PHYSICAL REVIEW C VOLUME 25, NUMBER 4 APRIL 1982

Systematics of $E2$ transition strengths in the Zn–Kr region

D. P. Ahalpara and K. H. Bhatt,
Physical Research Laboratory, Ahmedabad-380 009, India
(Received 21 July 1981)

The observed electromagnetic properties, namely, (1) the $B(E2)$ values for inband transitions in the collective bands of even-even isotopes $^{62-70}$Zn, $^{66-78}$Ge, $^{70-82}$Se, and $^{74-86}$Kr, and (2) their electric quadrupole moments of first 2^+ states have been studied in the projected Hartree-Fock model. The calculations have been performed in the $(1p_{3/2}0f_{5/2}1p_{1/2}0g_{9/2})$ model space using Kuo-Brown effective interaction. The $E2$ transition strengths have been studied for the yrast and yrare positive parity bands as well as for the recently observed negative parity collective bands. Using a simple structure for the collective band of states, namely, states with definite angular momentum projected from the lowest few deformed intrinsic Hartree-Fock states and using the effective charges $e_p = 1.6e$ and $e_n = 1.0e$ the observed systematics of $B(E2)$ values are fairly well reproduced.

[NUCLEAR STRUCTURE $^{62-70}$Zn, $^{66-78}$Ge, $^{70-82}$Se, and $^{74-86}$Kr.]

I. INTRODUCTION

In recent years the in-beam γ-ray spectroscopy following heavy ion induced reactions has given rise to a wealth of experimental data regarding the spectroscopic properties of the $(pf)g_{9/2}$ shell nuclei in the mass range $A = 60-90$. An interesting feature of these studies is the observation of multiple collective band structure in several nuclei. In many cases the members of the bands have been observed with spins ranging up to $J = 16^+$. Negative parity collective bands in the even-even isotopes of Zn, Ge, Se, and Kr have also been observed. An overview on the systematics of the observed collective band structures in $(pf)g_{9/2}$ shell nuclei has recently been written by Hamilton *et al.*[1] and by Vergnes.[2]

The electromagnetic properties of these collective bands, and in particular the $E2$ transition strengths for the inband transitions, give quite useful information about the microscopic structure of the collective states. In recent years the following systematics of these electromagnetic properties have emerged: (a) The $B(E2)$ values for

(1) the $2^+ \rightarrow 0^+$ transitions in ^{64,66,68,70}Zn,[3–6] ^{68,70,72,74,65}Ge,[1,4–12] ^{72,74,76,78,80,82}Se,[1,13–21] and ^{76,78,80,82,84,86}Kr[1,22–29];

(2) the inband transitions in the yrast states of ^{64,66}Zn,[3–5] ^{68,70,72}Ge,[4–9] ^{72,74,76}Se,[1,13–18] and ^{76,78,80}Kr[1,22–28];

(3) the inband transitions in the excited bands of positive parity states in ^{74,76}Se (Ref. 16–18) and ^{78}Kr[23,26]; and

(4) the inband transitions in the excited bands of negative parity states in ^{64}Zn,[1] ^{68}Ge,[1] ^{74}Se,[1] and ^{78}Kr.[1,23,26]

(b) The quadrupole moments $Q_{2_1^+}$ of the first 2^+ states in ^{64,70}Zn,[30,31] ^{72,74,76,78}Ge,[7,32–35] and ^{74,76,78,80,82}Se.[19,31,36,37]

Various theoretical attempts to study the electromagnetic properties in some of the $(pf)g_{9/2}$ shell nuclei have been made in the past using the following models.

(1) Shell model calculations for ^{64,66,68}Zn by Van Hienen *et al.*[38]

(2) Interacting boson approximation (IBA) calculations for ^{72}Se by Lieb and Kolata,[13] for ^{76}Se by Wells *et al.*,[18] and for ^{78}Kr by Hellmeister *et al.*,[23] by Gelberg and Kaup,[39] and by Kaup and Gelberg.[40]

(3) Hartree-Fock-Bogolubov (HFB) calculation for ^{64,66,68}Zn by Sharma.[41]

(4) Quasiparticle-phonon-model (QPM) calculation for ^{64,66,68,70}Zn and ^{68,70,72,74,76}Ge by Vries and

Brussaard.[32]

(5) Generator coordinate method incorporating quasiparticle excitations (GCM + QP) calculation for ^{70}Zn and ^{72}Ge by Didong *et al.*[42]

(6) Dynamic deformation theory (DDT) calculation for ^{70,72,74}Ge by Kumar.[43]

(7) Coexistence model calculation, soft asymmetric rotor (SAR) calculation, and harmonic vibrator (HV) calculation for ^{72}Se by Lieb and Kolata.[13]

(8) Potential energy surface calculation in collective model for ^{72}Se by Piercey *et al.*[16]

(9) Triaxial rotor (TAR) model calculation and SU(5) model calculation for ^{78}Kr by Hellmeister *et al.*[23]

(10) Rotational model and vibrational model calculations for ^{80}Kr by Friederichs *et al.*[27]

(11) Collective model calculation for ^{78}Se by Holzwarth and Lie.[44]

The above various models have been applied to specific nuclei and do not cover fully the even-even isotopes of Zn, Ge, Se, and Kr for which experimental data regarding electromagnetic properties have become available recently. In the present paper, an attempt is made to study the electromagnetic properties of the even-even isotopes of $(pf)g_{9/2}$ shell nuclei in a single microscopic model, namely, the projected Hartree-Fock (PHF) model. It has been shown earlier by Dhar and Bhatt[45] that for the nuclei of the first half of the $(0f\text{-}1p)$ shell the calculated electromagnetic properties of the states projected from the lowest HF intrinsic states reproduce well the observed $E2$ transitions. It is therefore interesting to see whether for the nuclei in the upper part of the $(pf)g_{9/2}$ shell the association of the states projected from the lowest energy HF states with the observed yrast bands would be equally successful in correlating the $E2$ transition data. It would be noted that by comparing the present HF results with the more extensive HF calculation for Ge isotopes by Ardouin *et al.*,[46] which includes seven major shells and uses Skyrme effective interaction, it is found that both calculations give rise to similar deformation trends for the lowest energy intrinsic HF states in that a shape transition from oblate to prolate is obtained with ^{68,70,72,74}Ge being oblate and ^{76,78}Ge being prolate.

With ^{56}Ni as the core, the valence nucleons are distributed in the model space consisting of $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$, and $0g_{9/2}$ single particle orbits. Kuo-Brown effective interaction matrix elements calculated for this model space have been used. The electromagnetic properties have been calculated using the effective charges $e_p = 1.6e$ and $e_n = 1.0e$.

In Sec. II the details of the calculation are presented. The results are given in Sec. III. Finally, a brief discussion follows in Sec. IV.

