Large shell model and deformed shell model spectroscopy of $^{62}$Ga

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Abstract

In the present work we have interpreted recently available experimental data [H.M. David et al., Phys. Lett. B 726, 665 (2013)] for low-lying $T = 0$ and $T = 1$ states in the odd-odd $N = Z$ nucleus $^{62}$Ga using large shell-model calculations within the full $f_{5/2}g_{9/2}$ model space and deformed shell model based on Hartee-Fock intrinsic states in the same space. The calculations have been performed using jj44b effective interaction developed by B.A. Brown and A.F. Lisetskiy for this model space. The results obtained with the two models are similar and they are in good agreement with experimental data.
I. INTRODUCTION

In the recent past there are many experimental and theoretical investigations for heavy \( N = Z \) nuclei. In the case of even-even \( N = Z \) nuclei from \(^{68}\text{Se} \) \((Z = 34)\) to \(^{88}\text{Ru} \) \((Z = 44)\) many interesting phenomena have been observed. For example, \(^{68}\text{Se} \) exhibits oblate shape in the ground state \([1]\) and in the case of \(^{72}\text{Kr} \) \([2]\) shape-coexistence has been observed. On the other hand, the nuclei \(^{76}\text{Sr} \) \([3]\) and \(^{80}\text{Zr} \) \([4]\) have large ground-state deformation. Also, the even-even \( N=Z \) nuclei are waiting point nuclei for \( rp \)-process nucleosynthesis. As we move further, there is a decrease in deformation as seen for example in \(^{84}\text{Mo} \) \([5]\) and \(^{88}\text{Ru} \) \([6]\). However, more interesting are the \( N=Z \) odd-odd nuclei as they will allow us to investigate isospin effects and in particular about \( T = 0 \) vs \( T = 1 \) pairing. As a consequence there are continuous experimental efforts to study in detail odd-odd \( N=Z \) nuclei in the \( A \sim 60-80 \) region \([7–15]\). In this paper we will consider \(^{62}\text{Ga} \) where there are new and more complete data \([9]\) obtained recently by using heavy-ion fusion-evaporation reaction \(^{40}\text{Ca}(^{24}\text{Mg},pn)^{62}\text{Ga} \) near the Coulomb barrier with ATLAS accelerator and Gammasphere array. These data go much beyond the data reported previously in 1998 \([7]\) and 2004 \([8]\) on \( T = 0 \) and \( T = 1 \) levels in this nucleus. Theoretical results for low-lying \( T=0 \) and \( T=1 \) states, with low spins, of \(^{62}\text{Ga} \) obtained using SM \([16]\), DSM \([17]\) and IBM-4 \([16]\) are available in the literature. In the SM and DSM calculations realistic G-matrix interaction with a phenomenologically adjusted monopole part as given by the Madrid-Strasbourg group \([18]\) has been used. The aim of the present study is to explain, more comprehensively, the recent experimental data for \(^{62}\text{Ga} \) using large shell model (SM) calculations and also extend the deformed shell model (DSM) (based on Hartree-Fock states) calculations reported in the past for this nucleus \([17]\) both with a more recently introduced effective interaction jj44b \([19]\).

The paper is organized as follows. Section II gives some details regarding the effective interaction used and about DSM. Section III gives results from SM and DSM and their comparison with experimental data. Finally, concluding remarks are given in section IV.

II. METHOD OF CALCULATIONS

In the present work for both SM and DSM, \(^{56}\text{Ni} \) is taken as the inert core with the spherical orbits \( 2p_{3/2}, 1f_{5/2}, 2p_{1/2} \) and \( 1g_{9/2} \) as active orbits. The jj44b interaction due to
Brown and Lisetskiy [19] was employed in the calculations. This interaction was developed by fitting 600 binding energies and excitation energies from nuclei with \( Z = 28 - 30 \) and \( N = 48 - 50 \). Here, 30 linear combinations of \( JT \) coupled two-body matrix elements (TBME) are varied giving the rms deviation of about 250 keV from experiment. The single particle energies (spe) are taken to be [19] -9.6566, -9.2859, -8.2695 and -5.8944 MeV for the \( p_{3/2} \), \( f_{5/2} \), \( p_{1/2} \) and \( g_{9/2} \) orbits respectively. The large shell model calculations are carried out using the shell model code NuShell [20]. The maximum matrix dimension in \( M \)-scheme is for \( 0^+ \) states and it is 91564.

