STUDY OF LOW-LYING STATES IN ^{69}Ga

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Abstract. Three known negative parity states of ^{69}Ga at 318.6, 574.3 and 871.9 keV were studied by Coulomb excitation technique. The safe bombarding energy for Coulomb excitation of ^{69}Ga with proton beam was obtained to be 2.5 MeV for the first time. The de-excitation gamma-rays were detected and identified in the singles spectra recorded with a germanium detector using 2.2–4.2 MeV proton beams. The reduced transition probabilities B(E2)↑ were determined to be 0.67 ± 0.06, 0.35 ± 0.10 and 2.09 ± 0.95 e^2 $cm^4 \times 10^{-50}$, respectively for these levels. Our results clearly support the Alaga model calculations produced by using three particle cluster-core-coupling.

Key words: Proton beam, Coulomb Excitation, Gamma-rays, B(E2), Branching ratios.

1. INTRODUCTION

The spectroscopic experimental information about the odd-even ^{69}Ga nucleus have been compiled in Nuclear data Sheets [1]. Among various theoretical attempts, the three particle cluster-core-coupling Alaga model calculations [2, 3] and the shell model calculations [4, 5] have provided comparable results for the level sequence for ^{69}Ga. The corresponding theoretical B(E2) values obtained by them [2–5], however, differ significantly from one another for several low-lying levels. Besides, the corresponding experimental B(E2) values obtained either indirectly through lifetime measurements with DSA method in inelastic scattering [6,7], and compound nuclear reactions [6], or directly through Coulomb excitation with alpha [8–10] themselves are too discrepant to test critically the predictions of the alternate models. All the direct Coulomb excitation measurements conducted till now, had used relatively small detectors [8–10] with poor resolution in comparison to the present detector. Keeping in view the above discrepancies, we extracted B(E2) values for low-lying levels of ^{69}Ga *via* proton induced Coulomb excitation with improved energy resolution and relatively better detection efficiency. The branching ratios for various transitions were obtained from the gamma-ray spectra recorded at 55^{o} *w.r.t.* beam direction. The preliminary results of this experiment have been reported earlier [11]. The present study is in continuation of our earlier work [12–14] on proton induced coulomb excitation in the mass region of A < 100.

2. EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

A thick (0.25 mm) self-supporting pellet of spectroscopically pure Gallium oxide was used as a target. The experiment was performed using proton beam of 2.2–4.2 MeV energies from Variable Energy Cyclotron at Panjab University, Chandigarh, India. The target was rotated at an angle of 45^o with respect to the beam direction and was thick enough to stop incident protons. The singles gamma-ray spectra were recorded at 55^o with a Germanium detector having a resolution of 1.9 keV for the 1332 keV gamma-ray of ^{60}Co. This is relatively bigger Germanium detector used so far for these measurements. Since the target was thick enough to stop all the incident protons, it worked as a Faraday cup for the charge collection. The details of the experimental procedure and data analysis are given in our previous publications [14, 15]. The relevant portion of a typical gamma-ray spectrum with 2.5 MeV proton beam on gallium target is shown in Fig. 1.