II. CALCULATION

Considering ^{56}Ni as the closed inert core the deformed Hartree-Fock (HF) calculations have been carried out in the model space consisting of the four active single particle orbits $p_{3/2}$, $f_{5/2}$, $p_{1/2}$, and $g_{9/2}$. The Hamiltonian in this model space is defined by the single particle energies (spe) of the four orbits relative to the core and 133 two-body effective interaction matrix elements. The spe used in the calculation are 0.0, 0.78, 1.08, and 5.0 MeV for the $p_{3/2}$, $f_{5/2}$, $p_{1/2}$, and $g_{9/2}$ orbits, respectively. Out of these spe the first three have been taken empirically from the spectrum of ^{57}Ni.[47] The position of the $g_{9/2}$ single particle orbit has not been well defined as yet. In the ^{58}Ni$(p,d)^{57}$Ni reaction studied by Fortier,[47] the lowest state with $J = 9/2^+$ has been observed at 3.009 MeV with a very weak spectroscopic strength. The rest of the single particle strength has not been observed. In the present calculation we have used the spe of the $g_{9/2}$ orbit as 5.0 MeV. The effective interaction matrix elements used in the calculation have been supplied by Kuo.[48]

The axially symmetric deformed HF states $|\Phi_{K=0^+}\rangle$ with prolate and oblate deformations are first calculated for the even-even isotopes $^{62-70}$Zn, $^{66-78}$Ge, $^{70-82}$Se, $^{76-86}$Kr, and $^{78-86}$Sr. The states with definite angular momentum projected from the lowest energy $K = 0^+$ deformed intrinsic states are associated with the observed yrast bands in these nuclei. The excited positive parity bands have been observed in $^{74-76}$Se and ^{78}Kr and excited negative parity bands have been observed in ^{64}Zn, ^{68}Ge, ^{74}Se, and ^{78}Kr. The excited positive parity bands in ^{74}Se, ^{76}Se, and ^{78}Kr have been associated with states projected from lowest intrinsic states with $K = 2^+$ and the excited negative parity bands in ^{64}Zn, ^{68}Ge, ^{74}Se, and ^{78}Kr have been associated with states projected from lowest energy intrinsic states with $K = 1^-$, 1^-, 3^-, and 1^-, respectively. The excited intrinsic states are generated in the following way.

A tagged HF calculation is carried out in which the lowest energy solution for a given 1 particle-1 hole or 2 particle-2 hole configuration relative to

the ground HF state is looked for. The negative parity intrinsic states in the even-even nuclei have been obtained by doing a tagged HF calculation for 1 particle-1 hole configuration in which a nucleon from the $(p_{3/2}f_{5/2}p_{1/2})$ deformed orbit is excited to the $g_{9/2}$ orbit.

A standard projection method[49,50] has been used to calculate the electromagnetic properties, namely (1) $B(E2;J_i \rightarrow J_f)$ values for various transitions between these projected states and (2) the static electric quadrupole moments Q_{2^+} of the first $J=2^+$ states. In calculating the electromagnetic properties the effective charges $e_p=1.6e$ and $e_n=1.0e$ have been used. These effective charges have been derived earlier by Van Hienen *et al.*[38] in a least squares fit to the observed $E2$ transition strengths in the low lying levels of $^{63-68}$Zn isotopes using the shell model wave functions.

III. RESULTS

In this section a comparison is made between the calculated and experimental $E2$ transition strengths and quadrupole moments of first 2^+ states in even-even isotopes of Zn, Ge, Se, Kr, and Sr.

A. The $B(E2;2^+ \rightarrow 0^+)$ systematics

In Figs. 1 to 5 are plotted the calculated and experimental $B(E2;2^+ \rightarrow 0^+)$ values for the even-even isotopes of Zn, Ge, Se, Kr, and Sr, respectively. In the figures the thick lines join the experimental $B(E2)$ values whereas the dashed lines join the calculated ones.

In Zn isotopes (Fig. 1) the trend of the experimental $B(E2)$ values is reproduced in the present projected Hartree-Fock (PHF) calculation. The calculated values are, however, about a factor of 1.5 smaller compared to experiment indicating that not enough collectivity has gone in the lowest HF states in Zn isotopes. The mixing of more deformed excited intrinsic states is likely to improve the results. The experimental $B(E2)$ values in $^{68-76}$Ge isotopes (Fig. 2) have an overall increasing trend with mass number which is fairly well brought out by the calculation. The uncertainties in the observed values are rather large for isotopes with mass number $A=68$, 70, and 74, and it would be interesting to measure them with a better precision. Both the experimental and calculated $B(E2)$ values for $^{72-82}$Se isotopes (Fig. 3) show a peak at $A=76$. The overall trend is reproduced by the PHF calculation; however for ^{72}Se, the calculated $B(E2)$ value is rather large compared to experiment. It may be pointed out that for ^{72}Se two different measurements have given the $B(E2)$ values as 31 ± 6 Weisskopf units (W.u.) (Ref. 14) and 20 ± 2 W.u. (Refs. 1 and 13) out of which the larger value is favored by the present calculation. As shown in Fig. 4 the experimental $B(E2)$ values in $^{74-86}$Kr isotopes show a wide range; 85 W.u. for ^{76}Kr and 6 W.u. for ^{86} Kr. Moreover, as pointed

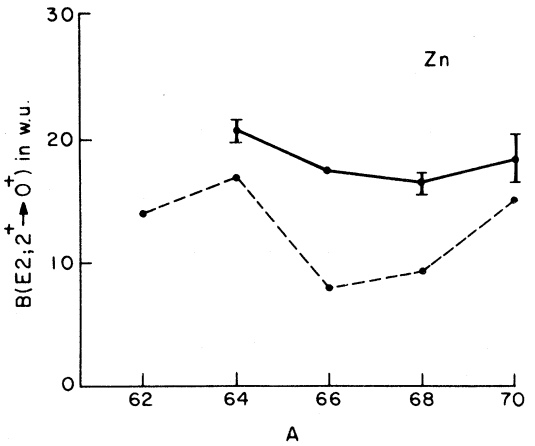

FIG. 1. Comparison between experimental and calculated $B(E2;2^+ \rightarrow 0^+)$ values in ^{62,64,66,68,70}Zn. The experimental and calculated values are connected by full and dashed lines, respectively.

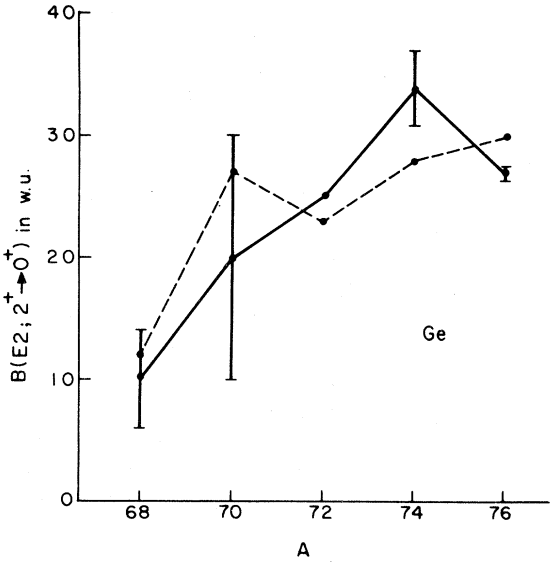

FIG. 2. Comparison between experimental and calculated $B(E2;2^+ \rightarrow 0^+)$ values in ^{68,70,72,74,76}Ge. The experimental and calculated values are connected by full and dashed lines, respectively.

