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DIRECTIONAL CORRELATION STUDIES OF GAMMA TRANSITIONS IN ^{69}Ga AND ^{71}Ga[1]

R. N. Saxena[2], A. Bairrio Nuevo Jr.[2], F. C. Zawislak[3] and I. D. Goldman[4]

ABSTRACT

The directional correlations of γ-transitions in ^{71}Ge and ^{69}Ga have been measured from the decay of ^{71m}Zn and ^{69}Ge, respectively, using a Ge(Li)-NaI(Tℓ) gamma spectrometer. Spin assignments to the levels, in ^{71}Ga, at 390(1/2$^-$), 487(5/2$^-$), 512(3/2$^-$), 964(5/2$^-$), 1107(7/2$^-$), 1494(9/2$^+$) and 2247 keV (7/2$^+$), and, in ^{69}Ga, at 318(1/2$^-$), 574(5/2$^-$), 872(3/2$^-$), 1106(5/2$^-$, 3/2$^-$), 1336(7/2$^-$), and 1923 keV (7/2) confirm the results of previous studies on these nuclei. The multipole mixing ratios $\delta(E2/M1)$, for several γ-transitions, in both nuclei, have been determined from the present angular correlation data. The results are: $\delta(121) = -0.2^{+0.3}_{-2.4}$, $\delta(142) = 0.04 \pm 0.04$, $\delta(386) = -0.003 \pm 0.014$, $\delta(487) = 0.04 \pm 0.07$, $\delta(512) = -0.14 \pm 0.10$, $\delta(620) = 1.3^{+0.8}_{-0.3}$, $\delta(753) = 0.00 \pm 0.01$ and $\delta(964) = 0.6^{+0.9}_{-0.3}$, for transition in ^{71}Ga, and $\delta(234) = 0.28 \pm 0.04$ or 0.08 ± 0.02, $\delta(587) = -1.1 \pm 0.08$, $\delta(1051) = 0.0 \pm 0.10$ and $\delta(1349) = 0.13 \pm 0.03$, for transitions in ^{69}Ga.

1 – INTRODUCTION

Considerable theoretical[2,3,7,14,17,18,24,28,31] as well as experimental[3,4,7-8,10,12,15,16,19,20,23,25-27,29-33,35-38] interest has recently been shown in the level structure of odd-A Ga isotopes. The spectra of these nuclei are quite similar. Some of the low-lying states show single particle character[3,8,35,36], while others seem to contain collective admixtures[12,16,19,31,33,37,38], and were interpreted in terms of doubly even core coupled to the single proton states. For ^{71}Ga, calculations are also available using a rotational model which includes permanent deformation and Coriolis-coupling[28]. Nevertheless, a satisfactory explanation of the existing data on the structure of these nuclei has not yet been achieved. The agreement between calculations and experiments in only limited.

The energy levels of ^{71}Ga and ^{69}Ga have been investigated in the past by several techniques. These include the β-decay ^{69,71}Zn[20,25,29-30,32,37-38] and ^{69}Ge[38], the proton stripping and capture reactions[8,21,23,26,27,35-38] and (n, n'γ) reactions[33], Coulomb excitation[3,10,12] and resonance fluorescence studies[4,19], and ^{69,71}Ga (α, $\alpha'\gamma$) and ^{66,68}Zn (α, pγ) reactions[15] as well as γ-γ angular correlation measurements[16,22]. The results of these various studies have led to consistent energy level schemes for ^{71}Ga and ^{69}Ga. Spin and parity assignments to several levels, in both nuclei, have also been made. All of the previous γ-γ directional correlation measurements, in ^{71}Ga and ^{69}Ga, have been carried out with the use of NaI(Tℓ) detectors, and prior to the detailed γ-ray studies by Zoller et al.[37,38]. Due to the rather complex nature of the spectra and close proximity of intense γ-rays, in the de-excitation of both nuclei, the interpretation of the results are not unambiguous. In the previously reported measurements, the angular correlations, in many cases, are the combination of more than one gamma cascade. Consequently, these data were unable to provide definite values of

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the multipole admixtures in γ-transitions. The main purpose of the present study is to measure the directional correlations of gamma cascades in ^{71}Ga and ^{69}Ga using a Ge(Li)-NaI(Tℓ) spectrometer, in order to clearly resolve γ-rays under investigation, and to determine the multipole admixtures of several transitions in each nuclei

2 – EXPERIMENTAL PROCEDURE

The radioactive sources of ^{71m}Zn ($T_{½} = 4$ h) were obtained by the ^{70}Zn(n, γ) reaction. Approximately, 7 mg of ZnO (enriched to 68% in ^{70}Zn) were enclosed in a silica tube, and irradiated with neutrons, at a flux 2×10^{13} n.cm^{-2} sec^{-1}, for 1.5 hr, in the IEA-R1 reactor. A single source was used in the experiment, for nearly 8 h, and then replaced by a new source.

The ^{69}Ge($T_{½} = 39$ h) sources were produced by ^{70}Ge(γ, n) reaction, irradiating 600 mg of natural germanium metal in powder form, using the bremsstrahlung of the linear electron accelerator at the Physics Institute, University of São Paulo. The sample was enclosed in an aluminum capsule, and irradiated for 24 h. The source was allowed to decay for two days before starting the measurements in order to permit the decay of ^{72}Ga($T_{½} = 14$ h) and ^{73}Ga($T_{½} = 5$ h) produced in small amounts by (γ, p) reaction on ^{73,74}Ge. No other activities were seen in the source. Each source was measured for three days before being replaced by a new one.

The γ-γ spectrometer was a combination of a true coaxial 35 cm^3 Ge(Li) detector and a 7.6 x 7.6 cm NaI(Tℓ) detector. Other details of the spectrometer system and the electronics are described elsewhere[13]. The coincidences were recorded at angular intervals from 90° to 270° in steps of 15°.

