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Deformed shell model for $T=0$ and $T=1$ bands in ^{62}Ga and ^{66}As

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A deformed configuration mixing shell model based on Hartree-Fock states with extension to include isospin projection is applied to study the structure of low-lying levels in the odd-odd $N=Z$ nuclei ^{62}Ga and ^{66}As. A realistic G-matrix interaction for the $(f_{5/2}pg_{9/2})$ space with monopole correction is employed in the calculations. The $T=0$ and $T=1$ spectra for ^{62}Ga compare well with experiment and shell model. The predicted spectrum for ^{66}As is close to the recent interacting boson model (IBM-4) results.

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I. INTRODUCTION

In the last few years there has been considerable interest in investigating the structure of heavy nuclei near the proton drip line and in particular the odd-odd $N=Z$ nuclei in the mass range $A=60-100$ [1]. These nuclei are expected to give new insight into neutron-proton (np) correlations. For example using binding energies, several attempts have been made to study the signatures for possible Wigner's spin-isospin SU(4) symmetry, the relationship between $T=0$ pairing and the so-called Wigner energy, and the possible formation of a condensate of $T=0$ np Cooper pairs, etc. [2]. Going beyond this, recent experimental results for the energy spectra of ^{62}Ga [3], ^{66}As [4], ^{70}Br [5], and ^{74}Rb [6] have opened challenges for developing models for describing and predicting the spectroscopic properties of these and other $N=Z$ odd-odd nuclei in the $A=60$–100 region. With the advent of radioactive ion beam (RIB) facilities, it is expected that many spectroscopic details of these nuclei will be available in the near future. An important experimental observation is the appearance of $J=0^+,T=1$ ground states with $J=1^+,T=0$ excited states from ^{62}Ga onwards; the $J=1^+,T=0$ state appears at around 0.5 MeV excitation in ^{62}Ga, 1 MeV in ^{66}As, and so on. As protons and neutrons occupy the same shell model orbits in these nuclei, it is essential to have good isospin in the models that attempt to describe the levels in these nuclei. Towards this end, for example, the variational methods such as the BCS and HFB are extended to include $T=0$ and $T=1$ pairing correlations [7]. There are also attempts to apply the shell model Monte Carlo method as well as direct shell model diagonalization [8]. Another important step in developing models is in deriving effective boson Hamiltonians, through a mapping using the SU(4) symmetry, for the spin-isospin invariant interacting boson model (IBM-4). Using IBM-4, recently Juillet *et al.* described the observed levels in ^{62}Ga and predicted the spectra for ^{66}As and ^{70}Br [9].

In the last 15 years the deformed configuration mixing shell model based on Hartree-Fock (HF) single particle states [hereafter simply called deformed shell model (DSM)] has been employed, using a modified Kuo effective interaction in the $(f_{5/2}pg_{9/2})$ space, with good success in analyzing the band structures seen in many $N\neq Z$ nuclei in the mass $A=60-100$ region; examples are even-even Ge, Kr, and Sr isotopes [10], odd-A isotopes of Br, Sr [11], and some odd-odd Br isotopes [12]. To a large extent isospin projection is not essential for $N\neq Z$ nuclei and therefore DSM, where explicit isospin projection is not carried out, is successful for these nuclei. Let us add that the model was also applied to ^{64}Ge and ^{80}Zr [13]. However as mentioned earlier, for odd-odd $N=Z$ nuclei in the $A=60-100$ region, it is essential to project out good isospin. Our purpose in this paper is to report results of the DSM, with good isospin, for the $N=Z=31$ nucleus ^{62}Ga and $N=Z=33$ nucleus ^{66}As whose structure study is of current interest. Now we will give a preview.

In Sec. II a brief description of the DSM model is given and, with ^{62}Ga and ^{66}As examples, the method used for isospin projection is described in detail. In Sec. III spectroscopic results for ^{62}Ga and ^{66}As are described. Here some comparisons are made with shell model and IBM-4 results. Finally, Sec. IV gives concluding remarks and a future outlook.