Turning to DSM, for a given nucleus, starting with a model space consisting of the given set of single particle (sp) orbitals and effective two-body Hamiltonian (TBME+spe), the lowest energy intrinsic states are obtained by solving the Hartree-Fock (HF) single particle equation self-consistently. Excited intrinsic configurations are obtained by making particle-hole excitations over the lowest intrinsic state. These intrinsic states \( \chi_K(\eta) \) do not have definite angular momenta. and states of good angular momentum projected from an intrinsic state \( \chi_K(\eta) \) can be written in the form

\[
\psi_{MK}^J(\eta) = \frac{2J+1}{8\pi^2\sqrt{N_{J\eta}}} \int d\Omega D_{MK}^J(\Omega) R(\Omega) |\chi_K(\eta)\rangle
\]

where \( N_{J\eta} \) is the normalization constant given by

\[
N_{J\eta} = \frac{2J+1}{2} \int_0^\pi d\beta \sin \beta d_{K\eta}^J(\beta) \langle \chi_K(\eta)|e^{-i\beta J_y}|\chi_K(\eta)\rangle .
\]

In Eq. (1) \( \Omega \) represents the Euler angles \((\alpha, \beta, \gamma)\), \( R(\Omega) \) which is equal to \( \exp(-i\alpha J_z)\exp(-i\beta J_y)\exp(-i\gamma J_z) \) represents the general rotation operator. The good angular momentum states projected from different intrinsic states are not in general orthogonal to each other. Hence they are orthonormalized and then band mixing calculations are performed. In addition, as required for \( N=Z \) nuclei, isospin projection is also included in DSM. For details see for example [21–24]. DSM is well established to be a successful model for transitional nuclei (with \( A=60-90 \)) when sufficiently large number of intrinsic states are included in the band mixing calculations.

For \(^{62}\text{Ga} \) nucleus, Fig. 1 gives the HF single particle (sp) spectrum (the states are labeled by \( |k_\alpha\rangle \) where the \( \alpha \) label distinguishes different states with the same \( k \) value) for both prolate and oblate solution. As seen from the figure, the prolate solution is lowest. The lowest HF intrinsic state from the prolate solution consists of two protons and two
neutrons occupying the lowest \( k = 1/2^- \) state and the last unpaired odd proton and neutron occupying the next \( k = 1/2^- \) state. The HF energy \( (E) \), the mass quadrupole moment \( (Q) \) and band \( K \)-value are also shown in the figure. For the four nucleons (two protons and two neutrons) occupying the lowest \( k = 1/2^- \) sp state we have \( T = 0 \). Hence the isospin for \( ^{62}\text{Ga} \) is determined by the last proton and neutron. Thus the total isospin for the configuration shown in Fig. 1 is \( T = 0 \) as the odd proton and odd neutron, for \( K = 1^+ \), form a symmetric pair in the \( k \)-space (here and elsewhere in this paper symmetry in \( k \)-space means symmetry in space-spin co-ordinates as \( k \) contains both space (orbital) and spin co-ordinates). Particle-hole excitations over the lowest HF intrinsic state (from both prolate and oblate solutions) generate excited HF intrinsic states . There are 44 low-lying excited intrinsic states obtained by particle-hole excitation up to 3 MeV excitation. The HF intrinsic states are in general admixtures of various isospin components. As mentioned above, the lowest prolate and oblate HF intrinsic states will have \( T = 0 \). If in an excited intrinsic state, the unpaired proton occupies the single particle orbit specified by the azimuthal quantum number \( k_1 \) and the unpaired neutron occupies the state \( k_2 \), then one can also consider an intrinsic state where the occupancies of the unpaired nucleons are reversed. By taking a linear combination of these intrinsic states, one can construct intrinsic states which are symmetric (or antisymmetric) in \( k \)-space co-ordinates and they correspond to \( T = 0 \) and \( T = 1 \) states respectively. With this isospin projection, in the present calculation, there are 26 intrinsic states for \( T = 0 \) and 18 for \( T = 1 \) (total 44). All the configurations are listed in Table I. Then good angular momentum states are projected from all the \( T = 0 \) intrinsic states and a band mixing calculation is performed. Similar procedure is also applied for the \( T = 1 \) intrinsic states.

