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A band-mixing Hartree-Fock model for ^{62}Zn

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Abstract. Energy levels and electromagnetic transitions in ^{62}Zn have been calculated using band-mixing formalism in the framework of deformed Hartree-Fock theory. Matrix elements of Adjusted-Surface Delta Interaction (ASDI) and of Tabakin interaction have been used. Detailed structure of various nuclear states in terms of bands has been discussed. Although the calculated spectra for both the interactions are somewhat compressed as compared to the observed spectra, the ASDI results are in substantially better agreement with experiments. Several additional states of high spin ($J>4$) have been predicted. $B(E2)$ transitions between inter-band as well as some of the intra-band states are calculated to stimulate further experiments.

Keywords. ^{62}Zn; spectrum; band structure; $E2$ moments; $E2$ transitions.

1. Introduction

During the last few years, there has been an increasing effort towards elucidation of the structure of nuclei in the upper *f-p* shell i.e. for A>56. The theoretical investigations of such nuclei have been carried out in the framework of a variety of different models. The shell model calculations, of necessity, have been usually carried out with the assumption of a closed ^{56}Ni inert core, thus reducing the problem to that of $(f_{5/2}\ p_{3/2}\ p_{1/2})^n$ configurations. The latest calculations of this type have been those of Koops and Glaudemans (1977) for Ni and Cu isotopes, and of Van Hienen *et al* (1976) for Zn isotopes. References to earlier shell-model works can be found in these papers. The shell model calculations of Van Hienen *et al* (1976) do not report states of spin higher than $J = 4^+$. The presence of the first excited state $J = 2^+$ at about 1 MeV, and a triplet of states with $J = 0^+$, 2^+ and 4^+ at excitation energies of 1·8–2·3 MeV in some of these nuclei has also led to attempts to describe these nuclei in terms of an anharmonic vibrator (Lightbody 1972). It has been earlier shown (Khadkikar *et al* 1974) that such vibrator-like level structure can be explained in terms of deformations and band-mixing e.g. in ^{24}Ne. Therefore, such a description in the case for ^{62}Zn isotope seems worth exploring. In this paper we present results for the structure and spectrum of the isotope ^{62}Zn in the framework of the Hartree-Fock (HF) model. Faraggi *et al* (1972) have also attempted to study Zn nuclei in the framework of stretch scheme to look for quarter-type excitations. Several authors (Chandra and Rustgi 1971, Sandhu and Rustgi 1975, 1976) have carried out calculations using Hartree-Fock-Bogoliubov methods. However, recent experi-

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ments have shown a much richer structure in these nuclei, and since such theoretical results can be strongly interaction-dependent, it seems desirable to use interactions other than that of Kuo-Brown.

In a sense, the work presented in this paper is a continuation of our earlier work in *s-d* shell (Khadkikar *et al* 1974). It was shown there that if one carried out a deformed HF calculation taking into account shape-mixing as well as mixing of bands based on intrinsic states (prolate and oblate) obtained by considering particle-hole excitations over the lowest HF states, then mixing of relatively few (about 10) intrinsic states and bands of states projected from them can provide a description of nuclear properties that is quite close to that of the shell model, and then the necessity of constructing huge Hamiltonian matrices is easily avoided. Apart from this, in this approach the structure of various states can easily be visualised, one gets an insight into the bands of related states—states with similar intrinsic structures—and a number of nuclear properties other than spins and energies—such as electromagnetic transitions or spectroscopic factors—can be predicted very simply.

We follow the usual practice of treating ^{56}Ni as an inert closed core, and consider six nucleons in $f_{5/2}$, $p_{3/2}$ and $p_{1/2}$ subshells. This of course limits the scope of description, and assumes that the choice of effective interaction compensates for the neglect of other configurations as far as the energies of the states described here are concerned. The effective interaction used is that of Koops and Glaudemans (1977) and our major aim was to test the validity of this interaction for Zn isotopes. When our calculations were nearly complete, our attention was drawn to the results of Van Hienen *et al* (1976) and this has provided an excellent opportunity to compare the results of our simple approximations to the more complex shell model calculations and to see how these states are grouped into bands. We also report on high spin states ($J>4^+$) not given by Van Hienen *et al.* A few such states have now been experimentally seen (Bruandet *et al* 1976), and hopefully more studies will follow in the near future.