II. DEFORMED SHELL MODEL AND ISOSPIN PROJECTION FOR ^{62}Ga, ^{66}As

The details of the DSM have been discussed in several earlier publications [10–13]. First starting with a model space consisting of a given set of single particle orbitals and two-body effective interaction matrix elements the lowest prolate and lowest oblate intrinsic states for a given nucleus (valence particles) are obtained by solving the HF single particle equation self-consistently. Then various excited intrinsic states are obtained by making particle-hole excitations over the lowest intrinsic configuration and then performing a constrained HF calculation. Since we assume axial symmetry, each intrinsic state has a definite azimuthal quantum number K. We denote the various HF intrinsic states by $\chi_K(\mu)$. Here μ distinguishes different intrinsic states with the same K. $\chi_K(\mu)$ is an antisymmetrized product of deformed single particle orbits. It does not have definite angular momentum and is a superposition of several states of good angular momentum. States of good angular momentum $\phi^J_{MK}(\mu)$ are projected out from the intrinsic states $\chi_K(\mu)$ using the angu-

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lar momentum projection operator

$$P^J_{MK}=\frac{2J+1}{8\pi^2}\int D^{J*}_{MK}(\Omega)R(\Omega)d\Omega. \tag{1}$$

Here Ω represents the Euler angles (α, β, γ) and $R(\Omega)$, which is equal to $\exp(-i\alpha J_z)\exp(-i\beta J_y)\exp(-i\gamma J_z)$, represents the general rotation operator. However, the angular momentum projected states ϕ^J_{MK} obtained from different intrinsic states $\chi_K(\mu)$ are, in general, not orthogonal to each other. They are orthonormalized (for each J) by considering the overlap matrix

$$N^J_{K'\mu',K\mu}=\langle \phi^J_{MK'}(\mu')|\phi^J_{MK}(\mu)\rangle. \tag{2}$$

This matrix would be a unit matrix for an orthonormal set of vectors. However, in the case of a nonorthogonal basis, it is not diagonal. To obtain a orthonormal set of vectors, the above matrix is diagonalized and the resulting vectors can be written in the form

$$\Phi^J_M(\alpha)=\sum_{K\mu} S^J_{K\alpha}(\mu)\phi^J_{MK}(\mu), \tag{3}$$

where

$$S^J_{K\alpha}(\mu)=[n^J_M(\alpha)]^{-1/2}X^J_{K\alpha}(\mu). \tag{4}$$

Here n^J_M denotes the eigenvalues of N^J and $X^J_{K\alpha}(\mu)$ corresponds to the element of the unitary transformation matrix that diagonalizes the overlap matrix N^J. $\Phi^J_M(\alpha)$ constitutes an orthonormal set of vectors. It is clear from Eq. (4) that if any of the eigenvalues n^J_M of the overlap matrix N^J is vanishing, then the corresponding vector is spurious and should be eliminated. The Hamiltonian matrix is transformed from a nonorthogonal basis to an orthogonal basis using Eqs. (3) and (4),

$$\langle \Phi^J_M(\nu)|H|\Phi^J_M(\nu')\rangle = \sum_{K\eta}\sum_{K'\eta'} S^{J*}_{K\nu}(\eta)S^J_{K'\nu'}(\eta')\langle \phi^J_{MK}(\eta)|H|\phi^J_{MK'}(\eta')\rangle. \tag{5}$$

Now diagonalizing the Hamiltonian matrix gives the energy spectrum of the given nucleus. Usually in carrying out HF calculations one takes into account pairing via BCS (or in fact HFB [7]). However in the DSM one considers all low-lying intrinsic states (see Fig. 2 below) in the band mixing calculations. This then includes some aspects of pairing. In addition to this standard procedure, in this paper isospin projection is added to the DSM as described below. In order to clarify the method let us consider the ^{62}Ga example in some detail.

In the calculations ^{56}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 with energies (as given in Ref. [14]) 0.0, 0.77, 1.113, and 3 MeV, respectively. The two-body interaction matrix elements in this space are defined by a realistic G-matrix interaction with a phenomenologically adjusted monopole part as given by the Madrid-Strasbourg (MS) group [14]. Hereafter this interaction along with the single particle energies listed above is referred to as the MS interaction. Successful shell model calculations were carried out for ^{62}Ga recently with the MS interaction [9]. Therefore these results will form a benchmark for testing the DSM with isospin projection.