III. RESULTS AND DISCUSSIONS

A. Shell model results

Fig. 2 shows comparison of recently available experimental data [9] with SM for the spectra with the lowest \( T = 1 \) band and three higher \( T = 0 \) bands with maximum spin \( 17^+ \). The agreements are reasonable. However, the SM gives the excitation energy of the lowest \( T = 0 \) level (with \( 1^+ \)) to be 148 keV against the experimental value 571 keV. In
order to bring out the structure of these levels, in Table 2 given are the dominant shell model configuration (and its probability) in a given level and also the occupancies of the four single particle orbits. In the lowest $T = 0$ band, the high-spin levels starting from $J^\pi = 13^+$ have $g_{9/2}$ occupancy close to 2 while the lower levels are essentially from the $f_{5/2}p$ orbits. For example, the structure changes from $1^+$ with dominant configuration $f_{5/2}^3p_{3/2}^3$ ($\sim 14.66\%$) to $17^+$ with dominant configuration $f_{5/2}^2p_{3/2}^2g_{9/2}^2$ ($\sim 68.87\%$). This shows that as we move to higher $J$ values, the $g_{9/2}$ orbital start playing an important role in the structure. It is also seen from Table 2 that the second $T = 0$ band is essentially from $f_{5/2}p$ orbits for spins up to $10^+$ while for the third band $g_{9/2}$ is important for the $10^+$ level. Turning to yrast $T=1$ states, it is seen that shell model gives very good agreement with available experimental data. The structure of $0^+$ to $10^+$ levels is mainly due to $(f_{5/2}p_{3/2}p_{1/2})^6$ configuration and the structure of low $J$ values is more fragmented in comparison to high $J$ values. This is reflected from the change in the probability $\sim 17.93\%$ ($0^+$) to $\sim 65.15\%$ ($10^+$).

There is interest in the number of low-lying (say up to 2 or 3 MeV) states in odd-odd $N=Z$ nuclei compared to the neighboring neutron-rich odd-odd nuclei. For example, the $^{62}$Ga with $N=Z$ has much lower number of levels up to 1.7 MeV excitation compared to those in $^{64}$Ga ($\sim 30$ levels) and $^{68}$Ga ($\sim 60$ levels); see the discussion in [9]. Because of this important issue, we show in Fig. 3 all the low-lying levels up to 3 MeV excitation. It is seen that the sequence of lowest-lying states is well reproduced by shell model although the calculated level energies are compressed.

Finally, some results for $B(E2)$’s are shown in Table 3 and for $B(M1)$’s in Table 4. For $T = 0$ state the $B(E2,3_1^+ \rightarrow 1_1^+)$ from shell model is 6.43 W.u. while the corresponding experimental value is 12 W.u. The result may improve if we slightly increase the effective charges. Similarly, the $B(M1)$ is largest for the $0_1^+$ of $T = 1$ to $1_1^+$ of $T = 0$. Further discussion is given below.