It may be emphasized that our purpose is not to reproduce the observed energy levels in all the minute details but to understand generally the shape and the structure of the states. The shell model calculations merely give a large number of states ordered in energy but without providing any clues to the intrinsic structure of the states or the relationships between various states. In our earlier calculations on ^{24}Ne (Khadkikar *et al* 1974) we have already established the methodology of band mixing calculations in HF framework and its usefulness. The main results of our paper are therefore, (i) to show that a considerably simpler calculation gives rise to a spectrum containing all the states and some more than that given by the earlier shell model calculations; (ii) we are able to show the intrinsic structure of these states and group them in four different bands of related states; (iii) the calculations show the shape of ^{62}Zn nucleus to be prolate in its low states, and (iv) we have reported states of spin greater than $J = 4$ which have not been calculated earlier and also we predict a large number of quadrupole moments and E_2 transitions which should stimulate experimentalists to verify the basic concepts of the structure of the ^{62}Zn.

The next section gives a brief summary of the method followed, and section 3 describes the main spectroscopic results, as well as the band structure of the various states. Section 4 contains the results for $B(E_2)$ transitions amongst the states of various bands, and section 5 contains the summary and concluding remarks.

2. Calculations

As mentioned earlier in the introduction, our configuration space consists of distributions of two protons and four neutrons (for ^{62}Zn) in $p_{3/2}$, $f_{5/2}$ and $p_{1/2}$ orbits. The same space was used by Koops and Glaudemans (1977) who then obtained the single particle energies of these orbits as well as the effective two-body matrix elements (ASDI) by suitable modifications of those of a surface-delta interaction to fit as well as possible a chosen set of energy levels of Ni and Cu isotopes. We take the same single particle energies, *viz.*

$$\begin{aligned} \epsilon(p_{3/2}) &= -10{\cdot}242 \text{ MeV} \\ \epsilon(f_{5/2}) &= -9{\cdot}456 \text{ MeV} \\ \epsilon(p_{1/2}) &= -9{\cdot}140 \text{ MeV} \end{aligned} \tag{1}$$

and also the same set of two-body matrix elements. The Hamiltonian is cast in the usual one plus two-body form,

$$H = \sum_{\alpha} \epsilon_{\alpha} a_{\alpha}^{+} a_{\alpha} + \tfrac{1}{4} \sum_{\alpha\beta\gamma\delta} \langle \alpha\beta \mid V \mid \gamma\delta \rangle a_{\alpha}^{+} a_{\beta}^{+} a_{\delta} a_{\gamma} \tag{2}$$

where ϵ_α are the single-particle energies, V denotes the two-body matrix elements of the effective interaction, and a_α^+ (a_α) denote the creation (destruction) operators on single particle orbits—all in spherical shell model representations.

In addition, to test the interaction-dependence of the results, we have also considered the Tabakin interaction. Earlier Clement (1969) has obtained the G-matrix elements for this interaction, and he has also renormalised the matrix elements to take into account the effects of core-polarization. These matrix elements have been used with the same single particle energies and the configuration space as for the case of ASDI.

In the first step a deformed HF calculation has been carried out. This yields possible axially symmetric prolate and oblate intrinsic states and their energies. We do not deal with triaxially symmetric HF solutions. For ^{62}Zn we did not find a low triaxial solution.