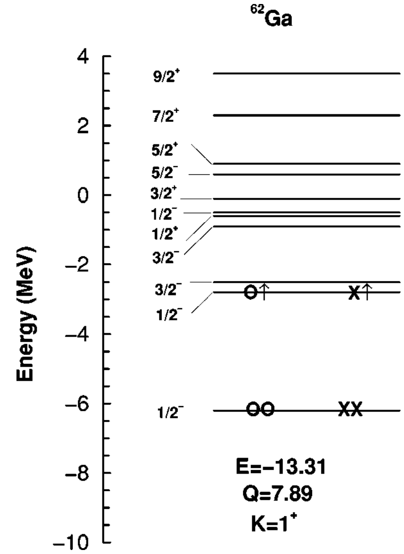

FIG. 1. Spectrum of single particle states for the lowest energy HF intrinsic state for ^{62}Ga. The circles represent protons and the crosses represent neutrons. The small difference in the energy of the single particle states $|k\rangle$ and $|-k\rangle$ because of time reversal symmetry breaking is neglected in plotting the single particle spectrum. The up arrow implies that the nucleon is in the state $|k\rangle$ and the down arrow corresponds to the occupancy of the nucleon in the $|-k\rangle$ state. The Hartree-Fock energy (E) is in MeV and the mass quadrupole moment (Q) is in units of the square of the oscillator length parameter. The total K-quantum number of the intrinsic state in the figure is $K=\Sigma k_i=1$ where the sum is over the occupied states and the parity $\pi=+1$. In the figure this is given as $K=1^+$.

For the ^{62}Ga nucleus Fig. 1 gives the HF single particle (sp) spectrum (the states are labeled by $|k_\alpha\rangle$ where the α label distinguishes different states with the same k value) for the lowest HF intrinsic state; note that, with the ^{56}Ni core, there are six valence nucleons. This state 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), mass quadrupole moment (Q), and band K value are also shown in the figure. For odd-odd nuclei the time reversal symmetry in the HF spectrum is broken. Therefore in general the energies and wave functions of the sp states $|k_\alpha\rangle$ and $|-k_\alpha\rangle$ are different. However this difference is usually small and neglecting this gives $T=0$ for the four nucleons (two protons and two neutrons) occupying the lowest $k=1/2^-$ sp state. Hence the isospin for ^{62}Ga is determined by the last proton and neutron. Thus the total isospin for the configuration shown in Fig. 1 is $T=0$, since the odd proton and odd neutron, for $K=1^+$, form a symmetric pair in k space [here and elsewhere in this paper symmetry in k space means symmetry in space-spin coordinates as k contains both space (orbital) and spin coor-

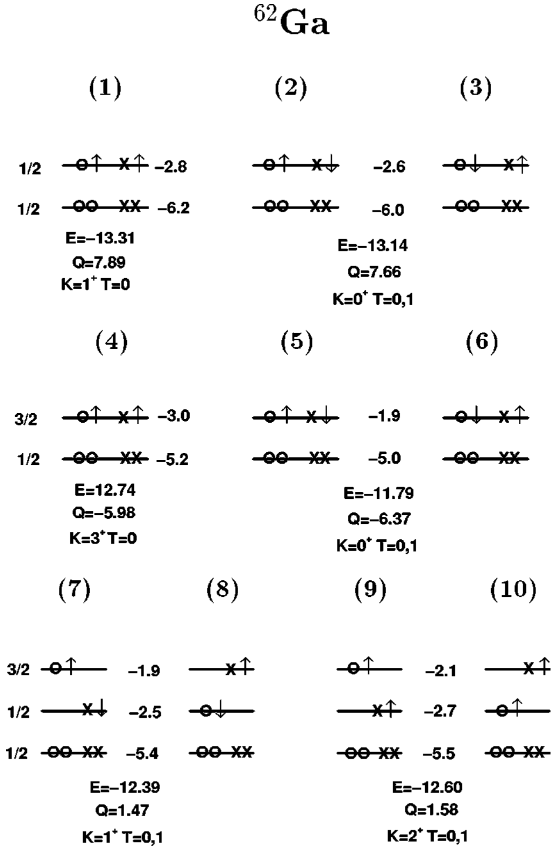

FIG. 2. For ^{62}Ga, the occupancy of the single particle states in the excited configurations. The configuration (1) corresponds to the lowest HF intrinsic state (Fig. 1). All other configurations are obtained by making $1p$-$1h$ and $2p$-$2h$ excitations over this lowest intrinsic state. Symmetric combination of the states (2) and (3) generates a $T=0$ intrinsic state and the antisymmetric combination generates a $T=1$ intrinsic state. Similarly for the pairs (5,6), (7,8), and (9,10) one obtains $T=0,1$ states as shown in the figure. See Fig. 1 for further details.