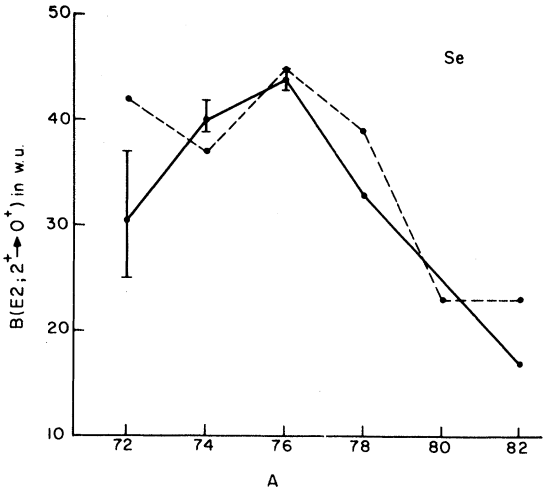

FIG. 3. Comparison between experimental and calculated $B(E2;2^+\rightarrow 0^+)$ values in ^{72,74,76,78,80,82}Se. The experimental and calculated values are connected by full and dashed lines, respectively.

out by Zhao *et al.*,[22] the $B(E2)$ value for ^{76}Kr is the largest among the experimental $B(E2)$ values for $2_1^+\rightarrow 0_1^+$ transitions in the Zn–Kr region. Both of these features are well reproduced by PHF calculation. As more and more nucleons are added to ^{76}Kr the deformation decreases and for ^{86}Kr the HF state is close to a spherical solution in which the intrinsic mass quadrupole moment is very small. The $B(E2)$ values in Sr isotopes have not been measured as yet. As shown in Fig. 5 the calculated $B(E2)$ values show quite a similar feature

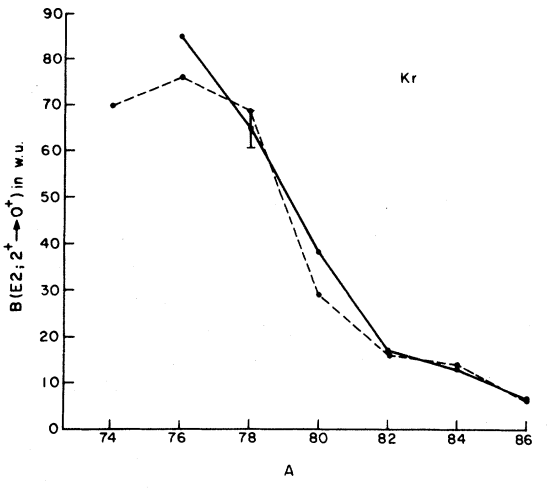

FIG. 4. Comparison between experimental and calculated $B(E2;2^+\rightarrow 0^+)$ values in ^{74,76,78,80,82,84,86}Kr. The experimental and calculated values are connected by full and dashed lines, respectively.

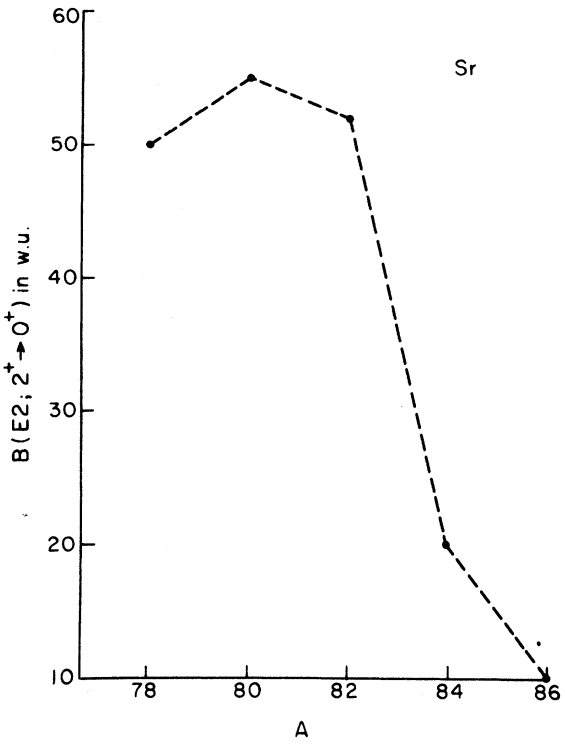

FIG. 5. The calculated $B(E2;2^+\rightarrow 0^+)$ values in ^{78,80,82,84,86}Sr.

as in Kr isotopes with a peak at $A=80$ and a steep fall for higher mass isotopes.

B. The $B(E2)$ systematics for inband yrast transitions

In Tables I to IV the calculated $B(E2)$ values for inband transitions in the yrast bands of ^{64,66}Zn, $^{68-76}$Ge, $^{70-84}$Se, $^{74-84}$Kr, and $^{78-86}$Sr, respectively, are compared with experiment and with previous theoretical results.

As shown in Table I the calculated $B(E2)$ values in PHF and shell model[38] for ^{64}Zn are qualitatively similar and agree fairly well with experiment. The Hartree-Fock-Bogolubov (HFB) calculation[41] gives quite large $B(E2)$ values for $4^+\rightarrow 2^+$ and $6^+\rightarrow 4^+$ transitions. This is related to the occupation of 2 nucleons in the $g_{9/2}$ orbit in the HFB state giving rise to a large intrinsic quadrupole moment and thereby large collectivity. With regard to ^{66}Zn it is interesting to note that the observed $B(E2)$ values in the yrast band show a sudden dip for $8^+\rightarrow 6^+$ transition indicating a substantial change in the structure of the two states. A single intrinsic HF state would not reproduce this feature. We mention here a rather detailed deformed configuration

TABLE I. A comparison between experimental and calculated $B(E2;J\rightarrow J-2)$ values (in W.u.) for transitions in the yrast bands of ^{64,66,68,70}Zn.

A	J	2^+	4^+	6^+	8^+	10^+	12^+
64	E_J(MeV)	0.992	2.307	3.993			
	Exp[a]	20.8 ± 0.7	10^{+13}_{-3}	18^{+5}_{-3}			
	PHF	17	21	19	14		
	SM[b]	19	26	24			
	HFB[c]	19	62	59			
	QPM[d]	18					
66	E_J(MeV)	1.039	2.450	4.179	5.205	6.291	7.517
	Exp[a]	17.3 ± 0.6					
	Exp[e]	20	8	11	<2	15	18
	PHF	8	10	8	5		
	DCM[f]	13	12	11	0.5	35	29
	SM[b]	17	21	20			
	HFB[c]	20	69	72			
	QPM[d]	18					
68	E_J(MeV)	1.0774	2.4173	3.688	4.397		
	Exp[a]	16.5 ± 0.7					
	PHF	9	11	8	5		
	SM[b]	16	17	15			
	HFB[c]	21	71	30			
	QPM[d]	17					
70	E_J(MeV)	0.8848	1.7865				
	Exp[g]	19 ± 2					
	PHF	15	20	20	18	15	
	(GCM + QP)[h]	19	23	7	18	25	
	QPM[d]	15					

[a]References 3 and 38.
[b]Reference 38.
[c]Reference 41.
[d]Reference 32.
[e]References 4 and 5.
[f]Reference 51.
[g]References 6 and 7.
[h]Reference 42.

mixing (DCM) calculation[51] involving the 12 lowest positive parity deformed intrinsic states and doing a band mixing calculation for the states projected from these intrinsic states. The calculation shows that the yrast states with $J=0^+$, 2^+, 4^+, and 6^+ arise mainly from $(p_{3/2}f_{5/2}p_{1/2})^{10}$ configuration, whereas the higher yrast states with $J=8^+$, 10^+, 12^+, and 14^+ arise from the 2 particle-2 hole $(p_{3/2}f_{5/2}p_{1/2})^8(g_{9/2})^2$ deformed configuration. The operator corresponding to $E2$ transition being a one-body operator would not connect these two configurations. Because of a small admixture due to the Hamiltonian of the two configurations in the structure of yrast states the calculated $B(E2)$ value for $8^+\rightarrow6^+$ transition is 0.5 W.u. (Table I) in good agreement with experiment. Both HFB and shell model calculations for ^{66}Zn give good agreement with experiment for the $B(E2;2^+\rightarrow0^+)$ value, whereas they overestimate the $B(E2)$ values for higher transitions.