Table 1 contains the structure of the single particle deformed orbitals for both the lowest prolate as well as oblate solutions for ^{62}Zn using the ASDI matrix elements, and table 2 contains corresponding results for the Tabakin interaction. It may be noted that these states have time-reversal symmetry, but not the isospin (neutron-proton) symmetry, and hence neutron orbitals differ slightly from the proton orbitals. However, the departures from isospin symmetry are marginal, and do not affect the final results i.e. the spectra. Figure 1 gives the single particle HF spectrum using both the interactions. We note that the Tabakin interaction gives nearly spherical solutions giving very little mixing of p- and f- states (see table 2), whereas the ASDI gives a sizable deformation. Such inherent difference in the interactions will lead to large differences in wavefunctions and electromagnetic and other properties. The prolate and oblate solutions have nearly degenerate energies (—12.12 MeV and

Table 1. Structure of the lowest prolate and oblate Hartree-Fock solutions for ^{62}Zn using ASDI. The upper number in each column corresponds to protons and the lower ones to neutrons. The rest of the orbitals are related to these by time reversal.

Shape	K	$1p_{1/2}$	$1p_{3/2}$	$0f_{5/2}$
Prolate	1/2	−0·4795	0·7578	0·4424
		−0·4957	0·7318	0·4677
	1/2′	−0·2058	−0·5872	0·7828
		−0·1854	−0·6153	0·7662
	3/2	0·0	0·6702	0·7422
		0·0	0·6470	0·7625
	3/2′	0·0	0·7422	−0·6702
		0·0	0·7625	−0·6470
	5/2	0·0	0·0	1·0
		0·0	0·0	1·0
	1/2″	0·8531	0·2843	0·4375
		0·8485	0·2930	0·4487
Oblate	3/2	0·0	0·9799	−0·1993
		0·0	0·9787	−0·2055
	1/2	0·6105	0·7396	0·2834
		0·6334	0·7092	0·3097
	5/2	0·0	0·0	1·0
		0·0	0·0	1·0
	1/2′	0·4753	−0·6284	0·6158
		0·4183	−0·6505	0·6339
	3/2′	0·0	0·1993	0·9799
		0·0	0·2055	0·9787
	1/2″	−0·6335	0·2412	0·7352
		−0·6510	0·2719	0·7087

Table 2. Structure of the lowest prolate and oblate Hartree-Fock solutions for ^{62}Zn using Tabakin interaction (for details see caption of table 1).

Shape	K	$1p_{1/2}$	$1p_{3/2}$	$0f_{5/2}$
Prolate	1/2	−0·2548	0·9647	0·0673
		−0·2891	0·9539	0·0807
	3/2	0·0	0·9998	0·0217
		0·0	0·9991	0·0426
	1/2′	0·9460	0·2631	−0·1894
		0·9226	0·3002	−0·2425
	1/2″	0·2004	−0·0154	0·9796
		0·2525	−0·0044	0·9668
	3/2′	0·0	−0·0217	0·9998
		0·0	−0·0426	0·9991
	5/2	0·0	0·0	1·0
		0·0	0·0	1·0
Oblate	3/2	0·0	0·9993	−0·0363
		0·0	0·9995	−0·0307
	1/2	0·4124	0·9104	0·0346
		0·3758	0·9256	0·0440
	1/2′	0·9030	−0·4136	0·1130
		0·9133	−0·3780	0·1514
	5/2	0·0	0·0	1·0
		0·0	0·0	1·0
	3/2′	0·0	0·0363	0·9993
		0·0	0·0307	0·9995
	1/2″	−0·1156	0·0146	0·9932
		−0·1568	0·0167	0·9875