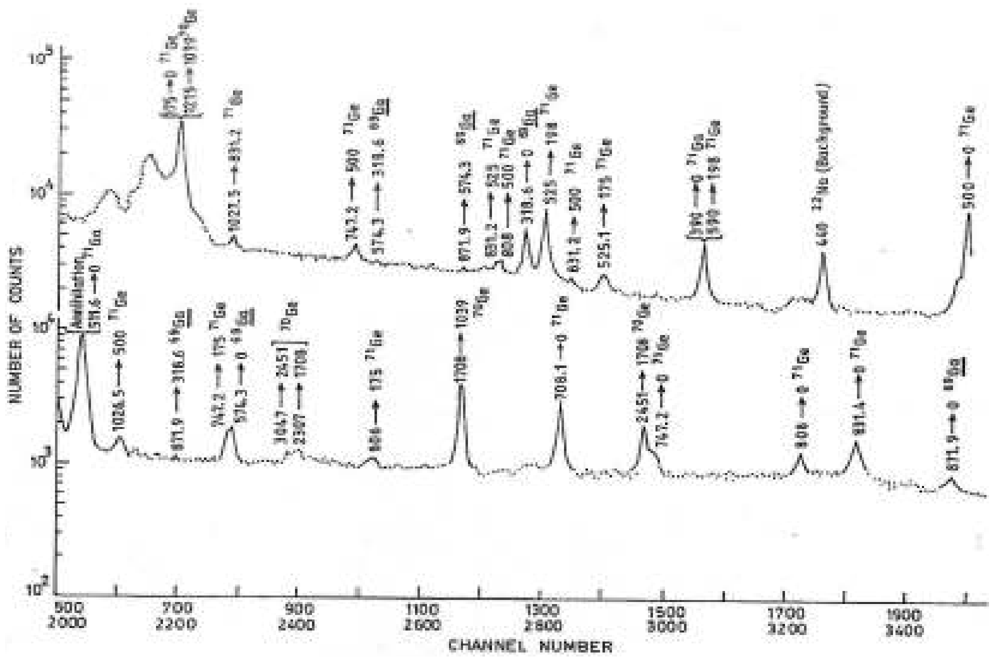

Fig. 1 – Relevant portion of a typical gamma-ray spectrum with 2.5 MeV proton beam on natural Gallium oxide target.

The Gamma-ray spectra were analysed using the computer code PEAKFIT [16]. The low-lying level scheme for ^{69}Ga on the basis of observed gamma-rays in the present experiment is shown in Fig. 2 and is similar to the reported one in earlier results [1]. The observed gamma-ray energies and the relative branching ratios as shown in Table 1, are the weighted average of the values at different incident proton energies. The contributions to population of low-lying levels in ^{69}Ga from the decay of ^{69}Ge (Half-life = 39 hours) formed above 3 MeV proton energies were taken in to account as suggested by Paradellis *et al.* [7]. The feeding of the low-lying levels through intermediate transitions from higher levels at various proton energies were also taken in to account. The contributions of the compound nuclear reactions to the thick target gamma-ray yields were calculated with computer code CINDY [17] taking into consideration various open channels as described in our previous publications [14, 15], while the Coulomb contributions were obtained using the theory of Alder *et al.* [18]. The safe proton beam energy for Coulomb excitation was found to be 2.5 MeV by using the similar methodology as used in our previous work for neighboring Cu and Zn nuclei [13]. At this bombarding energy, for ^{69}Ga target, the compound process mainly consists of (p, γ) channel because (p, n γ) channel does not open at this energy due to its higher reaction Q-value (= –3.01 MeV).

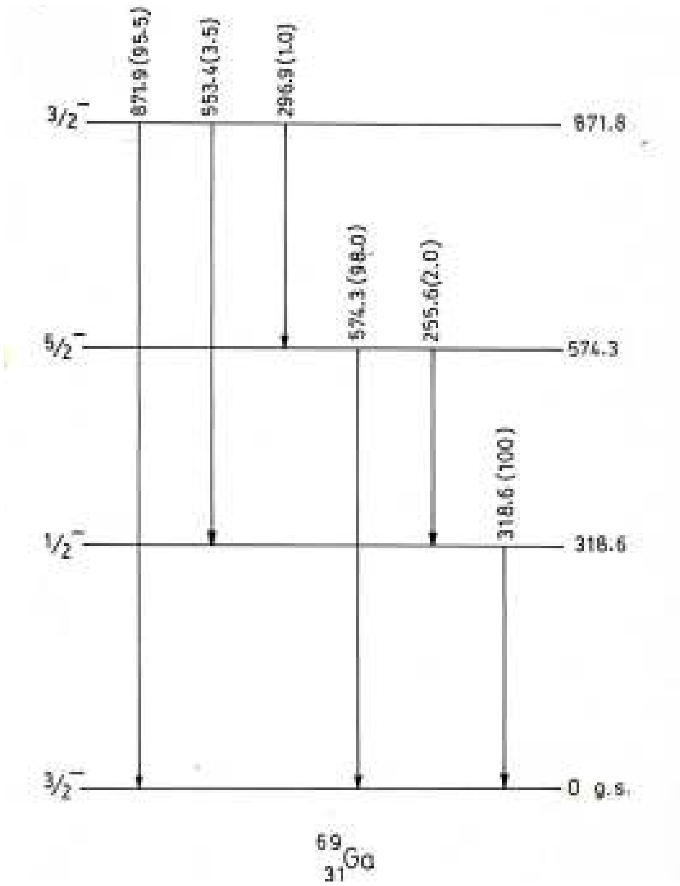

Fig. 2 – Low-lying level scheme of ^{69}Ga.

3. RESULTS AND DISCUSSIONS

The branching ratios and B(E2)↑ values obtained in this work are presented in Table 1 and 2, respectively and compared with the previous results [7, 10, 19]. The comparison of B(E2) values with experimental results [8, 10] and theoretical calculations [3, 5, 10] shows that the present results differ from some of the earlier measurements. The assigned errors in our B(E2) values arise mainly from the uncertainties in the peak area, background subtraction, efficiency of the detector and the stopping power for incident protons in the target material.