The quasiparticle-phonon model (QPM)[32] which couples two quasiparticles to the phonon states of the core of $(A-2)$ nucleons fairly reproduces the $B(E2;2^+\rightarrow0^+)$ values in $^{64-70}$Zn by using rather large effective charges $e_p=2.3e$ and $e_n=1.3e$. In ^{68}Zn the $B(E2;2^+\rightarrow0^+)$ value is well reproduced by shell model and QPM. The generator coordinate method incorporating quasiparticle excitations (GCM + QP) has been applied by Didong *et al.*[42] to study the spectroscopy of ^{70}Zn. Using the effec-

TABLE II. A comparison between experimental and calculated $B(E2;J\rightarrow J-2)$ values (in W.u.) for transitions in the yrast bands of ^{68,70,72,74,76}Ge.

A	J	2^+	4^+	6^+	8^+	10^+	12^+
68	E_J(MeV)	1.0158	2.2679	3.696	4.837	5.962	
	Exp[a]	10 ± 4	12^{+4}_{-3}	12^{+5}_{-3}	17^{+6}_{-2}	25^{+9}_{-5}	
	Exp[b]	9	13	12	7	27	
	PHF	12	16	15	11		
	QPM[c]	20					
70	E_J(MeV)	1.0396	2.1533	3.2975	4.432		
	Exp[a]	20^{+16}_{-10}	13^{+1}_{-3}	33^{+6}_{-7}	12^{+5}_{-8}		
	Exp[d]	20	13	33	12		
	Exp[e]	21 ± 0.4					
	Exp[f]	21					
	Exp[g]	21	≥ 5	≥ 6			
	PHF	27	37	38	36		
	DDT[h]	27					
	QPM[c]	19					
	HFB[i]	26	69	29			
72	E_J(MeV)	0.8339	1.7282				
	Exp[d]	25	24	37	40	46	27
	Exp[j]	23					
	Exp[e]	25 ± 3					
	PHF	23	32	32	30	26	21
	DDT[h]	30					
	QPM[c]	17					
	(GCM-QP)[k]	27	38	42	42	37	
	HFB[i]	26	102	135			
74	E_J(MeV)	0.5959	1.4637				
	Exp[l]	34 ± 3					
	Exp[m]	35					
	PHF	28	38	40	39	37	33
	DDT[h]	36					
	QPM[c]	15					
	HFB[i]	24	95	125			
76	E_J(MeV)	0.5629	1.4101				
	Exp[n]	27 ± 1					
	PHF	30	42	44	43	40	36
	QPM[c]	14					
	HFB[i]	23	82	109			

[a]Reference 1.
[b]References 4 and 5.
[c]Reference 32.
[d]Reference 5.
[e]Reference 6.
[f]Reference 7.
[g]Reference 8.
[h]Reference 43.
[i]Reference 41.
[j]Reference 9.
[k]Reference 42.
[l]Reference 10.
[m]Reference 11.
[n]Reference 12.

TABLE III. A comparison between experimental and calculated $B(E2;J\rightarrow J-2)$ values (in W.u.) for transitions in the yrast bands of ^{72,74,76,78,80,82,84}Se.

A	J	2^+	4^+	6^+	8^+	10^+	12^+	14^+
72	E_J(MeV)	0.862	1.6368	2.467	3.425	4.505	5.711	7.038
	Exp[a]	19	37	54	76	92	74	
	Exp[b]	31±6	137±34	≥165				
	Exp[c]	20±2	45±6	60±10	71±8	98±13	92±10	143^{+143}_{-48}
	Exp[d]	20±2	46±10	45±4	71±9	85^{+14}_{-10}	90^{+23}_{-15}	139^{+83}_{-38}
	PHF	42	58	60	57	51	42	30
	IBA[d]	24	43	60	71	79	84	84
	Coex[d]	20	35	78	80	83	85	85
	SAR[d]	18	32	52	69	85	101	117
	HV[d]	18	36	54	72	90	108	126
	HFB[e]	39	151	205				
74	E_J(MeV)	0.6348	1.3632	2.2314	3.1984	4.2563	5.4432	6.735
	Exp[f]	40^{+2}_{-1}	81±3	38±5	66±8	75^{+15}_{-10}	63^{+63}_{-21}	36^{+26}_{-11}
	PHF	37	51	53	50	44	35	22
	GG[g]	15	36	52				
	HFB[e]	38	148	200				
76	E_J(MeV)	0.5591	1.3307	2.2621	3.2693	4.2986	5.432	
	Exp[h]	44±1	71±2	61^{+245}_{-25}	104^{+104}_{-35}	47^{+47}_{-16}		
	Exp[i]	44						
	PHF	44	62	66	65	61		
	IBA[j]	44	73	86	87	78		
	HFB[e]	34	133	177				

tive charges $e_p=1.8e$ and $e_n=1.9e$ they reproduce well the experimental $B(E2;2^+\rightarrow 0^+)$ value.

As shown in Table II the $B(E2)$ systematics for yrast transitions in $^{68-72}$Ge is qualitatively described by the PHF calculation. In ^{70}Ge the experimental $B(E2)$ values peculiarly show large and small values for alternate yrast transitions. Using a single intrinsic state the PHF model generally gives a smooth variation for $B(E2)$ values in yrast transitions and would not reproduce the above feature. It would be necessary to incorporate low lying few intrinsic states and do a band-mixing calculation to improve the results. Also in ^{72}Ge quite large changes in experimental $B(E2)$ values are found for yrast transitions involving states with $J=4^+$ and 10^+. The calculations in dynamic deformation theory (DDT) by Kumar[43] give qualitative agreement with experimental $B(E2;2^+\rightarrow 0^+)$ values in $^{70-74}$Ge isotopes. The QPM model gives about a factor of 2, large and small values in ^{68}Ge and ^{74,76}Ge, respectively, and agrees well with experiment for ^{70}Ge. The HFB model[41] reproduces qualitatively the experimental $B(E2)$ values for $2^+\rightarrow 0^+$ transition in ^{70,72,74,76}Se. However, their calculated $B(E2)$ values for higher transitions, namely $4^+\rightarrow 2^+$ and $6^+\rightarrow 4^+$ are, in general, too large compared to other calculated and experimental $B(E2)$ values. It would be interesting to measure the inband $B(E2)$ values in ^{74,76}Ge isotopes and compare them with the predicted values.

The calculated $B(E2)$ values for the yrast transitions in $^{72-84}$Se isotopes are compared with experiment in Table III. The interacting boson approximation model (IBA) used by Lieb and Kolata[13] and by Wells *et al.*[18] gives quite a good agreement with the observed yrast $E2$ transitions in ^{72}Se and ^{76}Se, respectively. Lieb and Kolata[13] have also calculated the $B(E2)$ values in ^{72}Se using coexistence model, soft asymmetric rotor (SAR) model, and the harmonic vibrator (HV) model and they give qualitative agreement with experiment. Piercey *et al.*[16] have calculated $B(E2)$ values in ^{74}Se using the Gneuss-Griener model (GG) which gives rather small $B(E2)$ value for $2^+\rightarrow 0^+$ transition. The

TABLE III. (*Continued.*)

A	J	2^+	4^+	6^+	8^+	10^+	12^+	14^+
78	E_J(MeV)	0.6138	1.5024	2.542	3.578			
	Exp[i]	33						
	Exp[k]	38						
	Exp[l]	36						
	PHF	39	54	58	58	55	51	46
	HL[m]	38	58	68				
	HFB[e]	30	160	74				
80	E_J(MeV)	0.6664	1.7011					
	Exp[i]	25						
	Exp[n]	24	35					
	PHF	23	32	33	32	29	24	
82	E_J(MeV)	0.6544	1.7343					
	Exp[o]	17	19					
	PHF	23	31	30	26	20	12	
84	E_J(MeV)	1.451	3.69					
	PHF	13	16	11				

[a]Reference 15.
[b]Reference 14.
[c]Reference 1.
[d]Reference 13.
[e]Reference 41.
[f]References 1, 16, and 17.
[g]Reference 16.
[h]References 17 and 18.
[i]Reference 19.
[j]Reference 18.
[k]Reference 20.
[l]Reference 21.
[m]Reference 44.
[n]Reference 17.
[o]References 17 and 19.