In the ^{71m}Zn decay, most of the angular correlations were determined from the coincidence spectra obtained by gating the 386 keV photopeak in the γ-spectrum through the NaI(Tℓ) detector. However the additional gamma cascades 620-487 and 596-512 keV were also measured by gating the combined (620 + 596) keV photopeaks. The correction for the Compton scattered radiation of higher energy coincident γ-rays, in the 386 keV gate window, were determined from the similar measurements taken at the adjacent gate. For the (620 + 596) keV gate setting, the Compton effects were negligible and such measurements were not required.

In the study of ^{69}Ge decay, three gate positions with centroids at 318, 872 and 1340 keV were used to obtain the data. Compton corrections were necessary only in the case of 553-318 keV cascade which were estimated. The data in all the cases were corrected for the chance coincidences, for the decay of the source during the experiment and for the Compton contributions wherever necessary. The chance coincidences were determined in separate experiments for each gate setting. The angular correlation coefficients A_{kk} were obtained by the least squares fitting procedure in the usual manner. The phase convention of Becker and Steffen[5] has been adopted for the multipole mixing ratio δ, in the subsequent analysis of the experimental data.

3 – RESULTS

The low energy part of the γ-spectrum in the decay of ^{71m}Zn obtained with the Ge(Li) detector is in Figure 1. Typical γ-spectra in coincidence with the 386 and (620 + 596) keV photopeaks, respectively, are also shown in the same figure. The lower right hand side of the figure is the direct γ-spectrum obtained with the NaI(Tℓ) detector, where the position of the gate settings are also shown. The angular correlation curves, for various gamma cascades studied in ^{71}Ga, are shown in Figure 2, with the exception of the 386-(596)-512 cascade. The results for this cascade obtained from the 386 keV gate were slightly affected by the presence of a 511 keV annihilation radiation which came from impurity in the silica container. The data points at 180° and 165° were not included in the least squares analysis for this particular cascade. The 596-512 keV cascade measurements from the (620 + 596) keV gate are,

however, free from this effect. The relevant part of the level scheme of ^{71}Ga, taken from[37] is also shown in Figure 2. The level diagram shows only those transitions which are of interest in this study. The corresponding results in the study of ^{69}Ge decay are shown in Figures 3 and 4.

The results of the directional correlation coefficients A_{kk} obtained from the present study are summarized in Tables I and II, for ^{71}Ga and ^{69}Ga, respectively. The A_{kk} coefficients have been corrected for the effects of finite solid angles of the detectors[6,34]. The multipole mixing ratios $\delta(E2/M1)$ were obtained by the χ^2 analysis, with the spin assignments as indicated in Figure 2 and Figure 4, for each nucleus. In the analysis it was assumed that the 596 keV transition in ^{71}Ga is $E2$, and $\delta(573)$ and $\delta(872)$ in ^{69}Ga have values of -0.04 and -0.11, respectively[21] (see discussion).

Table I

Results of Directional Correlation Measurements of γ-Transitions in ^{71}Ga.

Gamma Cascade (keV)	Gating Transition (keV)	A_{22}	A_{44}	Mixed Transition (keV)	Multipole Mixing ratio $\delta(E2/M1)$
386-(596)-121	386	0.031 ± 0.014	0.165 ± 0.025	121	$-0.20\ ^{+0.3}_{-2.4}$
386-142	386	0.039 ± 0.011	-0.116 ± 0.019	142	0.04 ± 0.04
386-(620)-487	386	0.023 ± 0.006	-0.039 ± 0.010	487	0.12 ± 0.05
386-(596)-512	386	-0.042 ± 0.013	-0.012 ± 0.025	512	-0.08 ± 0.16
386-596	386	-0.052 ± 0.009	-0.032 ± 0.013	386	-0.003 ± 0.014
386-620	386	-0.107 ± 0.006	-0.043 ± 0.010	620	$1.3\ ^{+0.8}_{-0.3}$
753-386	386	0.093 ± 0.029	-0.053 ± 0.046	753	0.0 ± 0.01
386-(142)-964	386	-0.112 ± 0.032	-0.107 ± 0.045	964	$0.60\ ^{+0.9}_{-0.3}$
386-1107	386	-0.010 ± 0.036	0.056 ± 0.061	–	–
620-487	620	-0.199 ± 0.007	0.007 ± 0.010	487	-0.04 ± 0.08
596-512	596	-0.003 ± 0.013	0.006 ± 0.020	512	-0.20 ± 0.05

Table II

Results of Directional Correlation Measurements of γ-Transitions in ^{69}Ga.

Gamma Cascade (keV)	Gating Transition (keV)	A_{22}	A_{44}	Mixed Transition (keV)	Multipole Mixing ratio $\delta(E2/M1)$
553-318	318	0.015 ± 0.014	-0.016 ± 0.027	–	–
787-318	318	-0.001 ± 0.024	-0.070 ± 0.037	–	–
1206-318	318	0.003 ± 0.032	0.039 ± 0.051	–	–
234-872	872	-0.030 ± 0.009	0.001 ± 0.014	234	0.28 ± 0.04 [a]
–	–	–	–	–	0.08 ± 0.02 [b]
1052-872	872	0.007 ± 0.023	-0.042 ± 0.040	1052	0.0 ± 0.10 [c]
1349-574	1349	0.150 ± 0.015	0.053 ± 0.083	1349	0.13 ± 0.03
587-1336	1336	0.208 ± 0.023	0.07 ± 0.12	587	-1.1 ± 0.08

a) with the spin 3/2 – for the 872 keV level;
b) with the spin 5/2 – for the 872 keV level;
c) the value is for octopole/quadrupole mixing ratio.