dinates]. Particle-hole excitations over the lowest HF intrinsic state generate excited HF intrinsic states (both prolate and oblate states are considered in the calculations). There are nine low-lying $1p$-$1h$ and $2p$-$2h$ excited intrinsic states for ^{62}Ga and they are shown in Fig. 2 [they correspond to sp spectra (2)–(10) in the figure]. The HF intrinsic states are in general admixtures of various isospin components. In the lowest prolate and oblate HF intrinsic states [for example, configurations (1) and (4) in Fig. 2], the unpaired proton and neutron occupy the same HF single particle orbits and hence these are symmetric in k-space coordinates. Therefore these 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 coordinates. Symmetric combination will have isospin $T=0$ and the antisymmetric combination gives $T=1$. This procedure applies to the configurations (2,3), (5,6), (7,8), and (9,10) in Fig. 2. For example, $1/\sqrt{2}[\phi_{(2)}+\phi_{(3)}]$ gives $T=0$ and $1/\sqrt{2}[\phi_{(2)}-\phi_{(3)}]$ gives $T=1$; note that $\phi_{(i)}$ denotes a particular intrinsic state (i). There are four intrinsic states for $T=1$ and six for $T=0$ for ^{62}Ga. Then good angular momentum states are projected from all the $T=0$ intrinsic states and a band mixing calculation is performed. A similar procedure is also applied for the $T=1$ intrinsic states.

In ^{66}As, with 10 valence nucleons in the $(f_{5/2}pg_{9/2})$ space, a procedure similar to the ^{62}Ga case in fact applies for constructing good isospin states. The lowest prolate HF intrinsic state for this nucleus corresponds to the configuration with paired protons and neutrons in the lowest two $k=1/2^-$ sp states and the unpaired proton and neutron in a $k=3/2^-$ state, i.e., $(1/2_1)^{2p,2n}(1/2_2)^{2p,2n}(3/2)^{p\uparrow,n\uparrow}$. This gives $K=3^+$ and $T=0$. Similarly the lowest oblate intrinsic state corresponds to the configuration with paired protons and neutrons in the lowest $k=1/2^-$ and $k=3/2^-$ sp states with the unpaired proton and neutron in a $k=1/2^-$ state; i.e., $(1/2_1)^{2p,2n}(3/2)^{2p,2n}(1/2_2)^{p\uparrow,n\uparrow}$. This gives $K=1^+$, $T=0$. Considering particle-hole excitations (with a k flip), we have taken 10 additional intrinsic states. These are

(i)	$(1/2_1)^{2p,2n}(1/2_2)^{2p,2n}(3/2)^{p\uparrow,n\downarrow}$,	$K=0$;
(ii)	$(1/2_1)^{2p,2n}(1/2_2)^{2p,2n}(3/2)^{p\downarrow,n\uparrow}$,	$K=0$;
(iii)	$(1/2_1)^{2p,2n}(3/2)^{2p,2n}(1/2_2)^{p\uparrow,n\downarrow}$,	$K=0$;
(iv)	$(1/2_1)^{2p,2n}(3/2)^{2p,2n}(1/2_2)^{p\downarrow,n\uparrow}$,	$K=0$;
(v)	$(3/2)^{2p,2n}(1/2)^{2p,2n}(5/2)^{p\uparrow,n\downarrow}$,	$K=0$;
(vi)	$(3/2)^{2p,2n}(1/2)^{2p,2n}(5/2)^{p\downarrow,n\uparrow}$,	$K=0$;
(vii)	$(1/2_1)^{2p,2n}(3/2)^{2p,n\uparrow}(1/2_2)^{2n,p\uparrow}$,	$K=2$;
(viii)	$(1/2_1)^{2p,2n}(3/2)^{2n,p\uparrow}(1/2_2)^{2p,n\uparrow}$,	$K=2$;
(ix)	$(1/2_1)^{2p,2n}(3/2)^{2p,n\uparrow}(1/2_2)^{2n,p\downarrow}$,	$K=1$;
(x)	$(1/2_1)^{2p,2n}(3/2)^{2n,p\uparrow}(1/2_2)^{2p,n\downarrow}$,	$K=1$.

As all these configurations involve only p-n particle-particle [(i)–(vi)] or hole-hole [(vii)–(x)] states, the isospins generated by them will be $T=0,1$. The construction of good $T=0$ and $T=1$ intrinsic states is exactly same as the case with ^{62}Ga. For example the symmetric combination of the configurations (i) and (ii) gives a $T=0$ intrinsic state while the antisymmetric combination gives a $T=1$ state. Thus in ^{66}As a total of five $T=1$ and seven $T=0$ intrinsic states are constructed for angular momentum projection and band mixing calculations.