### B. Deformed shell model results

Figs. 2 and 3 shows comparison of DSM results with experimental data [9] and SM for high spin states and all low-lying levels respectively. The agreements between experiment and DSM and also between DSM and SM are reasonable. As discussed in [22], DSM can produce only the relative energies in the $T = 0$ levels and similarly for the $T = 1$ levels.
Following this, all the $T = 0$ levels are pushed up by 600 keV (experimental value is 571 keV with respect to the lowest $T = 1$ level just as in [22, 23]). For the lowest $T = 0$ band (see Fig. 1) it is seen that there is a band crossing at $11^+$ with clear structural change from $13^+$. The $13^+$, $15^+$ and $17^+$ mainly originate from the rotational aligned $K = 1^+$ band obtained by placing a proton (neutron) in a $k = 3/2^+$ and neutron (proton) in a $k = 1/2^+$ orbit. This corresponds to the configuration number 17 in Table 1. This configuration given by DSM is consistent with SM result as given Table II, i.e. the high-spin levels from $13^+$ have $g_{9/2}$ occupancy $\sim 2$. The levels below $11^+$ are essentially from $f_{5/2}p$ orbits (as in SM, see Table II) dominated by the deformed configurations #1, #2 and #4 in Table 1. As seen from the figure, there are two close-lying $9^+$ levels with $T = 0$ (this is seen for $9^+$ in experimental data) and the $9^+_1$ arise from the mixing of the configurations #1 and #10 (close in structure to $7^+_1$) while $9^+_2$ arise from mixing of configurations #1 and #6. The SM has also two $9^+$ levels as shown in Fig. 1. From the $B(E2)$ values shown in Table 1 for $9^+_1 \rightarrow 7^+_1$ it is clear, as we expect large $B(E2)$ value with the levels belonging to the same band, that the $9^+_1$ (5075 keV) of DSM should correspond to $9^+_2$ (5405 keV) of SM. For the two $11^+$ levels in DSM, there is considerable mixing of various configurations. From the $13^+_1 \rightarrow 11^+_1 B(E2)$ values shown in Table III and that there is clear structural change after $11^+$ allow as to conclude that the $11^+_2$ (6311 keV) of DSM corresponds to $11^+_2$ (7421 keV) of SM (see Fig. 2). With these correspondence between DSM and SM we expect the $B(E2)$ for $11^+_2 \rightarrow 9^+_1$ of DSM should be close to that of $11^+_2 \rightarrow 9^+_2$ of SM. This is indeed seen in Table III (DSM gives 0.4 W.u. and SM gives 1.05 W.u.). Thus we have a good correspondence between the yrast $T = 0$ levels in DSM and SM.

Going to the non-yrast $T = 0$ bands shown in Fig. 2, the first excited $2^+$ band like structure is mainly from configurations #5 and #6 and the second $2^+$ band arises mainly from configuration #1 shown in Table I. Going to the $T = 1$ band, this arises mainly from configurations #2 and #4. It is also seen that with increase in spin in the band, there more mixing of other deformed configurations (therefore SM configurations at higher spins are more pure as stated in Section III A). The $B(E2)$’s values from DSM and SM are similar for the $T = 1$ band and the collectivity starts decreasing from $6^+$. For the $10^+ \rightarrow 8^+$, the DSM value is much smaller than SM value. In addition, Table IV gives $B(M1)$ values for some of yrast $T = 1$ to yrast $T = 0$ transitions. It is seen that the $0^+_1 \rightarrow 1^+_1$ transition is strong and the DSM value is close to SM value. Other transition strengths are much smaller in both
models.

Turning to the low-lying levels, all levels (with $T = 0$ and $T = 1$) predicted by DSM below 3 MeV excitation are compared with SM and experimental data in Fig. 3. The number of levels in the experiment, SM and DSM with $T = 0$ up to 1.7 MeV are 7, 17 and 10. Note that in Fig. 3, for the SM we have shown only maximum three eigen values for a given $J$. As mentioned before, the experimentally observed level density up to 1.7 MeV excitation in the neighboring odd-odd Ga isotopes is much larger. Another important feature is that in the $T = 0$ levels, the experimental data show a well defined gap of $\sim 600$ keV above 1.575 MeV level. A similar gap is seen in both DSM and SM. Also, the $2^+_2$, $0^+_2$ and $3^+_1$ of $T = 1$ shown in Fig. 3 for DSM (also SM) are indeed seen in the isobaric analogue nucleus $^{62}$Zn.