4 – DISCUSSION

^{71}Ga nucleus

The spin and parities of a number of levels in ^{71}Ga are known from the β-decay studies[32,37] and from ^{71}Ga (n,n'γ) experiments[33] Additional information is also available from the (^{3}He,d) reaction[27] The ground state spin of ^{71}Ga has been measured as 3/2 and the parity is known to be negative[11]. Velkley et al.[33] determined the spin and parity values for many of the excited states in ^{71}Ga, from the angular distribution of γ-rays emitted in the ^{71}Ga (n,n'γ) reaction The suggested spin and parities for the levels, at 390(1/2$^-$), 487(5/2$^-$), 1107(7/2$^-$) and 1494 keV (9/2$^+$), are in agreement with the log ft values and γ-ray branching ratios that were observed in the beta-decay of ^{71m}Zn by Zoller et al.[37] For the 964 keV level, Zoller et al. suggested an assignment of 5/2$^-$ from their observation of a weak 575 keV transition from this state to the 390 keV (1/2$^-$) state, instead of the assignment of 7/2$^-$ made by Velkley et al.[33]. Most of the above spin assignments are also in general agreement with the results of (^{3}He,d) reaction[27].

The values of A_{kk} for the 386-596 keV cascade are consistent with the spin sequence 9/2-7/2-3/2. The 9/2$^+$ for the 1494 keV level is thus further confirmed. The 7/2$^+$ assignment to this level leads to an unreasonably large $M2$ admixture with $E1$ in the 386 keV transition. The 7/2$^-$ and 3/2$^-$ spin and parity assignments, to the 1107 keV and 512 keV levels, have already been established by various types of studies[33,37] With these assignments, both 386 and 596 keV transitions are of nearly pure multipolarities $E1$ and $E2$, respectively.

The results of 386-1107 keV cascade are the combination of two gamma cascades since there are two γ-rays of nearly the same energy 1107 keV de-exciting different levels but both in coincidence with the 386 keV transition (see the energy level diagram in Ref. 37). Therefore, it was not possible to determine the multipolarity of the 1107 keV transition deexciting the level of this energy from the measured A_{kk} values. However, if the 7/2$^-$ assignment for the level is accepted, then the 1107 keV transition must be $E2$.

The results of the 753-386 keV cascade were analyzed by assuming two probable spin sequences 7/2-9/2-7/2 and 5/2-9/2-7/2. The χ^2 analysis of the results favor the 7/2 spin for the 2247 keV level. Assuming positive parity[37] for this level, the 753 keV transition is almost pure $M1$. The A_{kk} values for the 386-620 keV cascade can fit both spin sequences 9/2-7/2-5/2 and 9/2-7/2-7/2. The 3/2 spin for the 487 keV level has been rejected as it results in a large octopole admixture in the 620 keV transition. The results of 620-487 keV cascade, however, do not agree with the 7/2 spin for the 487 keV level. The combined results of the 386-620 keV and 620-487 keV cascades, therefore, indicate that the only reasonable spin assignment to the levels at 1494, 1107 and 487 keV are 9/2, 7/2 and 5/2, respectively. The A_{kk} values, for the 386-142 and 386-(142)-964 keV cascades, can fit both 5/2 and 7/2 spin assignments to the 964 keV level. However, according to Zoller et al.[37] the observed 575 keV transition from this level to the 390 keV (1/2$^-$) level should eliminate the 7/2 spin value. The results of the (1,3) angular correlations, for the 386-(596)-512 and 386-(620)-487 keV, were analyzed to provide A_{kk} values for the (1,2) correlations of the 596-512 and 620-487 keV cascade using $\delta(596) = 0$ and $\delta(620) = 1.3$. The results of the calculation are in good agreement with experimental A_{kk} values for these cascades.

^{69}Ga nucleus

The spins and parities of the ground state (3/2$^-$) and of the first four excited states at 318(1/2$^-$), 574(5/2$^-$), 872(3/2$^-$) and 1106 keV (5/2$^-$, 3/2$^-$) in ^{69}Ga are fairly well established by various studies. These include β^-decay of ^{69m,g}Zn,[25,38], and β^+, EC decay of ^{69}Ge,[38], the (n, n'γ) [33], (d,n) [8,23], and (^{3}He,d), [27], reactions studies. Zoller et al.[38] gave an assignment of 5/2$^-$ for the 872 keV level. Later, Raman and Couch[25] showed that this level is populated in the ^{69}Zn

decay via a β-transition from the $1/2^-$ ground state, and not from the $9/2^-$ isomeric state, as assumed by Zoller et al.[38]. The correct assignment is, therefore, $3/2^-$. Zoller et al. assigned spin $3/2^-$ to the 1106 keV level. Later work by Ricato and David[27] and by Couch et al.[8] indicates that a $5/2^-$ spin assignment is also compatible. The level at 1336 keV has an assigned value of $7/2^-$ for its spin and parity from the $(n,n'\gamma)$, [33], and (He^3,d) [27], reaction work.

The spin assignment of 1/2 to the 318 keV level, in ^{69}Ga, is further confirmed from the results of present work. All the three gamma cascades 553-318, 787-318 and 1206-318 keV, which depopulate through the 318 keV level, show nearly isotropic angular correlation characteristic of spin < 1, for the intermediate level.

The γ-γ angular correlation measurements of Khodzhaev[16] lead to different spin assignments to some levels in ^{69}Ga. As mentioned before, Khodzhaev used a system with two NaI(Tℓ) detector, where it is difficult to make corrections for the contributions from other transitions. The values of the mixing parameters obtained in his study are, therefore, not considered in our discussion. The γ-transition of 574 and 872 keV are known to have various values of the multipole mixing ratio δ from the previous studies which include Coulomb excitation in ^{69}Ga [3], radiative capture of protons by ^{68}Zn [21], $(n,n'\gamma)$ reaction[33] in ^{69}Ga, and nuclear resonance fluorescence in ^{69}Ga [21]. The values are $0.03 \leqslant \delta(574) \leqslant 0.1$ or $1.5 \leqslant \delta(574) \leqslant 3.5$ [33], $\delta(574) = -0.04 \pm 0.04$ or 3.05 ± 0.65 [21], $\delta(574) = 0.057$ [3], $|\delta(872)| < 0.55$ [19], $\delta(872) = -0.11^{+0.09}_{-0.08}$ or $-3.05^{+0.54}_{-1.15}$ [21], $\delta(872) = 0.13$ [3]. Most of these studies, however, agree that the 574 and 872 keV transitions are predominantly $M1$ rather than $E2$. The larger value of $\delta(574)$ leads to an $E2$ enhancement of about 300 Weisskopf units[8], in contradiction with the ratio of the experimental $B(E2)\downarrow$ to the $B(E2)_{s.p.}$ equal to 0.314 [3]. We have chosen the $\delta(574) = -0.04$ and $\delta(872) = -0.11$ values[21] for the 574 and 872 keV transitions, respectively, in calculating other mixing ratios from the present measurements.