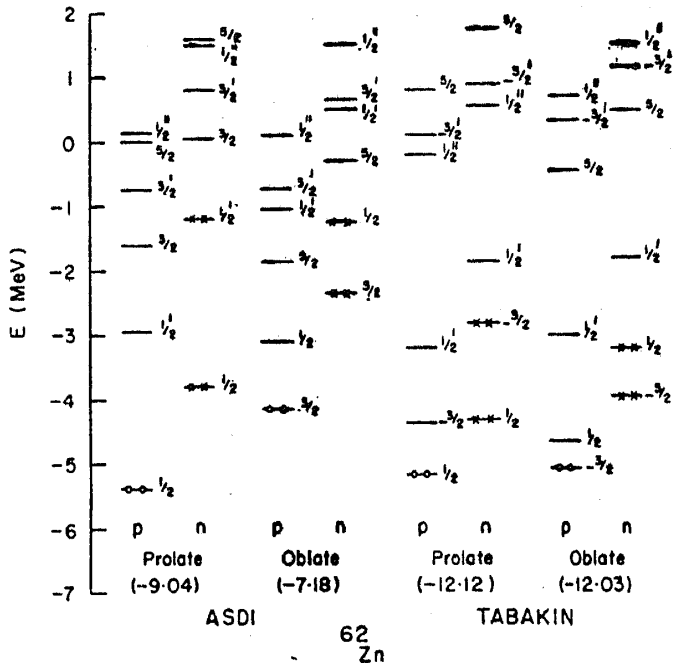

Figure 1. The Hartree-Fock single particle spectra of prolate and oblate solutions of ^{62}Zn. The numbers in the bracket denote the Hartree-Fock energies in MeV.

—12.03 MeV) for the Tabakin interaction, whereas they are separated by as much as 2 MeV (—9·04 MeV for prolate and —7·18 MeV for oblate solution) for the ASDI.

One can now generate additional excited intrinsic states in this deformed self-consistent field by exciting one or two nucleons from the uppermost occupied orbits to low unoccupied orbits. Since the HF gaps are not very large, it becomes essential to consider such configuration mixing. We thus consider in addition to the lowest prolate—oblate intrinsic states, several additional intrinsic states thus generated as particle-hole excitations over the lowest states, but limit considerations to only those intrinsic states with energies no more than 3 MeV above that of the lowest state. All such states considered for ^{62}Zn (about 12) and their configurations are shown in tables 3 and 4 for ASDI and Tabakin interactions respectively. A second Hartree-Fock state of prolate shape has also been obtained for ^{62}Zn with the intrinsic energy of —8·14 MeV, but its structure essentially corresponds to a two particle-hole excitation over the lowest prolate state. This second prolate state is also included in table 3, but particle-hole excitations on this state are not included.

Each of the intrinsic states thus constructed corresponds to a single determinant, and can be labelled by the usual quantum number K, sum of all individual k-quantum-numbers describing the single particle orbitals. Since we have several states with the same K, but different configurations, these states are denoted by $|K\mu\rangle$, μ distinguishing between states of the same K value. The energy of each intrinsic state is given by

$$E_{K\mu} = \langle K\mu \,|\, H \,|\, K\mu \rangle. \tag{3}$$

We next project out all possible states of good angular momentum J from each of these intrinsic states, and denote them by ϕ^J_{MK}. Such projected states for the same

Table 3. Various determinental states (along with their K values and energies) for ^{62}Zn used in the band mixing calculations with ASDI.

Band No.	Shape	K	E (MeV)
1	Prolate-I	0	−9·04
2	Prolate-II	0	−8·14
3	Oblate	0	−7·18
4	Prolate-I $1/2'n\rightarrow 3/2n$	1	−7·66
5	Prolate-I $1/2'n\rightarrow 3/2'n$	1	−7·63
6	Prolate-I $1/2p\rightarrow 1/2'p$	0	−6·38
7	Prolate-I $1/2'n\rightarrow 1/2''n$	0	−6·22
8	Prolate-I $1/2'n\rightarrow 5/2n$	2	−6·50
9	Oblate $-3/2p\rightarrow -1/2p$	1	−5·82
10	Oblate $1/2n\rightarrow 5/2n$	2	−6·52
11	Prolate-I $-1/2'n\rightarrow 3/2n$	2	−8·34
12	Prolate-II $-1/2'n\rightarrow 3/2'n$	2	−7·05

Table 4. Various determinental states (along with their K values and energies) for ^{62}Zn used in the band mixing calculations with Tabakin interaction.