IV. CONCLUSIONS

In the present work we have compared results of recently available experimental data for $T = 0$ and $T = 1$ states for $^{62}$Ga within shell model and deformed shell model results obtained using jj44b interaction. As discussed in detail in Section III, the SM and DSM explain the experimental data well. The analysis shows that DSM with much smaller number of (deformed) configurations is adequate for $^{62}$Ga. In future, it is also important to improve further the effective interactions in $f_{5/2}g_{9/2}$ space and also include proton and neutron excitations across the $Z=28$ shell by including the $1f_{7/2}$ orbital in the model space.

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TABLE I: Intrinsic states used for $^{62}$Ga in DSM calculation. For each intrinsic state, given are the corresponding configurations, the total $K$-quantum number and isospin ($T$). The states 1 to 20 are prolate configurations and 21 to 26 oblate. Superscript $(2p, 2n)$ implies that the orbit is occupied by two protons and two neutrons and similarly the superscript $(p, n)$. In addition, the superscripts $p(n)$ and $n(p)$ imply that the orbit(s) is(are) alternatively occupied by a proton and a neutron or a neutron and a proton.

| No. | $K$  | $T$  | Configuration                        |
|-----|------|------|--------------------------------------|
| 1.  | 1+   | 0    | $(1/2^-)^2p,2n(1/2^-)^p,n_2$          |
| 2.  | 0+   | 0.1  | $(1/2^-)^2p,2n(1/2^-)^p,n_2(1/2^-)^n(p)$ |
| 3.  | 3+   | 0    | $(1/2^-)^2p,2n(3/2^-)^p,n_1$          |
| 4.  | 0+   | 0.1  | $(1/2^-)^2p,2n(3/2^-)^p,n_1(3/2^-)^n(p)$ |
| 5.  | 1+   | 0    | $(1/2^-)^2p,2n(3/2^-)^p,n_1(1/2^-)^n(p)$ |
| 6.  | 2+   | 0    | $(1/2^-)^2p,2n(3/2^-)^p,n_1(1/2^-)^n(p)$ |
| 7.  | 3+   | 0    | $(1/2^-)^2p,2n(3/2^-)^p,n_1$          |
| 8.  | 0+   | 0.1  | $(1/2^-)^2p,2n(3/2^-)^p,n_1(3/2^-)^n(p)$ |
| 9.  | 1+   | 0    | $(1/2^-)^2p,2n(3/2^-)^p,n_1(1/2^-)^n(p)$ |
| 10. | 2+   | 0    | $(1/2^-)^2p,2n(3/2^-)^p,n_1(1/2^-)^n(p)$ |
| 11. | 0+   | 0.1  | $(1/2^-)^2p,2n(3/2^-)^p,n_1(3/2^-)^n(p)$ |
| 12. | 3+   | 0    | $(1/2^-)^2p,2n(3/2^-)^p,n_1$          |
| 13. | 1+   | 0    | $(1/2^-)^2p,2n(1/2^+)^p,n_1$          |
| 14. | 0+   | 0.1  | $(1/2^-)^2p,2n(1/2^+)^p,n_1(1/2^+)^n(p)$ |
| 15. | 3+   | 0    | $(1/2^-)^2p,2n(3/2^+)^p,n_1$          |
| 16. | 0+   | 0.1  | $(1/2^-)^2p,2n(3/2^+)^p,n_1(3/2^+)^n(p)$ |
| 17. | 1+   | 0    | $(1/2^-)^2p,2n(3/2^+)^p,n_1(1/2^+)^n(p)$ |
| 18. | 2+   | 0    | $(1/2^-)^2p,2n(3/2^+)^p,n_1(1/2^+)^n(p)$ |
| 19. | 1+   | 0    | $(1/2^-)^3p,2n(1/2^-)^p,n_1$          |
| 20. | 0+   | 0.1  | $(1/2^-)^3p,2n(1/2^-)^p,n_1(1/2^-)^n(p)$ |
| 21. | 5+   | 0    | $(3/2^-)^3p,2n(5/2^-)^p,n_1$          |
| 22. | 0+   | 0.1  | $(3/2^-)^3p,2n(5/2^-)^p,n_1(5/2^-)^n(p)$ |
| 23. | 1+   | 0    | $(3/2^-)^3p,2n(1/2^-)^p,n_1$          |
| 24. | 0+   | 0.1  | $(3/2^-)^3p,2n(1/2^-)^p,n_1(1/2^-)^n(p)$ |
| 25. | 3+   | 0    | $(3/2^-)^3p,2n(5/2^-)^p,n_1(1/2^-)^n(p)$ |
| 26. | 2+   | 0    | $(3/2^-)^3p,2n(5/2^-)^p,n_1(1/2^-)^n(p)$ |
TABLE II: Shell model configurations and occupancies for $T = 0$ and $T = 1$ levels.