Two gamma cascades 234-872 and 1051-872 were measured from the spectra gated by the 872 keV photopeak. Both spin sequences 3/2-3/2-3/2 and 5/2-3/2-3/2 are compatible with the measured values A_{kk} for the 234-872 keV cascade. However, with either sequence the 234 keV transition is predominantly $M1$. In a recent study of $^{69}Ga(\alpha,\alpha'\gamma)\,^{69}Ga$ and $^{66}Zn\ (\alpha,p\gamma)\,^{69}Ga$ reactions Ivascu et al.[15] report that they obtain good agreement for the lifetime, branching ratios and $B(E2)$ and $B(M1)$ values only for a $5/2^-$ spin assignment for the 1107 keV state. The A_{kk} values of the 1051-872 keV cascade can fit 3/2, 5/2 as well as 7/2 spin assignments to the 1923 keV level. The angular correlation results of the 587-1336 keV and 1349-574 keV cascades, originating from the same 1923 keV level, were also analyzed assuming the above spin values. Only the results of 587-1336 keV cascade provide a unique assignment of a 7/2 spin value. The 3/2 spin value gives a large octopole admixture in the 587 keV transition and, hence is rejected, while the 5/2 spin gives a much larger χ^2 for the fitting of the data compared to the 7/2.

5 – CONCLUSIONS

A number of theoretical approaches have been developed in the recent years to explain the properties of the low lying levels of odd-A nuclei in the region $28 \leqslant Z \leqslant 40$. A considerable attention has been given to the intermediate coupling model.

In the case of ^{69}Ga and ^{71}Ga several such calculations have been carried out[2,3,24,31]. The agreement between experiment and theory is reasonable for the energy of the levels. The agreement with the $B(E2)$ values[3] is, however, only marginal. Isakov[14], using the shell model concepts in his calculations for ^{71}Ga, obtained a somewhat better agreement with the experimental values of $B(E2)$[3].

According to the results given in[16], some of the states in ^{69}Ga and ^{71}Ga show substantial collective behaviour and were interpreted in terms of an excited-core model[9]. The results of the present study, however, indicate that several γ-transitions in both the nuclei have considerable magnetic dipole admixtures, and an interpretation in terms of collective model may have a somewhat limited value. According to the results of Coulomb excitation studies[3], the $B(E2)$ values for the ground state transitions from 390, 487, 512 and 1107 keV states in ^{71}Ga, and 574 and 872 keV states in ^{69}Ga, are not much different from the single particle estimates, and in most cases much lower than the average $B(E2: 2^+ \rightarrow 0^+)$ values in the neighbouring even-even nuclei.

The theoretical problems, connected with the interpretation of nuclear properties in this mass region, are quite complex, and the purpose of this study is only to provide additional results in the hope that further attempts can be made to improve the theoretical calculations.

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RESUMO

Foram medidas correlações direcionais de transições γ, em ^{71}Ga e ^{69}Ga, a partir do decaimento de ^{71m}Zn e ^{69}Ge, respectivamente, usando um espectrômetro de Ge(Li)-NaI(Tl). Os spins associados aos níveis no ^{71}Ga a 390(1/2$^-$), 487(5/2$^-$), 575(3/2$^-$), 984(5/2$^-$), 1107(7/2$^-$), 1494(9/2$^+$) e 2247 keV (7/2$^+$), e no ^{69}Ga a 318(1/2$^-$), 574(5/2$^-$), 872(3/2$^-$), 1106(5/2$^-$, 3/2$^-$), 1336(7/2$^-$), e 1923 keV (7/2) confirmam os resultados de estudos anteriores destes núcleos. Foram determinadas razões de mistura de multipolaridade $\delta(E2/M1)$ para várias transições em ambos os núcleos, a partir dos presentes dados de correlação angular. Os resultados são: $\delta(121) = -0.2^{+0.3}_{-2.4}$, $\delta(142) = 0.04 \pm 0.04$, $\delta(386) = -0.003 \pm 0.014$, $\delta(487) = 0.04 \pm 0.07$, $\delta(512) = -0.14 \pm 0.10$, $\delta(620) = 1.3^{+0.8}_{-0.3}$, $\delta(753) = 0.00 \pm 0.01$ e $\delta(964) = 0.6^{+0.9}_{-0.3}$, para transições no ^{71}Ga, e $\delta(234) = 0.28 \pm 0.04$ ou 0.08 ± 0.02, $\delta(587) = -1.1 \pm 0.08$, $\delta(1051) = 0.0 \pm 0.10$ e $\delta(1349) = 0.13 \pm 0.03$, para transições no ^{69}Ga.