PHF model reproduces fairly well the $B(E2)$ values for yrast transitions in $^{72-76}$Se; however it fails to show a sudden increase in observed $B(E2)$ values for $14^+ \rightarrow 12^+$ transition in ^{72}Se, $4^+ \rightarrow 2^+$ transition in ^{74}Se, and $8^+ \rightarrow 6^+$ transition in ^{76}Se. In ^{78}Se both PHF and the calculation by Holzwarth and Lie[44] (HL) give similar results for yrast $E2$ transitions and agree well with the experimental $B(E2;2^+ \rightarrow 0^+)$ value. The $B(E2)$ values for $2^+ \rightarrow 0^+$ transition in ^{72,74,76,78}Se are fairly reproduced by HFB model[41]; however, as was also found for Zn and Ge isotopes, the $B(E2)$ values for higher transitions are overestimated.

The yrast $E2$ transition strengths in $^{74-86}$Kr are shown in Table IV. In ^{76}Kr the experimental $B(E2)$ values are well described by PHF except for $12^+ \rightarrow 10^+$ transition for which the sudden fall in the observed value is not reproduced by the calculation. Perhaps this indicates the onset of back bending as a result of the crossing of the ground state band with the more deformed excited band. In ^{78}Kr both PHF and IBA (Ref. 23) calculations give quite similar results but are about a factor of 2 larger than experiment. The SU(5) and the triaxial rotor (TAR) models[23] give even larger $B(E2)$ values for higher yrast transitions. In ^{80}Kr the rotational model[27] (ROT) gives better agreement with experiment as compared to the vibrational (VIB) model.[27] The VIB model gives $B(E2;I \rightarrow I-2)$ values proportional to spin I in contrast to the experimental situation which shows a smaller increase as a function of spin I. In $^{82-86}$Kr isotopes the $B(E2)$ values for yrast transitions have not been measured so far and it would be interesting to measure them and compare with the predicted values. In Table V the $B(E2)$ values for yrast transitions in $^{78-86}$Sr isotopes calculated in PHF model are given.

TABLE IV. A comparison between experimental and calculated $B(E2;J\rightarrow J-2)$ values (in W.u.) for transitions in the yrast bands of ^{74,76,78,80,82,84,86}Kr.

A	J	2^+	4^+	6^+	8^+	10^+	12^+	14^+	16^+
74	E_J(MeV)	0.4557	1.0135						
	PHF	70	99	105	104	100	93		
76	E_J(MeV)	0.424	1.034	1.858					
	Exp[a]	85	121	90	116	129	60		
	PHF	76	106	114	115	113	108		
78	E_J(MeV)	0.4550	1.1191	1.9778	2.9928	4.105			
	Exp[b]	66±4	89±8	99^{+20}_{-14}	85^{+13}_{-10}	>48		59^{+33}_{-16}	≥31
	Exp[c]	65±4	72^{+20}_{-13}	49^{+14}_{-9}	54^{+21}_{-12}	52±12			
	Exp[d]	52							
	Exp[e]	58±7	58±14	49±11	54±16	52±12			
	PHF	69	98	105	105	103	97		
	IBA[b]	66	97	106	103	91	79	58	36
	SU(5)[b]	66	116	149	165	165	145	116	66
	TAR[b]	66	94	118	130	138	142	148	151
80	E_J(MeV)	0.617	1.4368	2.3931	3.410				
	Exp[c]	38	46	50	92	47			
	Exp[f]	35±2	45±4	67±18	61				
	Exp[g]	37							
	Exp[h]	33							
	PHF	29	41	43	43	42	39	36	
	ROT[f]	35±2	50±3	56±3	58±3				
	VIB[f]	35±2	71±4	106±6	141±8				
82	E_J(MeV)	0.777	1.821	2.920					
	Exp[g]	28							
	Exp[h]	17							
	PHF	16	22	22	21	18	15	7	
84	E_J(MeV)	0.882	2.095	3.173					
	Exp[g]	12							
	Exp[i]	14							
	Exp[j]	8							
	Exp[k]	15							
	PHF	14	19	18	15	12			
86	E_J(MeV)	1.565	2.249						
	Exp[g]	7							
	Exp[j]	6							
	PHF	6	7	4					

[a]Reference 22.
[b]References 23, 39, 40, and 53.
[c]Reference 1.
[d]References 24 and 25.
[e]Reference 26.
[f]Reference 27.
[g]Reference 24.
[h]References 25 and 28.
[i]Reference 25.
[j]Reference 29.
[k]Reference 28.

TABLE V. The calculated $B(E2;J\rightarrow J-2)$ values (in W.u.) for transitions in the yrast bands of ^{78,80,82,84,86}Sr.

A	J	2^+	4^+	6^+	8^+	10^+	12^+	14^+
78	E_J(MeV)	0.505	1.263	2.01				
	PHF	50	70	74	74	70	65	58
80	E_J(MeV)	0.3854	0.9802	1.763				
	PHF	55	78	84	85	83	79	74
82	E_J(MeV)	0.5734	1.3285	2.230				
	PHF	52	74	80	81	80	78	74
84	E_J(MeV)	0.7934	1.768	2.808	3.924			
	PHF	20	27	29	29	28	25	19
86	E_J(MeV)	1.0766	2.2297	2.8569	2.956			
	PHF	10	13	13	13	12	8	

C. $B(E2)$ systematics for inband transitions in the excited positive parity bands

In Table VI are given the $B(E2)$ values for the inband transitions in the excited bands of ^{74,76}Se and ^{78}Kr. In ^{74}Se PHF gives $B(E2)$ values about a factor of 2 smaller than experiment; however, the uncertainties in experimental values are quite large and it would be interesting to measure them with better precision. In ^{76}Se both the PHF and IBA calculations give closely similar results and they agree fairly well for $6^+\rightarrow 4^+$ transitions but do not account for a sharp decrease at $4^+\rightarrow 2^+$ transition. The PHF, IBA, SU(5), and triaxial rotor (TAR) model calculations for ^{78}Kr give qualitative agreement with experimental $B(E2)$ values which have large uncertainties. It may be noted that the calculated $B(E2)$ values in ^{78}Kr for the interband transitions connecting the states in the excited band to those in the yrast band are all small (≤ 10 Wu). This agrees only qualitatively with experiment as some of the measured $B(E2)$ values for these interband transitions reported by Hellmeister *et al.*[23,40,53] are larger than the calculated values.