III. RESULTS FOR ^{62}Ga AND ^{66}As

A. ^{62}Ga

Recently Vincent *et al.* [3] identified in ^{62}Ga some of the low-lying $T=0$ levels (1^+, 3^+, 5^+, 7^+) and the ground state which is 0^+ with $T=1$. The $T=0$ band starts appearing at an excitation energy of 0.571 MeV from the ground state. The isobaric analog nucleus ^{62}Zn gives [15] the other $T=1$ levels in Fig. 3. Shell model calculations in $(f_{5/2}pg_{9/2})$ space with the MS interaction were carried out by Juillet *et al.* [9] and the results are shown in Fig. 3. It is seen that the observed $T=0$ and $T=1$ levels are well reproduced by the

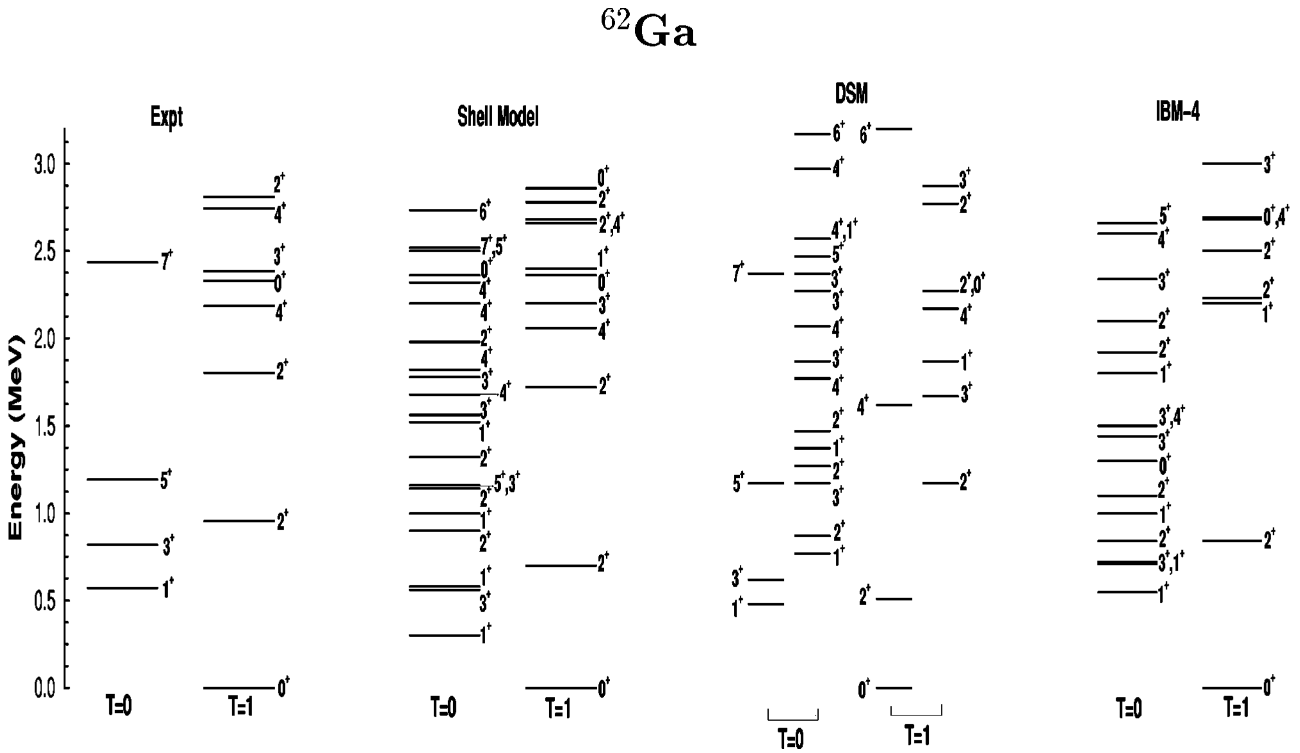

FIG. 3. $T=0$ and $T=1$ levels in ^{62}Ga obtained from the deformed shell model (DSM) are compared with experimental data (Ref. [3]), the shell model, and IBM-4 (Ref. [9]). See text for further details.

shell model. However the 1^+ $T=0$ level starts appearing at around 0.3 MeV above the 0^+ $T=1$ ground state. Besides the observed $T=0$ levels, the shell model also predicts a large number of other levels below 3 MeV excitation.