Band No.	Shape	K	E (MeV)
1	Prolate	0	−12·12
2	Oblate	0	−12·03
3	Prolate $1/2p\rightarrow 3/2p$ $-1/2p\rightarrow -3/2p$	0	−10·88
4	Prolate $-1/2p\rightarrow 3/2p$	2	−10·87
5	Prolate $-3/2n\rightarrow 1/2'n$	2	−11·15
6	Prolate $-3/2n\rightarrow 1/2''n$	2	−9·12
7	Oblate $-3/2p\rightarrow -1/2p$ $3/2p\rightarrow 1/2p$	0	−10·62
8	Oblate $-3/2p\rightarrow 1/2p$	2	−11·45
9	Oblate $-3/2p\rightarrow 1/2'p$	2	−9·69
10	Oblate $1/2n\rightarrow 1/2'n$	0	−10·28
11	Oblate $1/2n\rightarrow 1/2'n$ $-1/2n\rightarrow -1/2'n$	0	−8·79
12	Prolate $1/2p\rightarrow 1/2'p$	0	−9·74

value of J are not orthogonal, and hence do not provide an orthonormal basis for diagonalisation of the Hamiltonian. In other words, the overlap matrix

$$O^{J}_{K\mu,K'\mu'} = \langle \phi^{J}_{MK\mu} \mid \phi^{J}_{MK'\mu'} \rangle \tag{4}$$

is not a unit matrix. It is however possible in a straightforward manner to obtain linear combinations of ϕ^{J}_{MK} with various K values, which we shall denote by Φ^{J}_{M} which are orthonormal, and then construct the Hamiltonian matrix in this representation and diagonalise it to obtain the required energy eigenvalues and the eigenfunctions. The details of the entire method have been given by Kulkarni (1972) and Dhar *et al* (1975).

Figure 2 gives the spectra of states of ^{62}Zn thus obtained for ASDI and Tabakin interactions. We also include in this figure the experimental results, and the corresponding shell model results of Van Hienen *et al* (1976) for comparison.

3. Discussion

We see from figure 3 that our calculation provides a quite satisfactory description of the observed (Van Hienen *et al* 1976; Bruandet *et al* 1976; Farwell *et al* 1972; Jundt *et al* 1975) spectrum of ^{62}Zn with ASDI. The calculated spectrum is somewhat

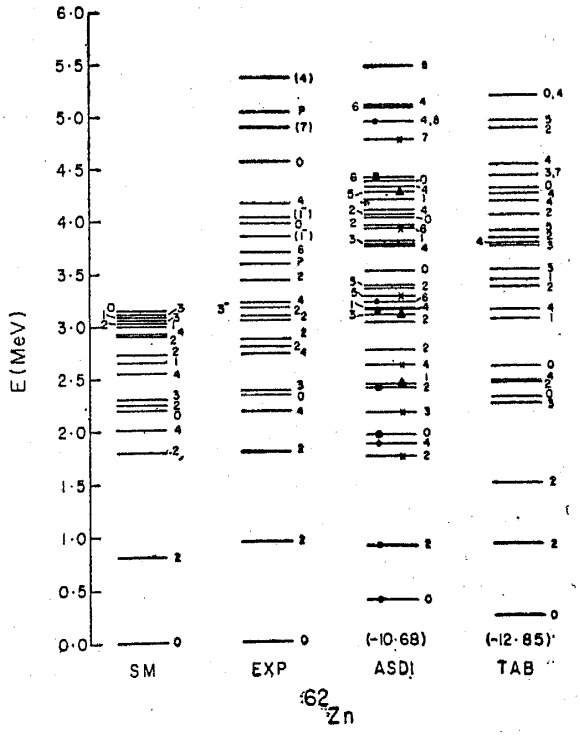

Figure 2. The calculated spectra of ^{62}Zn using ASDI and Tabakin (TAB) interaction along with the experimental (EXP) and shell-model (SM) results. The numbers in the parenthesis denote the absolute energies of ground states. The levels with dots (.) belong to band number 1 ($K=0$), those with squares (■) to band number 2($K=0$), those with crosses (×) to band number 11 ($K=2$), and those with triangles (▲) to band number 4 ($K=1$) in table 3.

more compressed than the observed one, and to put the results in a somewhat better perspective the entire calculated spectrum for ASDI has been shifted upwards by 0·4 MeV and similarly for Tabakin interaction by 0·25 MeV, to match our calculated first excited state 2^+ with that given by the shell model. This indicates that the band-mixing taken into account in the H-F space does not give proper binding energy for the ground state 0^+. It should be clear that it is immaterial where the zero of the spectrum is fixed since we are now primarily interested in the relative structure of a large number of excited states. The spectrum of the excited states above the lowest $J=2$ is reasonably well predicted. As we stated earlier our purpose is to understand broadly the nature of the states and the band structure. However, our calculation reproduces all the shell model states of Van Hienen *et al* (1976) up to 3·5 MeV, and also predicts additional states of spin 5^+ and 6^+ near 3·5 MeV excitation energy. The third excited 0^+ state observed near 4 MeV finds a counterpart in our spectrum near 3·5 MeV.