Table 1

Gamma-ray energies and branching ratios in the present work along with comparison with previous results

Level (keV)	Gamma-ray (keV)	Experimental branching ratios			
		Present	Ref. 19	Ref. 10	Ref. 7
318.6	318.6	100	100	100	100
574.3	574.3	98.0	99.8	99.8	–
	255.5	2.0	0.2	0.2	–
871.9	871.9	95.5	95.0	94.9	95.0
	553.4	3.5	4.8	4.9	5.0
	296.9	1.0	0.2	0.2	–

Table 2

Comparison of experimental and theoretical B(E2)↑ (e^2 cm^4 × 10^{-50}) values for three excited levels in ^{69}Ga

Level (keV)	Experimental B(E2)			Theoretical B(E2)		
	Present	Ref. 10	Ref. 8	Ref. 10	Ref. 5	Ref. 3[c]
318.6	0.67± 0.06	0.66 ± 0.01	0.65	0.69	0.65	0.6
574.3	0.35 ±0.10	0.085 ± 0.013	0.062	0.6	0.09	0.45
871.9	2.09± 0.95	0.85 ± 0.13	0.41	1.9	0.91	2.4

c: Alaga model calculations

The present B(E)↑ value of 0.67 ± 0.06 × 10^{-50} e^2 cm^4 for the 318.6 keV level is in excellent agreement with experimental values from Coulomb excitation with alphas [9, 10] as well as with theoretical values from the phenomenological particle-core coupling model [10], the cluster-core-coupling model [2, 3] and the shell model [5]. The B(E2)↓ / $B(E2)_w$ = 8 and B(E2)↓ / $B(E2)_{av}$ = 0.45 values (where $B(E2)_w$ = 0.168 × 10^{-50} e^2 cm^4 is the Weisskopf single particle estimate, and $B(E2)_{av}$ = 3 × 10^{-50} e^2 cm^4 is the average of experimental B(E2)↓ values [20, 21]) for the ground state transitions from the first 2^+ level in the even-even nuclei ^{68}Zn and ^{70}Ge suggest mixed character for this level. On contrary, in refs [2] and [3], this level is suggested to be predominantly single particle state. Paar [3] explained the relatively large value of B(E2)↓ as arising from the transfer of B(E2) strength from 1028.5 keV multiplet state.

The peak corresponding to the ground state transition from 574.3 keV level is contaminated with 572.3 keV transition from the 747.2 keV level of ^{71}Ge excited through ^{71}Ga(p, n γ)^{71}Ge reaction on natural gallium target. The 747.2 keV level de-excites through 247.3, 572.3 and 747.2 keV transitions. The branching ratios for these transitions are known [21] to be 29.8 ± 2.4, 45.4 ± 1.8 and 28.8 ± 1.1, respectively. The detailed analysis of the composite peak of 572.3 and 574.3 keV energies was done using the above branching ratios. This analysis produced the Coulomb excitation yield for ground state transition from 574.3 keV level from which the B(E2) value was obtained. The present B(E2)↑ value of $0.35 \pm 0.10 \times 10^{-50}$ e^2 cm^4 agrees satisfactorily with experimental value by Ivascu *et al.* [6] and theoretical value from cluster-core-coupling model [2, 3]. However, the other reported experimental values [9, 10], and the theoretical values from shell model [5] differ significantly with our results. The $B(E2)\downarrow$ / $B(E2)_w$ = 1.4 and $B(E2)\downarrow$ / $B(E2)_{av}$ = 0.08 values along with the reported spectroscopic values of C^2S = 1.14 [22], S = 0.53 [23] and S = 0.77 [24] indicate single particle character for this level.

The B(E2)↑ value of $2.09 \pm 0.95 \times 10^{-50}$ e^2 cm^4 for the 871.9 keV level with large statistical contribution to its uncertainty is in reasonable agreement with the reported experimental values [7, 10]. However, the value of Fagg *et al.* [9] measured with a small NaI detector and reported without associated errors seems to differ significantly from our values. The present value is also in excellent agreement with the cluster-core-coupling model [2, 3] and phenomenological intermediate particle core coupling model [10]. The $B(E2)\downarrow$ /$B(E2)_w$ = 11 and $B(E2)\downarrow$ /$B(E2)_{av}$ = 0.7 and reported spectroscopic factors C^2S = 0.58 [22], S = 0.11 [23] and S = 0.07 [24] suggest predominantly collective character for this level. According to cluster-core-coupling model [2, 3], this level configuration is dominated by one-phonon seniority-one quadruplet and seniority three components with zero expected value for spectroscopic factor S. So we conclude that our results are in better agreement with the predictions of cluster-core-coupling model [2, 3] and suggest that the 318.6, 574.3 and 871.9 keV levels have mixed, predominantly single-particle like, and mainly collective structure, respectively.

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