The results of the DSM are compared with experiment and shell model in Fig. 3. The model generates almost all the shell model states for both $T=0$ and $T=1$. In the figure the $T=0$ levels are shifted by 0.7 MeV relative to the 0^+ $T=1$ ground state so that the 1^+ $T=0$ level appears at about the same energy as in experiment. Without this correction the 0^+ $T=1$ level is 0.22 MeV above the 1^+ $T=0$ level. However, for ^{66}As, without this correction, the 0^+ $T=1$ level is 0.33 MeV below the 1^+ $T=0$ level. Thus with the same shift of 0.7 MeV the 1^+ $T=0$ level in ^{66}As appears (see Sec. III B) at 1.03 MeV excitation as compared to the tentative experimental value 0.84 MeV (see Ref. [4]). The IBM-4 calculations [9] predict this energy to be about 1 MeV. In addition, with the 0.7 MeV shift, the DSM calculation for ^{70}Br shows that the 1^+ $T=0$ state in this nucleus appears at 1.34 MeV excitation as compared to the IBM-4 prediction of 1.25 MeV. (Without this shift the 0^+ $T=1$ level is 0.64 MeV below the 1^+ $T=0$ level.) A recent ^{70}Br experimental spectrum indicates [5] that the $T=0$ levels in this nucleus will start from ~ 1.2 MeV (energy of the 3^+ level with $T=0$ is tentatively placed at 1.336 MeV from the 0^+ $T=1$ ground state). Let us add that the DSM is known to generate a shift in ground state energies relative to the corresponding shell model values and it was argued in the past that this is due to the mixing of only low-lying HF intrinsic states [16]. Also this could be a result of treating pairing effects only through band mixing. However, as can be seen from many successful DSM calculations [10–13] this shift does not significantly effect the relative energies and the structure of wave functions. In the present calculations, as T is projected out in the beginning, there will be a shift of both $T=0$ and $T=1$ spectra or in other words the DSM in its present form will not be able to reproduce (without an extra monopole correction) the shell model values for the 1^+ $T=0$ excitation energy relative to the 0^+ $T=1$ ground state. It is gratifying that a constant shift of 0.7 MeV describes well the data for ^{62}Ga, ^{66}As, and ^{70}Br. It is now an experimentally established fact that the 1^+ $T=0$ state (lowest $T=0$ state) in $N=Z$ odd-odd nuclei with $A=62$–86 appears above the $0^+T=1$ ground state [17]. Therefore it is essential to develop a prescription, with a theoretical basis, within the DSM for reproducing the 1^+ $T=0$ excitation energies and this will be addressed in a future publication.

In the DSM the observed 1^+ $T=0$ band is generated mainly by the intrinsic state (1) in Fig. 2. However the 7^+ state in the band has considerable mixing with the intrinsic state (4) in Fig. 2. The 3^+ to 1^+ spacing is somewhat compressed in the DSM compared to experiment. However the 5^+ and 7^+ levels are close to experiment. The DSM 6_1^+ $T=0$ level is about 0.4 MeV above the corresponding shell model level and this level is not yet identified experimentally. Moreover the high density of $T=0$ levels in the shell model is well reproduced by the DSM. Similarly the $T=1$ levels are also well reproduced. As a consistency check of the model, the ^{62}Zn (a system of two protons and four neutrons) $T=1$ levels are calculated and they are found to agree with the calculated ^{62}Ga $T=1$ levels (note that for the even-

even nuclei HF intrinsic states preserve time reversal symmetry). Let us point out that the 0^+ $T=1$ band is generated mainly by the antisymmetric state constructed out of the states (2) and (3) in Fig. 2. In Fig. 3, we also compare the DSM results with IBM-4 results for ^{62}Ga [9] (IBM-4 is the only other model used so far for ^{62}Ga for comparing with shell model and data). IBM-4 is quite successful in reproducing the 1_1^+ $T=0$ level relative to the 0^+ $T=1$ ground state. It also gives reasonable agreement with the shell model results. As the authors of IBM-4 have themselves pointed out, the 5^+ and 7^+ levels of the $T=0$ band lie very high in energy, unlike the DSM.