Recent observations of Bruandet *et al* (1976) have reported a 3^+ state at 2·384 MeV excitation, close to the triplet of 0^+ 2^+ 4^+ states. We find a counterpart of this state at about 2·25 MeV. These authors also report a 6^+ state at 3·707 MeV, and a possible $J=7$ state (of unknown parity) at 4.903 MeV. In our calculations, a 6^+ state is obtained at about 3·3 MeV, and also a 7^+ state near 5 MeV. Our calculations predict a number of other high spin states: $J=6^+$ near 4·0, 4·5 and 5·2 MeV, $J=7^+$ near 5 MeV, and $J=8^+$ near 5·0 and 5·5 MeV. It is hoped that future experiments on ^{62}Zn will show corresponding observed states.

Interestingly enough, both the shell model and the HF band-mixing calculations predict a large number of odd spin states above 3 MeV. Such a large number of positive parity, odd spin states (except for the $J=3^+$ observed at 2·38 MeV) have not yet been experimentally identified, and it should be of great interest to look for them in future experiments.

Although the results of the ASDI and the "realistic" Tabakin interaction are qualitatively similar, the Tabakin interaction does not give as good an agreement with detailed experimental spectrum. The second excited 2^+ is quite isolated, and the third 0^+ occurs too low in the calculated spectrum.

It will be interesting to examine the band structure of the states, since our approach is particularly suited to such interpretation. On examining the wavefunctions obtained for ASDI, we find that the Yrast states 0^+ (g.s.), 2^+ (0·95 MeV), 4^+ (2·19 MeV), 6^+ (3·71 MeV) and 8^+ (predicted near 5 MeV) form a neat band of states based on the lowest $K=0$ prolate state. The overlaps of the wavefunctions obtained for these states with those from the lowest $K=0$ prolate intrinsic state are about 0.85 to 0.95, increasing in value as J increases. The wavefunctions obtained with Tabakin interaction do not show a clean band-structure; this is in accordance with our earlier observation that this interaction yields relatively much smaller deformation compared to the ASDI. Hence the following remarks apply only to ASDI wavefunctions. According to our calculations, then, the ground state of ^{62}Zn is predominantly a prolate state. Sandhu and Rustgi (1975, 1976) have done an HFB calculation in the full *f-p* shell, using Kuo-Brown interaction, and find ^{62}Zn to be triaxial in its lowest state. We have carried out a calculation of the quadrupole moment of the first 2^+ state (given by ASDI) assuming the following values of the effective charges,

$$e_p = 1{\cdot}6 \text{ and } e_n = 1{\cdot}0 \qquad (5)$$

which are also the values preferred by Van Hienen *et al* (1976). The result is $-42{\cdot}2\ e(\mathrm{fm})^2$. An experimental measurement of the electric quadrupole moment of the first 2^+ state would be of great interest. Our model would also predict greatly enhanced $E2$ transitions between states of this prolate band, and the shell model calculations of Van Hienen *et al* (see their table 4a) support this interpretation for the $4^+\rightarrow 2^+$ and the $2^+\rightarrow 0^+$ interactions. The results of Bruandet *et al* (1976) also show the enhanced $E2$ transition between the 6^+ (3·71 MeV) and 4^+ (2·19 MeV) states.

