# Nuclear structure systematics in Ga isotopes for $40 \leq N \leq 50$

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## Introduction

The structural changes between $N = 40$ and $N = 50$ of gallium isotopes recently attracted much experimental attention. At Argonne National Laboratory, Stefanescu *et. al.* [1] have populated odd-A $^{71-77}$Ga isotopes in deep-inelastic reactions. More recently, in the Coulomb excitation experiment at REX-ISOLDE, the existence of a $1/2^-$, $3/2^-$ ground-state doublet has been proposed in $^{73}$Ga [2]. For odd-even Ga isotopes nuclear spins and moments has been reported in [3]. Recently ground-state spins and moments of $^{72,74,76,78}$Ga isotopes using laser spectroscopy has been reported in [4]. The evolution of the $1/2^-$ and $5/2^-$ levels in odd-A gallium isotopes are shown in Fig. 1. Except for $^{73}$Ga and $^{81}$Ga all have ground state (g.s.) $3/2^-$. The first $1/2^-$ reaches minimum in $^{73}$Ga where it becomes the ground state and the first $5/2^-$ start decreasing with $N = 40$ onwards and it becomes the ground state in $^{81}$Ga. This figure also demonstrate abrupt changes of structure from $N = 40$ to $N = 42$.

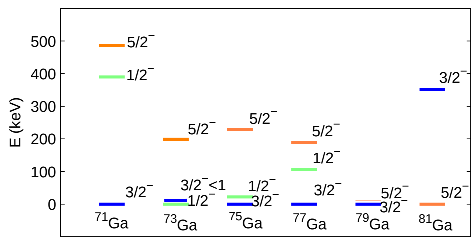


FIG. 1: Experimental low-energy systematics of odd-A gallium isotopes [1–3].

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Following our recent shell-model (SM) studies [5–9] in the present work we report large scale shell model calculations for Ga isotopes. Earlier shell model calculation using pairing plus quadrupole-quadrupole interaction for $^{75,77,79}$Ga isotopes have been reported by Yoshinaga *et. al.,* [10]. They consider only low-lying negative-parity states in the analysis. The aim of present study is to analyze recently accumulated experimental data which includes both positive and negative high-spin states on neutron-rich Ga isotopes. Further, this work will add more information in the earlier work for odd-even Ga isotopes by Cheal *et al.* [3], where only few excited negative-parity states (< 1 MeV) are studied in $f_{5/2}pg_{9/2}$ space. Present work also include further theoretical development which is proposed in [3], by including $f_{7/2}$ orbital in the model space.

## Results and Discussion

In the present work large scale shell model calculations have been performed for Ga isotopes in $f_{5/2}pg_{9/2}$ and $fpg_{9/2}$ model spaces with $^{56}$Ni and $^{48}$Ca core respectively. For the $f_{5/2}pg_{9/2}$ space, calculations have been performed with JUN45 [11] and jj44b [12] interactions and for $fpg_{9/2}$ model space with $fpg$ interaction [13]. In $fpg_{9/2}$ space, we use a truncation by allowing maximum three particle excitations.

Here in brief result of moments have been presented. We have calculated static quadrupole moments with effective charges $e_p^{eff} = 1.5e, e_n^{eff} = 1.1e$ and magnetic moments with $g_s^{eff} = 0.7g_s^{free}$ in $fpg_{9/2}$ model space as shown in Table I. The $fpg$ interaction predict correct sign of quadrupole moments for $^{71,73,75,77}$Ga and results are better than if we use only $f_{5/2}pg_{9/2}$ space [3]. The change in sign of quadrupole moments from $^{71}$Ga, i.e.

TABLE I: Calculated and experimental quadrupole moments and magnetic moments of Ga isotopes. For even Ga isotopes these state may not be predicted as ground state by shell-model.

| Nucleus | $I$ | $Q_{s,expt}$(eb) | $Q_{s,fpg}$(eb) | $\mu_{expt}(\mu_N)$ | $\mu_{fpg}(\mu_N)$ | Nucleus | $I$ | $\pi_{SM}$ | $Q_{s,expt}$(eb) | $Q_{s,fpg}$(eb) |
|---|---|---|---|---|---|---|---|---|---|---|
| $^{71}$Ga | 3/2 | +0.106(3) | +0.166 | +2.56227(2) | +2.198 | $^{72}$Ga | $3_1$ | − | +0.536(29) | +0.017 |
| $^{73}$Ga | 1/2 | 0 | 0 | +0.209(2) | +0.039 | $^{74}$Ga | $3_1$ | − | +0.549(40) | +0.425 |
| $^{75}$Ga | 3/2 | −0.285(17) | −0.338 | +1.836(4) | +1.715 | $^{76}$Ga | $2_1$ | − | +0.329(19) | +0.268 |
| $^{77}$Ga | 3/2 | −0.208(13) | −0.289 | +2.020(3) | +1.831 | $^{78}$Ga | $2_1$ | − | +0.327(18) | +0.381 |
| $^{79}$Ga | 3/2 | +0.158(10) | −0.074 | +1.047(3) | +1.489 | $^{80}$Ga | $6_1$ | − | +0.478(27) | +0.568 |
| $^{81}$Ga | 5/2 | −0.048(8) | +0.042 | +1.747(5) | +1.644 | $^{80}$Ga | $3_1$ | − | +0.375(21) | +0.394 |

$N = 40$ onwards, demonstrate a changing of shell structure. This is due to ground state of $^{71}$Ga have $\pi(p^3_{3/2})$ configuration ($\sim$ 28%) and $^{75,77}$Ga have $\pi p^1_{3/2}(f_{5/2}p_{1/2})^2$ configuration. These configurations reveal change of sign of quadrupole moments because filling of higher orbital started. Thus below $N = 42$, a hole configuration ($\pi(p^3_{3/2})$) has a positive quadrupole moment and above $N = 42$, a particle configuration ($\pi p^1_{3/2}(f_{5/2}p_{1/2})^2$) has a negative quadrupole moment. The *fpg* interaction predict correct sign of magnetic moment for $^{73}$Ga while JUN45 and jj44b gives negative sign. This support ground state as $1/2^-$ for $^{73}$Ga. We have also reported quadrupole moments for $^{72,74,76,78,80}$Ga isotopes with *fpg* interaction. For $^{74}$Ga the *fpg* give reasonable value of quadrupole moment in comparison to jj44b [4] while it predict too low value for $^{72}$Ga.

### Conclusions

Our calculated results predict high-spin sequences built on top of the $3/2^-$, $5/2^-$ and $9/2^+$ levels in odd $^{71-77}$Ga. The results of *fpg* interaction are better than JUN45 and jj44b in lighter isotopes. While for heavier isotopes, the results of jj44b interaction are quantitatively better than JUN45. The results of level energies for heavier Ga isotopes with *fpg* interaction are more compressed. The calculated $B(E2)$ values for $^{73}$Ga with jj44b interaction give reasonable agreement with experimental data. The energy level systematics of Ga isotopes are quite similar to that in Cu isotopes. There is a clear need for suitable interaction for neutron-rich nuclei in this region for better understanding of nuclear structure.

We thank V.K.B. Kota, M. Honma, J. Diriken, R.Sahu for usefull discussions. All the SM calculations are performed on the 20-node cluster computer at PRL using the code ANTOINE.

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