Experimentally the $B(E2;3_1^+\rightarrow 1_1^+)$, for the $T=0$ band, is deduced and its value is 197 ± 69 e^2 fm^4 [3]. Using effective charges $e_p=2$ and $e_n=1$ its value is 91 e^2 fm^4 in the DSM. These effective charges are larger than those used in the shell model. This could be because, as pointed out in Ref. [3], the $g_{9/2}$ orbit plays an important role in the shell model in generating the observed $B(E2)$ value and the DSM wave functions structure is independent of $g_{9/2}$. In any case the DSM is better tested if many more $B(E2)$'s are measured. In fact it is possible to eliminate the dependence on effective charges by measuring $B(E2)$ ratios in the $T=0$ band (similarly in the $T=1$ band). For example, the DSM gives, for the $T=0$ band, $B(E2;5_1^+\rightarrow 3_1^+)/B(E2;3_1^+\rightarrow 1_1^+)=1$. Similarly for the $T=1$ band, $B(E2;4_1^+\rightarrow 2_1^+)/B(E2;2_1^+\rightarrow 0_1^+)=1.5$ and $B(E2;6_1^+\rightarrow 4_1^+)/B(E2;2_1^+\rightarrow 0_1^+)=1.6$.

Before proceeding to ^{66}As results, some general remarks related to the role of the $g_{9/2}$ orbit and the MS interaction are in order. The intrinsic states that generate the low-lying $T=0$ and $T=1$ levels (below 3 MeV excitation) derive from $(f_{5/2},p_{3/2},p_{1/2})$ orbits. Thus the wave functions structure for these is independent of $g_{9/2}$. However it is seen that the $g_{9/2}$ orbit is essential for generating the sp energies of the HF intrinsic states. Therefore the $g_{9/2}$ orbit, in the DSM, for ^{62}Ga and ^{66}As play only an indirect role. Secondly, using a modified Kuo's interaction that is employed in all earlier DSM studies [10–13] the ^{62}Ga spectroscopy is repeated. It is seen that the Kuo interaction produces a larger deformation for the $T=0$ band resulting in a much more compressed spectrum compared to the spectrum generated by the MS interaction. Similarly the $T=1$ levels are less deformed and therefore the corresponding spectrum is more stretched. Thus it appears that the MS interaction is more appropriate for describing the energy levels in $N=Z$ nuclei in the $A=60-100$ region.

B. ^{66}As

Grzywacz *et al.* [4] established the decay scheme for ^{66}As and identified several levels but not uniquely their spins. They established that the ground state is 0^+ with $T=1$ (via superallowed $0^+\rightarrow 0^+$ Fermi transitions) and also argued that the 1_1^+ (with $T=0$) appears at 837 keV from the ground state. As described earlier, with a 0.7 MeV shift, the DSM gives the 1_1^+ level at about 1 MeV from the 0^+ $T=1$ ground state. As the data is scarce and shell model results are not available for ^{66}As, the DSM results for $T=0$ and $T=1$ levels in this nucleus are compared only with the recent IBM-4 predictions [9] in Fig. 4. Both IBM-4 and the DSM give similar results for this nucleus except for some minor differences. Just as in the case of ^{62}Ga, the $T=1$ spectrum is more dense in the DSM as compared to IBM-4. As the shell model spectrum for ^{62}Ga is close to that predicted by the DSM, it can be argued that the DSM predicted $T=1$ levels (below 3 MeV) may be seen in future experiments. Recently in a conference report, Grzywacz *et al.* [18] have reported many levels for this nucleus. All transitions seen in their experiment are placed above the 3024 keV isomer. (In the present study, we are interested in low-lying states below 3 MeV excitation.) For $T=1$ they report a band consisting of the 0^+ ground state and a 2^+ excited state at 0.963 MeV. The excited 2^+ level is reproduced reasonably well by both IBM-4 and the DSM. For $T=0$, they have identified a band consisting of the levels 1^+, 3^+, 5^+, and 7^+ at 0.837, 1.231, 1.901, and 2.908 MeV. The DSM and IBM-4 have 1^+ and 3^+ levels at around the experimental energies. However, the DSM predicts a 5^+ level which is about 0.7 MeV higher than experiment and the 7^+ level lies above 3 MeV. Similar is the case with IBM-4. The lowest $(0^+,2^+,4^+)$ $T=1$ band comes mainly from the antisymmetric state constructed out of the configurations $(1/2_1)^{2p,2n}(3/2)^{2p,2n}(1/2_2)^{p\uparrow,n\downarrow}$, $K=0$ and $(1/2_1)^{2p,2n}(3/2)^{2p,2n}(1/2_2)^{p\downarrow,n\uparrow}$, $K=0$. The $T=0$ spectrum is quite similar to IBM-4 except that the DSM predicts a comparatively smaller number of 2^+ states below 3 MeV. The lowest $(3^+,5^+)$ $T=0$ levels come mainly from the $(1/2_1)^{2p,2n}(1/2_2)^{2p,2n}(3/2)^{p\uparrow,n\uparrow}$ configuration. However, the 1_1^+ level comes mainly from the symmetric state constructed out of the configurations $(3/2)^{2p,2n}(1/2)^{2p,2n}(5/2)^{p\uparrow,n\downarrow}$, $K=0$ and $(3/2)^{2p,2n}(1/2)^{2p,2n}(5/2)^{p\downarrow,n\uparrow}$, $K=0$. Finally let us add that the results in Fig. 4 may be used as a guide for future ^{66}As experiments.