| T=0 | % probability | configurations | nucleon occupation numbers $n_{ij}^p = n_{ij}^g (f_{j_3/2} d_{3/2}, p_{j_1/2} g_{9/2})$ |
|-----|---------------|----------------|--------------------------------------------------------------------|
| 1+  | 14.66         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 1.71  3.08  1.00  0.21                                              |
| 3+  | 24.18         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.12  2.76  0.92  0.21                                              |
| 5+  | 30.30         | $f_{5/2}^3 p_{3/2}^5 p_{1/2}^1 d_{9/2}^0$ | 2.22  2.74  0.79  0.24                                              |
| 7+  | 32.38         | $f_{5/2}^3 p_{3/2}^5 p_{1/2}^1 d_{9/2}^0$ | 2.21  2.82  0.78  0.19                                              |
| 9+  | 32.94         | $f_{5/2}^3 p_{3/2}^5 p_{1/2}^1 d_{9/2}^0$ | 2.32  2.97  0.59  0.11                                              |
| 13+ | 34.78         | $f_{5/2}^3 p_{3/2}^5 p_{1/2}^1 d_{9/2}^2$ | 2.29  1.16  0.49  2.05                                              |
| 11+ | 94.59         | $f_{5/2}^3 p_{3/2}^3 p_{0/2}^0 d_{9/2}^0$ | 3.94  1.94  0.01  0.11                                              |
| 15+ | 36.50         | $f_{5/2}^3 p_{3/2}^3 p_{0/2}^0 d_{9/2}^0$ | 2.22  1.25  0.50  2.03                                              |
| 17+ | 68.87         | $f_{5/2}^3 p_{3/2}^3 p_{0/2}^0 d_{9/2}^0$ | 2.33  1.65  0.00  2.02                                              |
| 2+  | 14.57         | $f_{5/2}^3 p_{3/2}^4 p_{1/2}^1 d_{9/2}^0$ | 1.87  2.97  0.94  0.21                                              |
| 4+  | 15.27         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.02  2.91  0.84  0.23                                              |
| 6+  | 17.89         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.62  2.43  0.70  0.25                                              |
| 8+  | 45.66         | $f_{5/2}^3 p_{3/2}^3 p_{0/2}^0 d_{9/2}^0$ | 3.04  2.27  0.45  0.23                                              |
| 10+ | 69.08         | $f_{5/2}^3 p_{3/2}^3 p_{0/2}^0 d_{9/2}^0$ | 3.09  2.64  0.16  0.10                                              |
| 2+  | 16.24         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.44  2.45  0.89  0.22                                              |
| 4+  | 18.51         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 1.66  3.19  0.92  0.22                                              |
| 6+  | 30.12         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.29  2.93  0.58  0.20                                              |
| 8+  | 26.35         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 3.03  2.42  0.44  0.11                                              |
| 10+ | 31.27         | $f_{5/2}^3 p_{3/2}^3 p_{0/2}^0 d_{9/2}^0$ | 2.90  0.91  0.28  1.90                                              |

| T=1 |               |               |                                                                  |
|-----|---------------|---------------|-----------------------------------------------------------------|
| 0+  | 17.93         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 1.89  2.85  0.81  0.43                                              |
| 2+  | 14.07         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.09  2.65  0.90  0.35                                              |
| 4+  | 17.23         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.53  2.41  0.74  0.33                                              |
| 6+  | 17.58         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.78  2.35  0.64  0.24                                              |
| 8+  | 24.55         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 2.86  2.50  0.44  0.19                                              |
| 10+ | 65.15         | $f_{5/2}^3 p_{3/2}^3 p_{1/2}^0 d_{9/2}^0$ | 3.28  2.59  0.14  0.11                                              |
TABLE III: $B(E2)$ values (in W.u.) in SM and DSM obtained using effective charges $e_p = 1.5e$ and $e_n = 0.5e$. Experimental value (shown in the last column) is taken from the NNDC database.

