslant40$. If the 0+ first excited state in ${}_{32}Ge_{40}{}^{72}$ is omitted, the energy ratio of the next two states is 1.75. Over the range of $32<N<50$, the spin of the second excited state is 2+ in all known cases, omitting the low-lying 0+ states in Ge^{70} and Ge^{72}. The enhancement of the electric quadrupole transition probability in the $2-2$ transition which was found in the present case is also characteristic of the $2-2-0$ cascades in other nuclei in this region.

The present work did not include any direct measurements involving the 0+ first excited state in Ge^{72}. However, it has been shown that various features of the Ge^{72} level structure are in good agreement with the systematics of even-even nuclei in this region if the 0+ state is ignored. The probable absence of a low-lying state of spin 4 would argue against the possibility that the 0+ state arises from the splitting of a degenerate level. One might speculate that the $p_{\frac{1}{2}}$ neutron shell and the $p_{\frac{3}{2}}$ proton shell are filled in Ge^{72} and the excitation to the 0+ state may result from raising a proton pair or a neutron pair to a higher configuration.[10]

ACKNOWLEDGMENTS

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