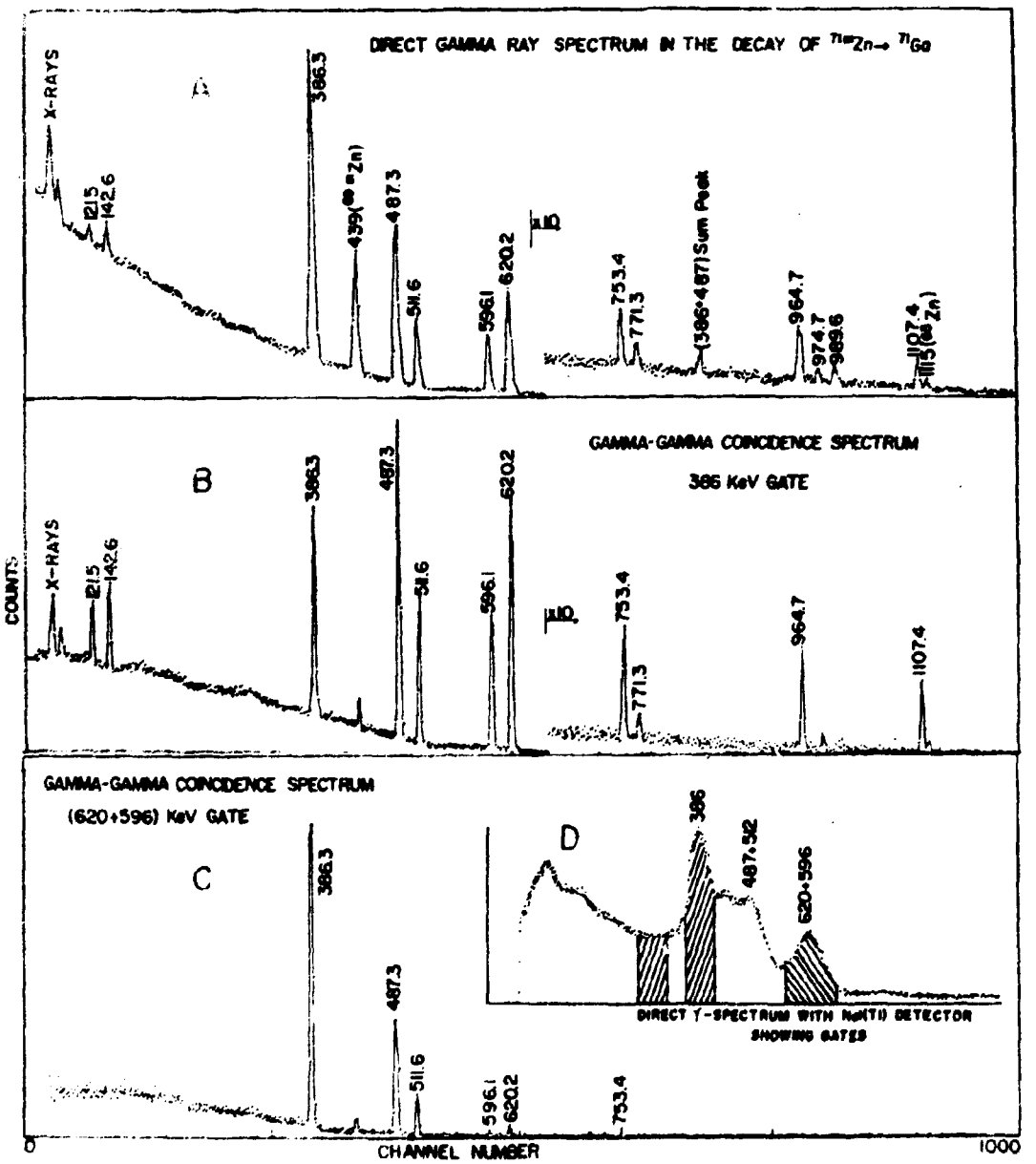

Figure 1 – The low energy γ-spectrum, in the decay of ^{71m}Zn obtained with the Ge(Li) detector (A), and with the NaI(Tℓ) detector (D). The gamma-gamma coincidence spectra, with the 386 KeV photopeak (B), and with the (596 + 620) KeV photopeaks (C).