| $I_f^+ \rightarrow I_i^+$ | DSM | SM | EXPT. |
|--------------------------|-----|----|-------|
| **T=0 (Isoscalar)**      |     |    |       |
| $3_1^+ \rightarrow 1_1^+$ | 24.7| 6.46| $12_{-3}^{+6}$ |
| $5_1^+ \rightarrow 3_1^+$ | 30.9| 14.43|
| $7_1^+ \rightarrow 5_1^+$ | 29.2| 13.92|
| $9_1^+ \rightarrow 7_1^+$ | 17.5| 0.0029|
| $9_2^+ \rightarrow 7_1^+$ | 0.02| 7.77 |
| $11_1^+ \rightarrow 9_1^+$ | 0.08| 16.17|
| $11_2^+ \rightarrow 9_1^+$ | 0.4 | 0   |
| $11_1^+ \rightarrow 9_2^+$ | 1.1 | 0   |
| $11_2^+ \rightarrow 9_2^+$ | 5.9 | 1.05|
| $13_1^+ \rightarrow 11_1^+$ | 0.005| 16.21|
| $13_1^+ \rightarrow 11_2^+$ | 0.006| 0   |
| $15_1^+ \rightarrow 13_1^+$ | 36.0| 12.49|
| $17_1^+ \rightarrow 15_1^+$ | 20.5| 8.49 |
| **T=1 (Isoscalar)**      |     |    |       |
| $2_1^+ \rightarrow 0_1^+$ | 51.6| 42.57|
| $4_1^+ \rightarrow 2_1^+$ | 64.7| 53.91|
| $6_1^+ \rightarrow 4_1^+$ | 45.9| 52.52|
| $8_1^+ \rightarrow 6_1^+$ | 20.6| 23.13|
| $10_1^+ \rightarrow 8_1^+$ | 6.5 | 18.12|
TABLE IV: $B(M1)$ values in $\mu^2_N$. Here $g_s = g_{\text{free}}$ used in both SM and DSM calculations.

| $I_f^+ \rightarrow I_i^+$ | DSM | SM  |
|--------------------------|-----|-----|
| T=1 $\rightarrow$ T=0 (Isovector) |     |     |
| $0_1^+ \rightarrow 1_1^+$  | 1.2 | 1.39|
| $2_1^+ \rightarrow 1_1^+$  | 0.005 | 0.14|
| $2_1^+ \rightarrow 3_1^+$  | 0.13 | 0.01|
| $4_1^+ \rightarrow 3_1^+$  | 0.08 | 0   |
| $4_1^+ \rightarrow 5_1^+$  | 0.13 | 0   |
| $6_1^+ \rightarrow 7_1^+$  | 0.06 | 0.013|
| $8_1^+ \rightarrow 7_1^+$  | 0.41 | 0.16|
FIG. 1: HF single particle spectra for $^{62}$Ga corresponding to lowest prolate and oblate configurations. In the figures circles represent protons and crosses represent neutrons. The Hartree-Fock energy ($E$) in MeV, mass quadrupole moment ($Q$) in units of the square of the oscillator length parameter and the total $K$ quantum number of the lowest intrinsic states are given in the figure.
FIG. 2: Comparison of deformed shell model and shell-model results using jj44b interaction with experimental data. Energies are in keV.
FIG. 3: Comparison of experimental data with deformed shell model and shell-model results obtained using jj44b interaction for low-lying levels up to 3 MeV excitation. For SM we have only reported maximum three eigen values for a given $J$. 