D. $B(E2)$ systematics for inband transitions in negative parity bands

In Table VII a comparison is made between the experimental and calculated $B(E2)$ values for inband transitions in the negative parity bands in ^{64}Zn, ^{68}Ge, ^{74}Se, and ^{78}Kr. In ^{64}Zn, ^{68}Ge, and ^{74}Se the uncertainties in experimental $B(E2)$ values are large. The trend is fairly well reproduced by PHF calculation except for giving smaller values for higher transitions in ^{74}Se. In ^{78}Kr, PHF and IBA give fairly close $B(E2)$ values. The experimental values reported by three groups, namely, Robinson *et al.*,[26] Hellmeister *et al.*,[23] and Hamilton *et al.*[1] differ from one another significantly and it would be interesting to resolve these discrepancies. Robinson *et al.*[26] have pointed out that the $B(E2)$ values for transitions in the negative parity bands in ^{78}Kr are quite enhanced as compared to those for yrast transitions. The PHF and IBA calculations indeed give large $B(E2)$ values for transitions in negative parity bands.

TABLE VI. A comparison between experimental and calculated $B(E2;J\rightarrow J-2)$ values (in W.u.) for the inband transitions in the excited positive parity bands in ^{74,76}Se and ^{78}Kr.

Nucleus	J	3^+	5^+	7^+	9^+	2^+	4^+	6^+	8^+	10^+	12^+
^{74}Se	E_J(MeV)	1.884	2.662	3.525	4.450	1.269	2.108	2.987			
	Exp[a]			133^{+135}_{-81}	111^{+55}_{-28}						
	PHF		45	59	62		29	54	61		
^{76}Se	E_J(MeV)	1.689	2.489	3.432		1.216	2.026	2.976			
	Exp[b]						$2^{+0.3}_{-1.3}$	46^{+24}_{-12}			
	PHF		32	41	43		20	38	43	43	39
	IBA[c]						43	59			
^{78}Kr	E_J(MeV)	1.565	2.299	3.202	4.251	1.148	1.873	2.731	3.771	4.858	
	Exp[d]		75 ± 17	76^{+38}_{-25}			63 ± 17	45^{+45}_{-22}			
	Exp[e]		90 ± 40	68^{+46}_{-19}	64 ± 13		<50	35^{+38}_{-12}	99 ± 28		
	PHF		56	75	80		36	68	79	81	79
	IBA[d]		59	76			49	63			
	SU(5)[d]		87	113			78	113			
	TAR[d]		63	90			30	51			

[a]Reference 16.
[b]References 17 and 18.
[c]Reference 18.
[d]References 23, 39, 40, and 53.
[e]Reference 26.

E. STATIC ELECTRIC QUADRUPOLE MOMENT OF FIRST 2^+ STATE

The electric quadrupole moment Q_{2^+} of the first 2^+ states in even-even isotopes of Zn, Ge, Se, Kr, and Sr is shown in Table VIII. In Zn isotopes the PHF, shell model,[38] and HFB (Ref. 41) calculations give closely similar quadrupole moments for ^{62,64}Zn. For ^{64}Zn these values are about a factor of 2 larger than the experimental value. The rotationally invariant core (RIC) model[31] gives fair agreement with experiment for the quadrupole moments in ^{64,70}Zn. The quasiparticle-phonon model[32] (QPM) gives small Q_{2^+} values for $^{62-70}$Zn. This is related to coupling of two quasiparticles to the phonon states of $(A-2)$ nucleons. The phonon vibrations of the core would not contribute to the overall deformation of the nucleus, and hence, the model gives rise to small quadrupole moments arising from the deformations of two quasiparticles only.

The experimental quadrupole moments of Ge isotopes indicate a shape transition from near spherical to prolate for the isotopes with mass range $A=70$ to 76.[35] This feature is not brought out by any calculation and poses a challenge to theoretical models. The present PHF calculation gives an oblate to prolate transition for mass range $A=68$ to 78 with $^{68-74}$Ge having oblate shape and $^{76-78}$Ge having prolate shape. This is in accordance with a more detailed HF calculation by Ardouin *et al.*[46] for the study of shapes of Ge isotopes. Doing HF calculation in model space of seven major shells and using Skyrme interaction they were able to plot energy versus deformation curves for $^{68-78}$Ge isotopes by introducing a quadrupole constraint. This calculation also shows an oblate to prolate transition for $^{68-78}$Ge isotopes with $^{68-74}$Ge being oblate and $^{76-78}$Ge being prolate. Both the present HF and the above mentioned detailed HF calculation give opposite signs for quadrupole moments for ^{72,74}Ge. In Table VIII we have also quoted in the PHF column the calculated quadrupole moments corresponding to prolate shapes for ^{70,72,74}Ge. These values are also about a factor of 2 larger than experimental values. It

TABLE VII. A comparison between experimental and calculated $B(E2;J\rightarrow J-2)$ values (in W.u.) for the inband transitions in the excited negative parity bands in ^{64}Zn, ^{68}Ge, ^{74}Se, and ^{78}Kr.

Nucleus	J	3	5	7	9	11	13	4	6	8	10	12	14
^{64}Zn	E_J(MeV)	2.999	3.925	4.981									
	Exp[a]		>4	21 ± 7									
	PHF		29	33									
^{68}Ge	E_J(MeV)	2.649	3.649	4.054	5.331	7.045							
	Exp[a]		16^{+16}_{-8}										
	PHF		9	9	10								
^{74}Se	E_J(MeV)	2.350	2.843	3.516	4.403	5.492	6.685						
	Exp[a]			64^{+43}_{-26}	116^{+46}_{-26}	78^{+11}_{-8}							
	PHF			46	56	58	56						
^{78}Kr	E_J(MeV)		2.749	3.288	4.028	4.965	6.087	2.764	3.220	3.919	4.809		
	Exp[b]			144 ± 18	151 ± 14	159^{+61}_{-24}	73^{+64}_{-24}			187 ± 56	≥ 50		
	Exp[c]			210^{+360}_{-80}	90 ± 30	81 ± 11				120 ± 30			
	Exp[a]			130^{+200}_{-80}	84 ± 23	81 ± 11							
	PHF			103	104	102	98			104	104	100	95
	IBA[b]			102	115	114	106			99	105		
	SU(5)[b]			116	149	165	165			127	152		

[a]Reference 1.
[b]References 23, 39, 40, and 53.
[c]Reference 26.

would be interesting to see whether the observed trend of quadrupole moments in Ge isotopes[35] is reproduced in a detailed band mixing calculation incorporating the lowest few deformed HF states. The calculation by Kumar[43] in the dynamic deformation theory (DDT) gives oblate shapes for ^{70,72,74}Ge isotopes. His calculated quadrupole moments of first 2^+ states in ^{70,72,74}Ge are 15, 23, and 24 e fm^2, respectively. The signs for these quadrupole moments are opposite to experimental values for ^{72,74}Ge. It would be interesting to extend this calculation to also include other Ge isotopes and study their shapes in the mass range $A=68-78$. The QPM model[32] gives very small quadrupole moments for $^{68-76}$Ge isotopes corresponding to prolate shapes. The RIC model[31] gives fair agreement with experiment for the quadrupole moment of ^{74}Ge and gives a larger value for ^{76}Ge.