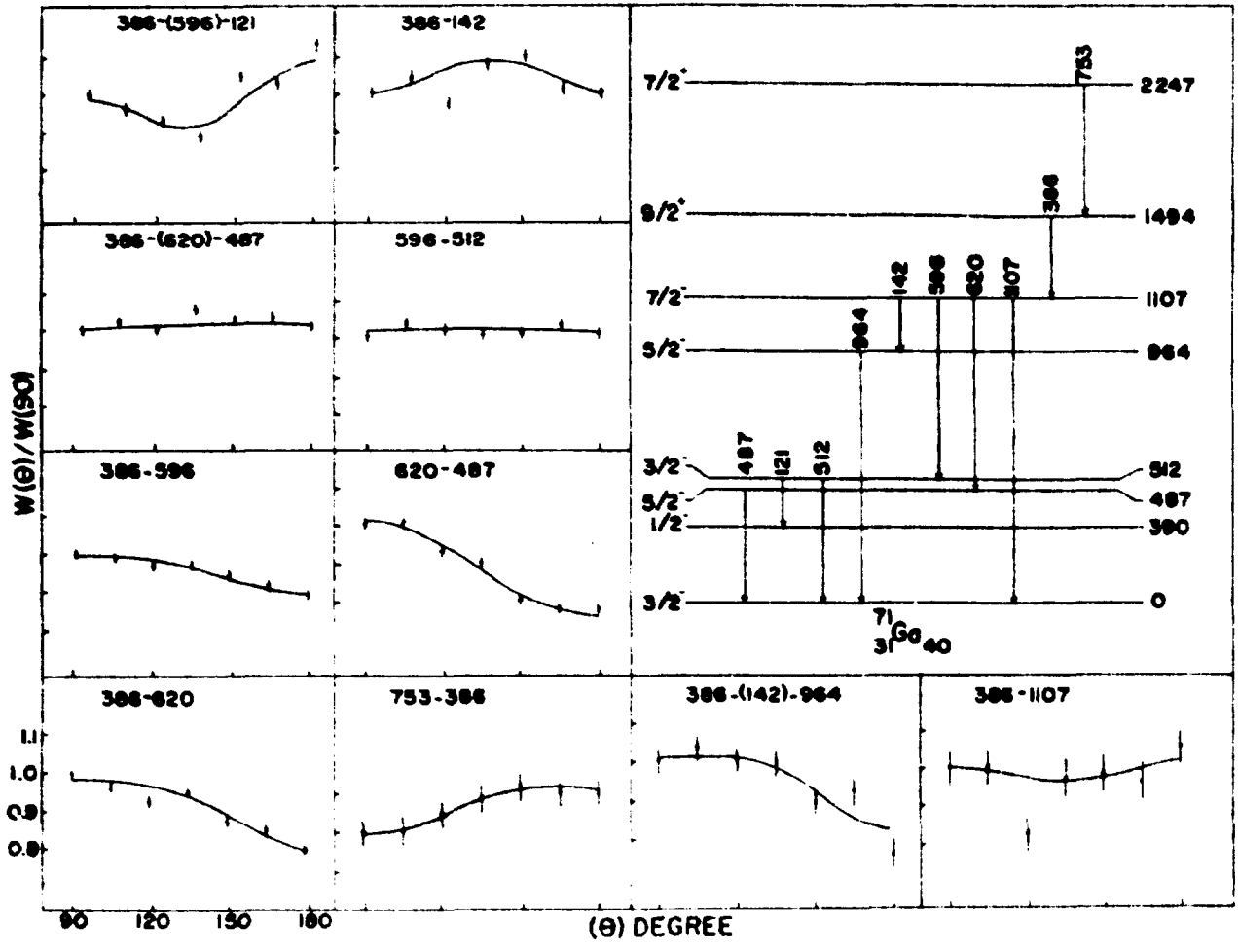

Figure 2 — The angular correlation courves for various gamma cascades in ^{71}Ga and the relevant part of the level scheme of ^{71}Ga.

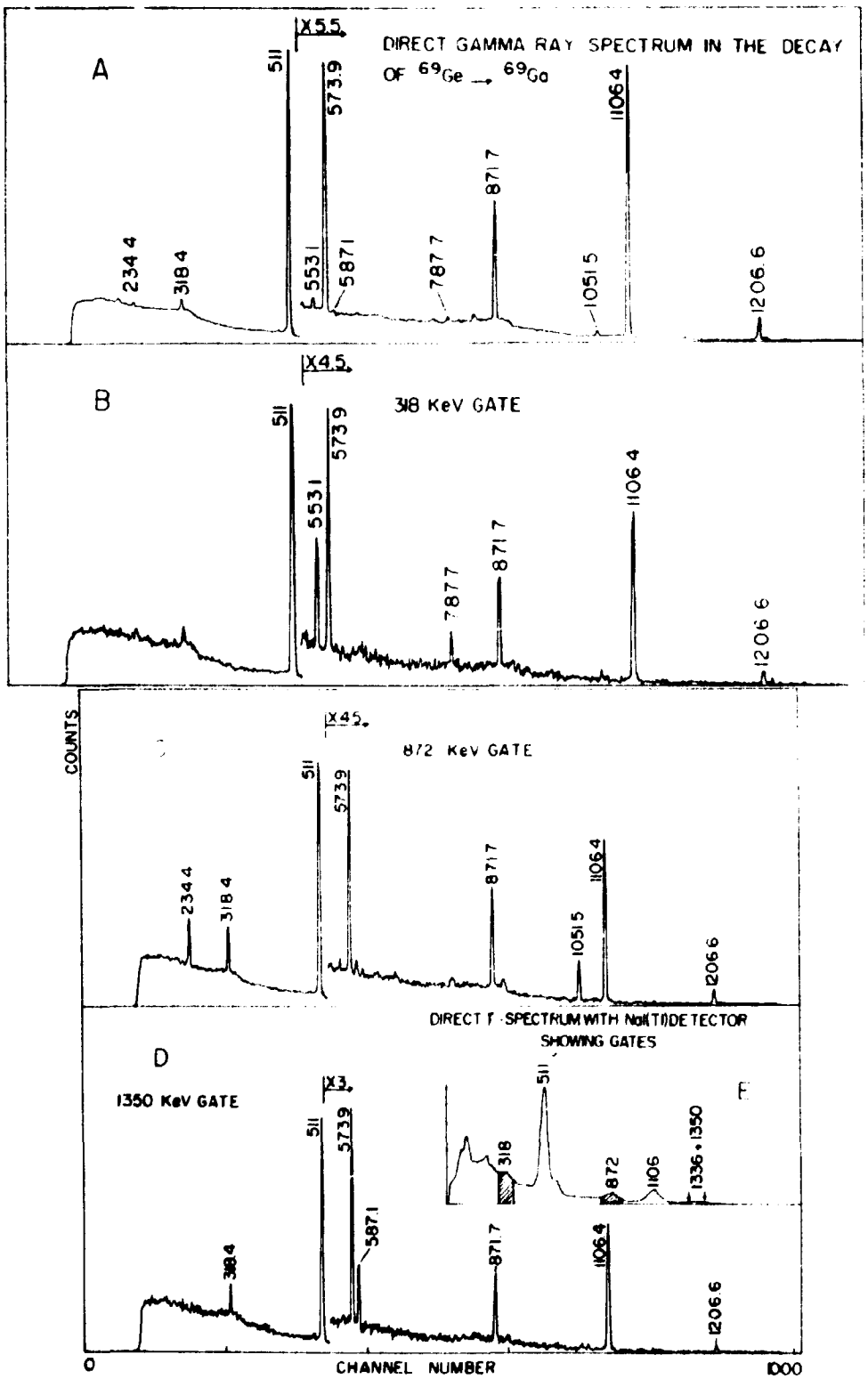

Figure 3 – The low energy γ-spectrum, in the decay of ^{69}Ge, obtained with the Ge(Li) detector (A), and with the NaI(Tl) detector (E). The gamma-gamma coincidence spectra, with the 318 KeV (B), the 872 KeV (C), and the (1336 + 1380) KeV photopeaks (D).