The second 0^+ at 2·33 MeV arises predominantly from the *excited* prolate Hartree-Fock state shown in table 3. As we mentioned earlier, the structure of this prolate state corresponds to a two-particle-two-hole excitation over the lowest prolate state. The calculated 0^+ at 2·33 MeV has an overlap of 0·79 with the state projected from this excited prolate state. Similarly the third 2^+, 4^+ and 6^+ states (predicted at about 2·3 MeV, 3·2 MeV and 4·5 MeV) also belong predominantly to this band and should show enhanced $E2$ transitions amongst themselves.

The second 2^+ state at 1·80 MeV is an almost pure state arising from the $K=2$ intrinsic state numbered as 11 in table 3. Other states that belong to this band can be identified from their wavefunctions as the first 3^+ (2·38 MeV), the second 4^+ (2.74 MeV), the lowest 5^+ predicted near 3·3 MeV, second 6^+ predicted near 4 MeV, and 7^+ predicted near 5 MeV, etc.

In addition to the above bands, our analysis of the wavefunctions also suggests the existence of a nearly pure $K=1$ band consisting of the first 1^+ state, and second 3^+, 5^+ and 7^+ states. The calculated energies of the members of the four bands identified

Table 5. Band structure of states in ^{62}Zn obtained with ASDI, along with the associated observed energy levels. The numbers in brackets in column 1, correspond to band numbers in table 3. The calculated spectrum is raised by 0·4 MeV so that the first 2^+ level matches with the experimental one.

Bands	J	Energy (MeV)	
		Calculated	Observed
$K=0$ (1)	0_1	0·40	0·00
	2_1	0·91	0·96[a]
	4_1	1·87	2·19[a]
	6_1	3·23	3·71[b]
	8_1	4·95	
$K=0$ (2)	0_2	1·95	2·33[a]
	2_3	2·39	2·81[a]
	4_3	3·15	3·22[c]
	6_3	4·41	
$K=1$ (4)	1_1	2·43	
	3_2	3·10	
	5_2	4·28	
	7_2	4·85	
$K=2$ (11)	2_2	1·75	1·80[a]
	3_1	2·16	2·38[b]
	4_2	2·62	2·74[a]
	5_1	3·28	
	6_2	3·93	
	7_1	4·78	4·90[b]
	8_2	5·47	

(a) Ref. 2; (b) Ref. 7; (c) Ref. 11.

above and their possible association with the observed ones are given in table 5. Such band structures cannot be easily identified by shell model calculations, and it should be very exciting to look for them in suitable experiments by their electromagnetic transitions, etc.

Although some attempts (Lightbody 1972) have been made in earlier literature to identify anharmonic vibrations in ^{62}Zn, by considering the first 2^+ state as a one-phonon state, and the next triplet of 0^+, 2^+, 4^+ near 2 MeV as the two-phonon states, our results show such an interpretation to be not valid. These triplet of states arise from quite different intrinsic states, and belong to different bands, whereas the 4^+ of this triplet should show a strongly enhanced $E2$ transition to the first 2^+, the 0^+ state of the triplet would show only a weak $E2$ transition, since they belong to different bands. The weakness of the crossover transition from the 2^+ of this triplet to the ground state is also easily understood as an inter-band transition, and does not need to invoke a vibrational model.

4. *E2* transitions and moments

The electric quadrupole moments and transitions provide one of the best clues to the collective nature and deformations of nuclei. As yet there is very little experimental data on such transitions and moments in ^{62}Zn. We therefore provide in this section a set of theoretical predictions which can hopefully stimulate further experiments on this nucleus. The electromagnetic moments and transitions provide a very elegant test of the nuclear wavefunctions and show up very distinctly the band structure of nuclear states as well as inter-band relations.

Since the theoretical calculations of the nuclear wavefunctions have been carried out in a truncated configuration space and utilize effective two-body interactions, it is well known that a satisfactory calculation of electromagnetic properties also requires assumption of suitable effective one-body operators, e.g. in our case effective neutron and proton charges. Van Hienen *et al* (1976) have obtained the values of these effective charges by treating them as independent parameters in a least-squares fit to 16 pieces of $E2$ data in Zn isotopes from $A=63$ to $A=68$. These values are given in eq. (5), and we use them to calculate the relevant $E2$ properties from our wavefunctions. The calculations of the $E2$ moments and transitions are now straightforward, and we only describe the results, calculated with ASDI interaction.