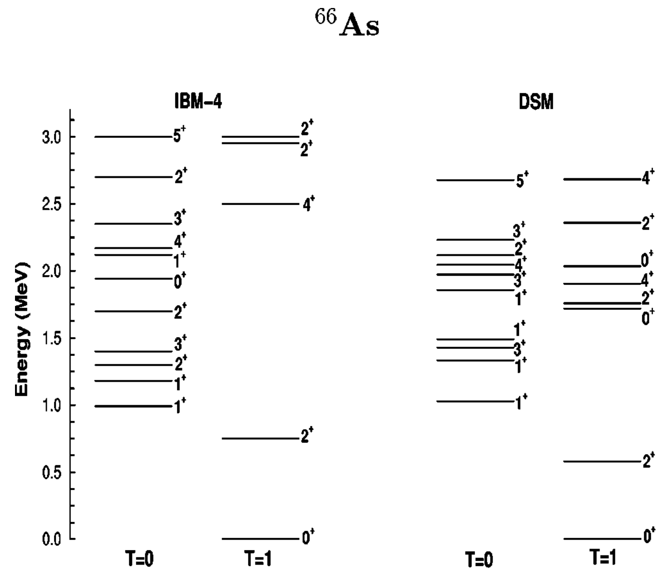

FIG. 4. $T=0$ and $T=1$ levels for ^{66}As obtained from the deformed shell model (DSM) are compared with the IBM-4 results in (Ref. [9]).

IV. CONCLUSIONS AND FUTURE OUTLOOK

In this paper DSM results, with isospin projection, for the $T=0$ and $T=1$ levels in $N=Z$ odd-odd nuclei are presented. The spectra of ^{62}Ga and ^{66}As are analyzed and the results for ^{62}Ga compare well with experiment and the shell model while those of ^{66}As (where there is neither a shell model nor sufficient experimental data) with recent IBM-4 results. These results suggest that the DSM, with isospin projection, can be used for understanding the structure of $N=Z$ odd-odd nuclei in the $A=60-100$ region. One source of success of the present calculations is the use of a MS interaction. However, the usefulness of this interaction for heavier $N=Z$ nuclei is not clear at present. Towards this end, data for the nuclei ^{70}Br [5] and ^{74}Rb [6] are being analyzed using a MS interaction and the results will be presented in a future publication. As pointed out in Sec. III A, the DSM in its present form requires a constant shift of 0.7 MeV to reproduce the excitation energy of 1_1^+ $T=0$ levels in ^{62}Ga, ^{66}As, and ^{70}Br. The origin of this shift is being analyzed in order to develop a prescription for solving this problem.

The important aspect of the present calculations is the inclusion of isospin projection in the DSM. For the two nuclei considered in this paper, the isospin projection is not complicated as the relevant HF intrinsic states have only one unpaired proton and neutron in the last occupied HF deformed sp states (see Fig. 2). More general cases involving four or more nucleons will be dealt with elsewhere and these will have applications in analyzing excited states in $N=Z$ odd-odd nuclei in the $A=60$–100 region, for example, ^{74}Rb, ^{78}Y, etc. In addition, this may also allow one to study the structure of high-spin states in even-even $N=Z$ nuclei; see Ref. [19] for recent interest in this question. Finally, in the future the DSM will also be used to investigate the goodness of IBM-4 symmetries proposed recently [20] for $N=Z$ odd-odd nuclei.

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