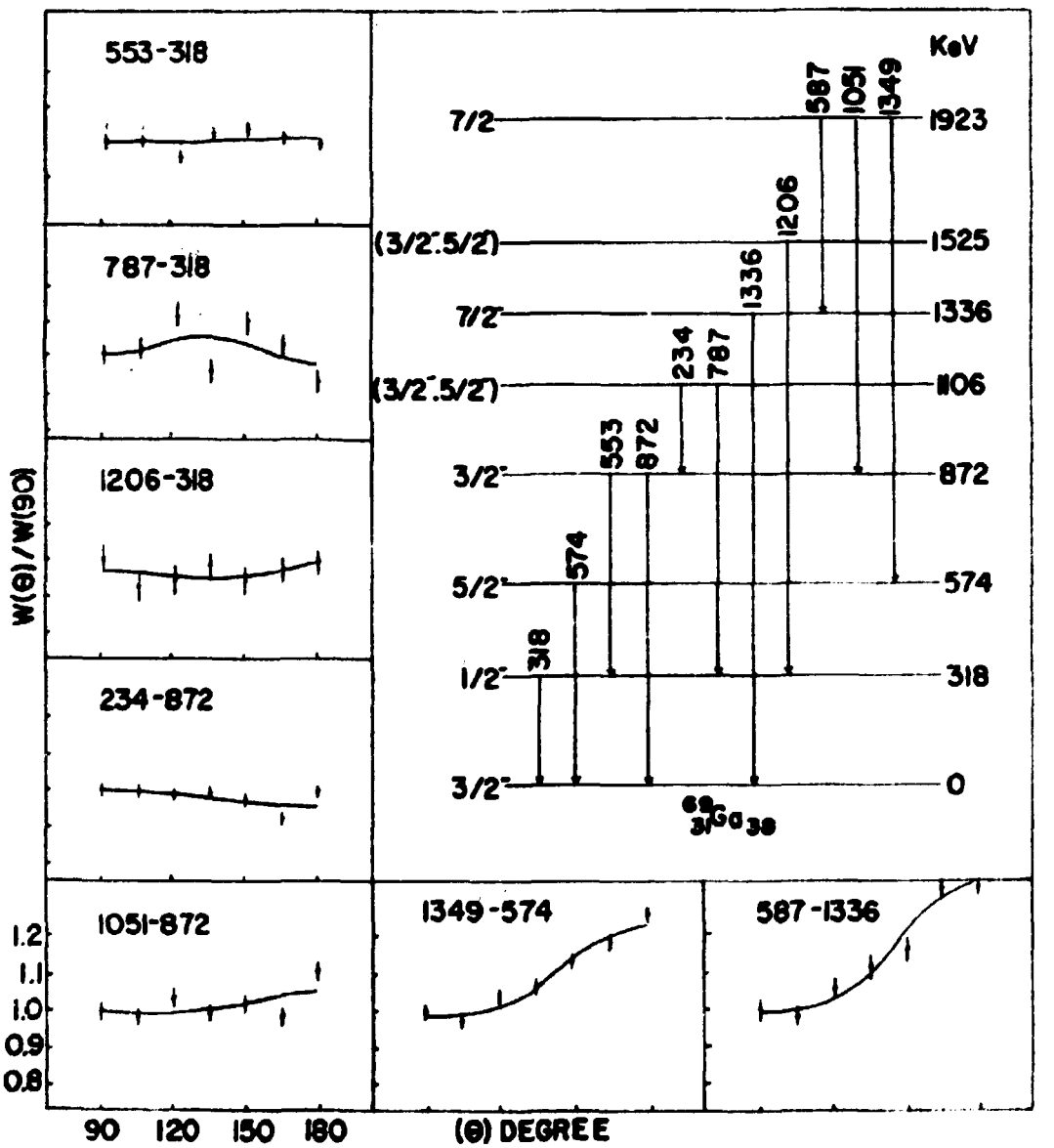

Figure 4 — The angular correlation courves for various gamma cascades, in ^{69}Ge, and the relevant part of the level scheme of ^{69}Ga.

REFERENCES

1. ALAGA, G. In: JEAN, M., ed. *Cargèse lectures in physics.* New York, Gordon & Breach, 1969. v.3, p.579.

2. ALMAR, R. et alii. Structure of the odd-mass gallium isotopes with a particle-phonon coupling model. *Phys. Rev. C.* Ithaca, N. Y., 6:187-95, 1972.

3. ANDREEV, D. S. et alii. Coulomb excitation of ^{69}Ga and ^{71}Ga. *Bull. Acad. Sci. USSR, phys. Ser.*, New York, 36:738-52, 1972.

4. ARNOLD, R. G. et alii. Resonance-fluorescence studies. 1. ^{45}Sc, ^{69}Ga and ^{71}Ga. *Phys. Rev. C.* Ithaca, N. Y., 7:1490-500, 1973.

5. BECKER, A. J. & STEFFEN, R. M. M_1-E_2 mixing ratios and conversion-electron particle parameters for the electromagnetic transitions in As^{75}. *Phys. Rev.*, Ithaca, N. Y., 180:1043-8, 1969.

6. CAMP, D. C. & VAN LEHN, A. L. Finite solid-angle corrections for Ge(Li) detectors. *Nucl. Instrum. Meth.*, Amsterdam, 76:192-240, 1969.

7. COOPER, L. R. & EASTERDAY, H. T. The decay of 4.1 hour ^{71}Zn^n and the levels of ^{71}Ga by the unified model. *Nuovo Cim.*, Pisa, 64B:188-200, 1969.

8. COUCH, R. G. et alii. Spectroscopy of ^{65,67,69}Ga by (d,n) reaction. *Phys. Rev. C*, Ithaca, N. Y., 2:149-60, 1970.

9. DE-SHALIT, A. Core excitation in nondeformed, odd-A, nuclei. *Phys. Rev.*, Ithaca, N. Y., 122:1530-6, 1961.

10. DZUBAY, T. G. Coulomb displacement energies for Zn-Ga isobars. *Nucl. Phys.*, Amsterdam, A133:653-8, 1969.

11. EWBANK, W. B. et alii. ^{71}Ga. *Nucl. Data Sh.*, Washington, D. C. B1(6), 1966.

12. FAGG, L. W. et alii. Coulomb excitation of V, Ni, Ga, and Rb. *Phys. Rev.*, Ithaca, N. Y., 104:1073-6, 1956.

13. GUALDA, J. M. et alii. Directional correlations of γ-transitions in ^{134}Xe. *Nucl. Phys.*, Amsterdam, A234:357-64, 1974.