Table 6 lists the electric quadrupole moments of a few excited states. The measurements of such moments will give crucial information on the shapes associated with different bands.

Table 6. Electric quadrupole moments

J	Energy (MeV)	$Q'2$ (e. fm^2)
2_1	0·96	−42·2
4_1	2·19	−55·1
2_2	1·80	+40·8
3_1	2·38	+ 0·6
4_2	2·74	−22·25
2_3	2·81	−33·9

Table 7. $B(E2)$ values for transitions between states.

J_i	J_f	E_i	E_f (MeV)	$B(E2)$ in $e^2 fm^4$	
				Our values	Shell model
2_1	0_1	0·96	0·00	423	280
4_1	2_1	2·19	0·96	550	370
6_1	4_1	3·71	2·19	503	310
8_1	6_1	(4·95)	3·71	354	
2_3	0_2	2·81	2·33	263	
4_3	2_3	3·22	2·81	450	
6_3	4_3	(4·41)	3·22	467	
3_1	2_2	2·38	1·80	721	
4_2	3_1	2·74	2·38	517	
4_2	2_2	2·74	1·80	212	109
6_2	4_2	(3·93)	2·74	323	190
2_2	0_1	1·80	0·00	32	3
2_3	0_1	2·81	0·00	2	
2_3	2_1	2·81	0·96	1	0
4_3	2_1	3·22	0·96	17	
4_2	2_1	2·74	0·95	21	0
4_1	2_2	2·19	1·80	0	0

Table 7 lists a number of $E2$ transitions between various excited states. Only a few of the important transitions showing clearly the band characteristics are shown. It is clear from comparison with table 5 that the transitions between the states of the same band are quite strong, whereas those between states of different bands are quite weak. For comparison we also quote the shell model values of Van Hienen *et al* (1976). Although our values are generally larger, the qualitative features are identical. We would like to point out that it is possible that not only the effective charges but even the effective interaction used in HF calculations need not be the same as the ones used in the shell model calculations. However, as yet there has been no definite and clear investigation of the differences in the effective operators to be used in shell model and HF approaches. This is a separate problem and we hope to deal with it some other time. The criteria for using the effective charges of eq. 5 have been that these values seem to be normally accepted by the authors in this region of nuclei. Since the electromagnetic properties predicted by using these values have yet to be observed, it is useless at this stage to be much too particular about slight possible variations in the effective charges. When more experimental data on $E2$ transition and moments are available, we can revise the values of the effective charges.

5. Summary

The isotope ^{62}Zn has been studied using band-mixing methods in the deformed HF configuration space. The calculations have been carried out using as few as 12 different determinental states, and using two different types of interactions viz., the phenomenological ASDI and the realistic Tabakin interaction.

It has been found that the lowest prolate and oblate intrinsic states are much less deformed (almost spherical) with Tabakin interaction compared to those with ASDI interaction. This fact is very well reflected in the wavefunctions of the states in the

calculated spectra of these interactions. The calculated spectrum of ^{62}Zn obtained with ASDI interaction, though compressed, is in reasonably good agreement with the observed one. It is also shown that almost all the levels in the shell-model spectrum obtained by Van Hienen *et al* (1976) are reproduced in our calculations. Besides, many high spin states as well as odd J positive parity states have been predicted. Further the formalism enables us to identify 4 different fairly well-defined bands in the calculated spectrum. This information has been used to make quantitative calculation of $E2$ transitions and moments for a number of states belonging to these bands. Unfortunately little experimental data are available to verify these. In the light of our results, more experimental investigations for this nucleus seem to be certainly worth undertaking. The spectrum obtained using Tabakin interaction, is not as good in agreement with the observed one. Due to nearly spehrical nature of the HF solutions, there does not exist any well-defined band structure in the spectrum calculated with the Tabakin interaction. It therefore seems that the phenomenological ASDI interaction fitted to Ni and Cu isotopes, also gives a good description for ^{62}Zn.

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