The measured quadrupole moments in $^{74-82}$Se isotopes have been reported by three groups, namely, Zalm *et al.*,[31] Lecomte *et al.*,[19,36] and Vold *et al.*[37] in which the first two groups give quite similar values but differ from the values quoted by the latter group for ^{76,78}Se isotopes. The present PHF calculation favors the quadrupole moments measured by Vold *et al.*[37] giving good agreement for ^{76,78}Se and a large value for ^{80}Se. For ^{74}Se the Table VIII includes two values in the PHF column corresponding to oblate and prolate deformations, respectively. The oblate shape corresponds to the lowest energy HF state, however, the lowest prolate solution gives quadrupole moment in good agreement with experiment (Table VIII). The RIC model[31] reproduces quite well the measured quadrupole moments of $^{76-82}$Se isotopes.[19,31,36] The calculation by Holzwarth and Lie[44] (HL) gives the quadrupole moment of ^{78}Se as -118 e fm^2, which is about a factor of 3 times larger than the experimental value. The IBA calculation for ^{72}Se by Lieb and Kolata[13] gives the quadrupole moment as -56 e fm^2. Present PHF calculation gives a similar value for the quadrupole moment with opposite sign. The Table VIII also includes the calculated quadrupole moment of ^{72}Se corresponding to prolate shape which is about a factor of 3 smaller than the IBA value.

The quadrupole moments of first 2^+ states for ^{74,76,78,80,82,84}Kr and ^{78,80,82,84,86}Sr isotopes have not

TABLE VIII. A comparison between experimental and calculated quadrupole moments Q_{2+} (in e fm^2) of the first 2^+ states in even-even isotopes $^{62-72}$Zn, $^{68-78}$Ge, $^{72-84}$Se, $^{74-86}$Kr, and $^{78-86}$Sr.

	A	E_{2+} (MeV)	Exp[a]	Exp[b]	Exp[c]	PHF	RIC[d]	SM[e]	HFB[f]	QPM[g]
Zn	62	0.954				−29		−33	−25	−10.8
	64	0.992	−14±2			−33	−18	−29	−32	−8.2
	66	1.039				−31		−19	−24	−5.7
	68	1.077				−24		−6	−19	−3.5
	70	0.884	−21±3			−45	−18			−1.9
	72	0.650				−40				
Ge	68	1.016				28				−1.0
	70	1.039	0±10	0±10	3±6 or				−29	−0.6
					9±6				−36	−0.3
	72	0.834			−13±6	41,0.0				
	74	0.596	−25±10	−12±16	−25±6	45,−45	−28		−30	−0.4
	76	0.563	−15±10		−19±6	−48	−29		−28	−1.2
	78			−11±4		−42				
Se	72	0.862				55,−18			−49	
	74	0.635		−36±7		53,−38			−37	
	76	0.559	−31±4	−34±7	−44±9	−45	−31		−34	
	78	0.614	−28±7	−26±9	−40±8	−51	−27		−33	
	80	0.666	−32±6	−31±7	−32±9	−44	−24			
	82	0.654	−22±7	−22±7		−45	−24			
	84	1.455				−35				

[a]References 30, 31, 33, and 54.
[b]References 19, 34, and 36.
[c]References 35 and 37.
[d]Reference 31.
[e]Reference 38.
[f]Reference 41.
[g]Reference 32.

been measured as yet. The calculated values of the quadrupole moments in the present model for Kr isotopes are 73, 77, 75, 49, −37, −35, and −22 e fm^2, respectively, and for Sr isotopes are 63, 68, 67, 41, and 28 e fm^2, respectively. It is noted that HF calculation gives quite stable oblate shapes for ^{74,76,78,80}Kr and ^{78,80,82,84}Sr with the oblate to prolate energy gap being more than 2 MeV. It would be interesting to measure the quadrupole moments of these isotopes and compare them with the predicted values.

IV. DISCUSSION

The spectra of transitional nuclei in the $(pf)g_{9/2}$ shell region are quite complex. It would therefore not seem possible *a priori* that the lowest energy Hartree-Fock states of the nuclei would fairly well reproduce the observed systematics of $B(E2)$ values for inband transitions. On the contrary, the present projected Hartree-Fock (PHF) calculation using Kuo-Brown effective interaction in $(pf)g_{9/2}$ model space gives a pleasant surprise by showing that the large variation in the observed $B(E2)$ values as well as the enhancement near ^{76}Kr, as recently reported by Zhao *et al.*,[22] is fairly well described. In many cases the details of variation of $B(E2)$ values within the yrast bands are also brought out. The agreement with experiment for the $B(E2)$ values in upper part of $(pf)g_{9/2}$ shell nuclei is found similar to the one obtained earlier in (sd) shell by Gunye[52] and in (fp) shell by Dhar and Bhatt.[45]

Comparing the present PHF results with the available IBA results for $B(E2)$ values it is noted that both models give quite similar results for the yrast transitions in ^{76}Se and ^{78}Kr as well as for the

transitions in the excited positive and negative parity bands in ^{78}Kr. For ^{78}Kr the calculated $B(E2)$ values in the yrast bands are, however, about a factor of 2 larger than experiment. In ^{72}Se, IBA gives a slightly better agreement with experiment for the yrast $E2$ transitions.

We also note some glaring discrepancies between the PHF results and experiment for the $B(E2)$ values and suggestions for the improvement. In Zn isotopes the calculated $B(E2)$ values for $2^+ \rightarrow 0^+$ transitions are about a factor of 2 smaller than experiment (Fig. 1). This indicates that not enough collectivity has gone in the lowest intrinstic HF states. As is noted for ^{66}Zn more detailed calculation incorporating mixing of excited intrinsic HF states would give a better description of yrast $E2$ transitions. Secondly, in Se isotopes the $B(E2)$ values for higher transitions in the yrast bands are underestimated. Moreover, the sudden increase in $B(E2)$ values for the yrast transitions, e.g., for $14^+ \rightarrow 12^+$ transition in ^{72}Se and for $8^+ \rightarrow 6^+$ transition in ^{76}Se are not brought out by both PHF and IBA models. In ^{76}Se, the $B(E2)$ value for $4^+ \rightarrow 2^+$ transition in the excited band is overestimated by PHF and IBA models. Sudden changes similar in experimental $B(E2)$ values are also noted in Kr isotopes, e.g., for $12^+ \rightarrow 10^+$ transition in ^{76}Kr and for $8^+ \rightarrow 6^+$ transition in ^{80}Kr. Perhaps such sudden changes in $B(E2)$ value would be due to the onset of backbending at corresponding high spin states. In PHF framework the use of a single intrinsic state as is done in present analysis, generally gives rise to a rather smooth variation for the $B(E2)$ values in yrast transitions. It would therefore be necessary to look for possible band crossing of the ground state band and the more deformed excited band in order to describe the finer details in the observed variation of $B(E2)$ values for yrast $E2$ transitions.

It is interesting to note that a major challenge to all theoretical models in the $(pf)g_{9/2}$ shell studies has been to simultaneously account for the electric quadrupole moments of first 2^+ states along with the $B(E2)$ values. The present PHF model, as well as the shell model and Hartree-Fock-Bogolubov models, give in general large quadrupole moments compared to experiment. In the present model this disagreement would suggest the need to include prolate-oblate shape mixing and it would be interesting to carry out band mixing calculations incorporating low-lying deformed HF states.

The authors are grateful to Prof. S. P. Pandya for taking keen interest in the present study and for going through the manuscript.

[1]J. H. Hamilton, R. L. Robinson, and A. V. Ramayya in *Proceedings of the International Conference on Nuclear Interactions, Canberra, 1976,* edited by B. A. Robson (Springer, New York, 1978), p. 253.

[2]M. Vergnes in *Proceedings of the Conference on the Structure of Medium-Heavy Nuclei, Rhodes, 1979,* edited by G. S. Anagnostatos, C. A. Kalfas, S. Kossionides, T. Paradellis, L. D. Skouras, and G. Vourvopoulos (Institute of Physics, Bristol, 1980), p. 25.