14. ISAKOV, V. I. Properties of ^{71}Ga according to the shell model. *Bull. Acad. Sci. USSR, phys. Ser.*, New York, 36:727-9, 1972.

15. IVASCU, M. et alii. Spectroscopy of the ^{69}Ga and ^{71}Ga isotopes with the ^{69,71}Ga($\alpha,\alpha'\gamma$) ^{69,71}Ga and ^{66,68}Zn(α,pγ) ^{69,71}Ga reactions. *Nucl. Phys.*, Amsterdam A225:357-64, 1974.

16. KHODZHAEV, M. M. Quantum characteristics of excited states of Ga^{69} and Ga^{71} nuclei. *Soviet J. nucl. Phys.*, New York, 10:516-20, 1970.

17. LISSLINGER, L. S. & KUMAR, K. Static quadrupole moment of vibrational, even nuclei and the coupling scheme for odd nuclei. *Phys. Rev. Lett.*, New York, 19:1239-43, 1967.

18. _____ & SORENSEN, R. A. Spherical nuclei with simple residual forces. *Rev. mod. Phys.*, Minneapolis, 35:853-915, 1963.

19. LANGHOFF, H. & FREVERT, L. Nuclear resonance fluorescence in ^{69}Ga. *Nucl. Phys.*, Amsterdam, A111:225-35, 1968.

20. LI, A. C. & MONARO, S. Gamma radiation from ^{71}Zn and ^{71m}Zn. *Nucl. Phys.*, Amsterdam, A91:353-64, 1967.

21. NEMASHKALO, B. A. et alii. Radiative capture of protons by Zn^{64}, Zn^{66}, and Zn^{68} nuclei. *Soviet J. nucl. Phys.*, New York, 17:117-9, 1973.

22. NUCLEAR DATA SHEETS, New York, 10(3):221, 1973.

23. OKOROKOV, V. V. et alii. The reactions $Ni^{58,60,62,64}$ (d,n) $Cu^{59,61,63,65}$ and $Zn^{64,66,68}$ (d,n) $Ga^{65,67,69}$. *Soviet J. nucl. Phys.*, New York, 8:387-92, 1969.

24. PAAR, V. Coupling of a three-particle (hole) valence-shell cluster to quadrupole vibrations (Alaga model): the Z = 50 region: odd Ag and I isotopes; and the Z = 28 region: odd Mn and Ga isotopes. *Nucl. Phys.*, Amsterdam, A211:29-76, 1973.

25. RAMAN, S. & COUCH, R. G. Spin and parity assignment for the 872-KeV level in ^{69}Ga. *Phys. Rev. C*, Ithaca, N. Y., 1:744-6, 1970.

26. RESTER, D. H. et alii. Level schemes of ^{67,68,70}Ga. *Nucl. Phys.*, Amsterdam, 80:1-13, 1966.

27. RICCATO, A. & DAVID, P. The reactions ^{68,70}Zn (^{3}He,d)^{69,71}Ga and level systematics of the odd-mass Ga isotopes. *Nucl. Phys.*, Amsterdam, A228:461-77, 1974.

28. SCHOLZ, W. & MALIK, F. B. Level spectra of odd isotopes of Ga, As, Br, and Rb in the coriolis coupling model with a residual interaction of the pairing type. *Phys. Rev.*, Ithaca, N. Y., 176:1355-65, 1968.

29. SONMINO, T. et alii. The decay of 4.1 hour Zn^{71}. *Nucl. Phys.*, Amsterdam, 54:568-76, 1964.

30. TAYLOR, H. W. & SINGH, B. Levels in ^{71}Ga excited by the decay of 4 h ^{71}Zn. *Nucl. Phys.*, Amsterdam, A148:548-60, 1970.

31. TEMPERLEY, J. K. et alii. Level scheme of Ga^{69}. *Phys. Rev. B*, Ithaca, N. Y, 139:1125-34, 1965.

32. THWAITES, T. T. & PRATT, W. W. Decay of the Zn^{71} isomers. *Phys. Rev.*, Ithaca, N. Y., 124:1526-31, 1961.

33. VELKLEY, D. E. et alii. Levels of ^{69}Ga and ^{71}Ga via the (n,n'γ) reactions. *Phys. Rev.*, Ithaca, N. Y., 179:1090-9, 1969.

34. YATES, M. J. L. Finite solid angle corrections. In: KARLSSON, E. et alii, eds. *Perturbed angular correlations*. Amsterdam, North-Holland, 1964. Appendix 4, p.453-66.

35. ZEIDMAN, B. Proton states in lf2p-shell nuclei. In: ARGONNE NATIONAL LABORATORY, Argonne, Ill. *Physics Division summary report January-March 1967*. Argonne, Ill., s.d. (ANL-7312). p.53.

36. _____ et alii. Study of $Zn^{66,68}$ (He^{3},d) $Ga^{67,69}$ reactions. *Bull. Am. phys. Soc.*, Ithaca, N. Y., 10:1126, FD10, 1965.

37. ZOLLER, W. H. et alii. Decay of 2.4 min ^{71g}Zn and 3.9 h ^{71m}Zn to levels of ^{71}Ga. *Nucl. Phys.*, Amsterdam, A142:177-203, 1970.

38. ZOLLER, W. H. et alii. Decay of 56 min ^{69g}Zn, 14 h ^{69m}Zn and 39 h ^{69}Ge to levels of ^{69}Ga. *Nucl. Phys.*, Amsterdam, A124:15-33, 1969.