[3]R. Neuhausen, Habilitationsschrift, Institut fur Kernphysik, Universitat Mainz, KPH22/74, 1974.

[4]C. Morand, J. F. Bruandet, A. Giorni, and T. U. Chan, J. Phys. 38, 1319 (1977).

[5]C. Morand, J. F. Bruandet, B. Chambon, A. Dauchy, D. Drain, A. Giorni, and T. U. Chan, Nucl. Phys. A313, 45 (1979).

[6]A. C. Rester, J. H. Hamilton, and A. V. Ramayya, Nucl. Phys. A162, 481 (1971).

[7]K. R. Alvar and S. Raman, Nucl. Data Sheets, B8, 1 (1972).

[8]R. L. Robinson, H. J. Kim, R. O. Sayer, J. C. Wells Jr., R. M. Ronningen, and J. H. Hamilton, Phys. Rev. C 16, 2268 (1977).

[9]K. R. Alvar, Nucl. Data Sheets 11, 121 (1974).

[10]P. H. Stelson and L. Grodzins, Nucl. Data Sheets A1, 21 (1965).

[11]D. C. Kocher, Nucl. Data Sheets 17, 519 (1976).

[12]F. K. McGowan and P. H. Stelson, Phys. Rev. 126, 257 (1962).

[13]K. P. Lieb and J. J. Kolata, Phys. Rev. C 15, 939 (1977).

[14]K. E. G. Lobner, G. Dannhauser, D. J. Donahue, O. Hausser, R. L. Hershberger, R. Lutter, W. Klinger, and W. Witthuhn, Z. Phys. A 274, 251 (1975).

[15]J. H. Hamilton, H. L. Crowell, R. L. Robinson, A. V. Ramayya, W. E. Collins, R. M. Ronningen, V. M. Rezwani, J. A. Maruhn, N. C. Singhal, H. J. Kim, R. O. Sayer, T. Magee, and L. C. Whitlock, Phys. Rev. Lett. 36, 340 (1976).

[16]R. B. Piercey, A. V. Ramayya, R. M. Ronningen, J. H. Hamilton, V. M. Rezwani, R. L. Robinson, and H. J. Kim, Phys. Rev. C 19, 1344 (1979).

[17]J. Barrette, M. Barrette, G. Lamoureux, S. Monaro, and S. Marikza, Nucl. Phys. A235, 154 (1974).

[18]J. C. Wells Jr., R. L. Robinson, H. J. Kim, R. O. Sayer, R. B. Piercey, A. V. Ramayya, J. H. Hamilton, and C. F. Maguire, Phys. Rev. C 22, 1126 (1980).

[19]R. Lecomte, P. Paradis, J. Barrette, M. Barrette, G.

Lamoureux, and S. Monaro, Nucl. Phys. A284, 123 (1977).
[20]T. Paradellis and S. Hontzeas, Nucl. Phys. A142, 204 (1970)
[21]D. Rabenstein and H. Vonach, Z. Naturforsch. 3, 458 (1971).
[22]Z. Z. Zhao, X. J. Sun, R. B. Piercey, J. H. Hamilton, C. F. Maguire, A. V. Ramayya, R. L. Robinson, H. J. Kim, and J. Wells, in Proceedings of the International Conference on Nuclear Physics, Berkeley, California, 1980, edited by D. S. Saxon *et al.* (LBL Report No. LBL-11118), Vol. I, p. 310.
[23]H. P. Hellmeister, J. Keinonen, K. P. Lieb, U. Kaup, R. Rascher, R. Ballini, J. Delaunay, and H. Dumont, Nucl. Phys. A332, 241 (1979).
[24]N. Sakamoto, S. Matsuki, K. Ogino, Y. Kadota, T. Tanabe, and Y. Okuma, Phys. Lett. B83, 39 (1979).
[25]N. P. Heydenburg, G. F. Pieper, and C. E. Anderson, Phys. Rev. 108, 106 (1957).
[26]R. L. Robinson, H. J. Kim, R. O. Sayer, W. T. Milner, R. B. Piercey, J. H. Hamilton, A. V. Ramayya, J. C. Wells Jr., and A. J. Caffrey, Phys. Rev. C 21, 603 (1980).
[27]H. G. Friederichs, A. Gelberg, B. Heits, K. P. Lieb, M. Uhrmacher, K. O. Zell, and P. Von Brentano, Phys. Rev. Lett. 34, 745 (1975).
[28]R. L. Saxena, L. C. Jahnel, and F. C. Zawislak, Phys. Rev. C 21, 1531 (1980).
[29]B. K. Arora, D. K. Olsen, P. J. Rilley, and C. P. Browne, Phys. Rev. C 10, 2301 (1974).
[30]J. W. Lightbody Jr., Phys. Lett. 38B, 475 (1972).
[31]P. C. Zalm and P. J. Brussard, Z. Phys. A 287, 265 (1978).
[32]H. F. de Vries and P. J. Brussard, Z. Phys. A 286, 1 (1978).
[33]D. W. Grissmer, P. Beyer, R. P. Scharenberg, G. Schilling, J. A. Thomson, and J. W. Tippie, Nucl. Phys. A196, 216 (1972).
[34]A. Christy and O. Hausser, Nucl. Data Tables, 11, 281 (1972).
[35]R. Lecomte, M. Irshad, S. Landsberger, P. Paradis, and S. Monaro, Phys. Rev. C 22, 1530 (1980).
[36]R. Lecomte, S. Landsberger, P. Paradis, and S. Monaro, Phys. Rev. C 18, 2801 (1978).
[37]P. B. Vold, D. Cline, J. K. Sprinkle, and R. P. Scharenberg in Annual Report, Nuclear Structure Research Laboratory, The University of Rochester, Rochester, New York, 1979, p. 69.
[38]J. F. A. Van Hienen, W. Chung, and B. H. Wildenthal, Nucl. Phys. A269, 159 (1976).
[39]A. Gelberg and U. Kaup in *Interacting Bosons in Nuclear Physics,* edited by F. Iachello (Plenum, New York, 1979), p. 59.
[40]U. Kaup and A. Gelberg, Z. Phys. 293, 311 (1979).
[41]S. K. Sharma, Phys. Rev. C 22, 2612 (1980).
[42]M. Didong, H. Muther, K. Goeke, and A. Faessler, Phys. Rev. C 14, 1189 (1976).
[43]K. Kumar, J. Phys. G 4, 849 (1978).
[44]H. Holzwarth and S. G. Lie, Z. Phys. 249, 332 (1972).
[45]A. K. Dhar and K. H. Bhatt, Phys. Rev. C 16, 792 (1977).
[46]D. Ardouin, R. Tamisier, M. Vergnes, G. Rotband, J. Kalifa, G. Barrier, and G. Grammaticos, Phys. Rev. C 12, 1745 (1975).
[47]S. Fortier, Nucl. Phys. A321, 137 (1979).
[48]T. T. S. Kuo, private communication.
[49]C. S. Warke and M. R. Gunye, Phys. Rev. 159, 1084 (1967).
[50]G. Ripka, Adv. Nucl. Phys. 1, 183 (1968).
[51]D. P. Ahalpara, K. H. Bhatt, S. P. Pandya, and C. R. Praharaj, Nucl. Phys. A371, 210 (1981).
[52]M. R. Gunye, Phys. Lett. 37B, 125 (1971).
[53]R. F. Casten, Nucl. Phys. A347, 173 (1980).
[54]K. R. Alvar and S. Raman, Nucl. Data Sheets 8, 1 (1972).