Electromagnetic transitions in ^{49}Cr

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Deformed configuration mixing shell model calculations based on Hartree-Fock theory within the full $1f$-$2p$ shell space have been carried out for $^{49}_{24}Cr_{25}$ using modified Kuo-Brown effective interaction. The calculation gives rise to an excited $K = 1/2$ band in addition to the $K = 5/2$ ground state band. The spectrum of the latter is in excellent agreement with the experimental one. The calculated $B(E2)$, $B(M1)$ values, $(E2/M1)$ mixing ratios, branching ratios, and lifetimes compare reasonably well with the available observed values.

[NUCLEAR STRUCTURE ^{49}Cr; calculated spectrum, $B(E2)$, $B(M1)$, $(E2/M1)$ mixing ratios, branching intensities, lifetimes, predicted $K=\frac{1}{2}$ band, deformed configuration mixing shell model calculation based on projected Hartree-Fock theory in $(f$-$p)^n$ space, modified Kuo-Brown interaction, least squares fitted effective charges. Comparison with experiment and rotation-particle-coupling calculations.]

I. INTRODUCTION

The nucleus ^{49}Cr is the maximally quadrupole deformed odd-A nucleus in the $1f$-$2p$ shell space. The experimental data about this nucleus is given in Refs. 1–4. The $(f_{7/2})^9$ configuration model calculations for ^{49}Cr have been performed by Ginocchio.[5] The agreement of this calculation with the observed spectrum is not very good. The other calculations for this nucleus are of Malik and Scholz,[6] Zurmühle, Hutcheon, and Weaver,[4] and recently of Haas, Taras, and Styczen,[7] all based on rotation-particle-coupling (RPC) model calculations. Such calculations, however, are not microscopic and hence not very satisfactory.

In this paper we wish to describe the spectrum and the electromagnetic properties of the low-lying states of ^{49}Cr. We have performed deformed configuration mixing (DCM) calculations[8] based on projected Hartree-Fock (HF) theory for the study of this nucleus. Modified[9] Kuo-Brown effective interaction[10] labeled MWH2 and ^{41}Ca single particle energies have been employed in the calculations. Earlier, we have shown[8,11] that this interaction reproduces very well the structure of the low-lying states of nuclei in the f-p shell.

The calculations of the electric and magnetic properties of ^{49}Cr require the use of effective operators appropriate for the f-p shell space. In our calculations of the magnetic properties of ^{49}Cr we used the values of free g factors for the proton and neutron, while for the study of electric properties the proton and neutron effective charges $e_p = 1.32e$ and $e_n = 0.89e$ were employed. We obtained[12] these effective charges by a least squares fit between the observed and the calculated[13] $B(E2, 2 \to 0)$ transitions in even-even isotopes of Ti, Cr, and Fe. The best fit values are $e_p = (1.32 \pm 0.16)e$ and $e_n = (0.89 \pm 0.18)e$. These charges are quite close to the values $e_p = 1.21e$ and $e_n = 0.79e$ resulting from the macroscopic calculation[14] of Bohr and Mottelson, but are slightly large compared to the values $e_p = 1.25e$ and $e_n = 0.47e$ obtained recently by Kuo and Osnes[15] in a microscopic calculation. For the nucleus ^{49}Cr we have also computed $E2$ transitions by using the isoscalar effective charges $e_p = 1.5e$ and $e_n = 0.5e$. Some of the results of this calculation will also be presented. We have also compared the results of our calculations with those of the RPC calculations of Haas *et al.*[7] and Zurmühle *et al.*[4]

In Sec. II we shall describe the spectrum of ^{49}Cr as obtained in our DCM calculations. The discussion of the electromagnetic properties will be presented in Sec. III. A brief discussion follows in Sec. IV.

II. SPECTRUM

The spectrum of ^{49}Cr has been obtained by diagonalizing the Hamiltonian in the basis of orthonormalized states constructed from the nonorthogonal states of definite J projected from the lowest six intrinsic states including the prolate and oblate HF state of ^{49}Cr. It turns out that the states projected from the prolate $K=\frac{5}{2}$ HF intrinsic state and the $K=\frac{1}{2}$ 1p-1h excited intrinsic state mix very weakly with the other projected states. The other projected states are mixed considerably by the Hamiltonian. In Fig. 1 we have compared the calculated and observed spectrum of ^{49}Cr.

In the calculated spectrum the states drawn in thick lines are the members of the ground state

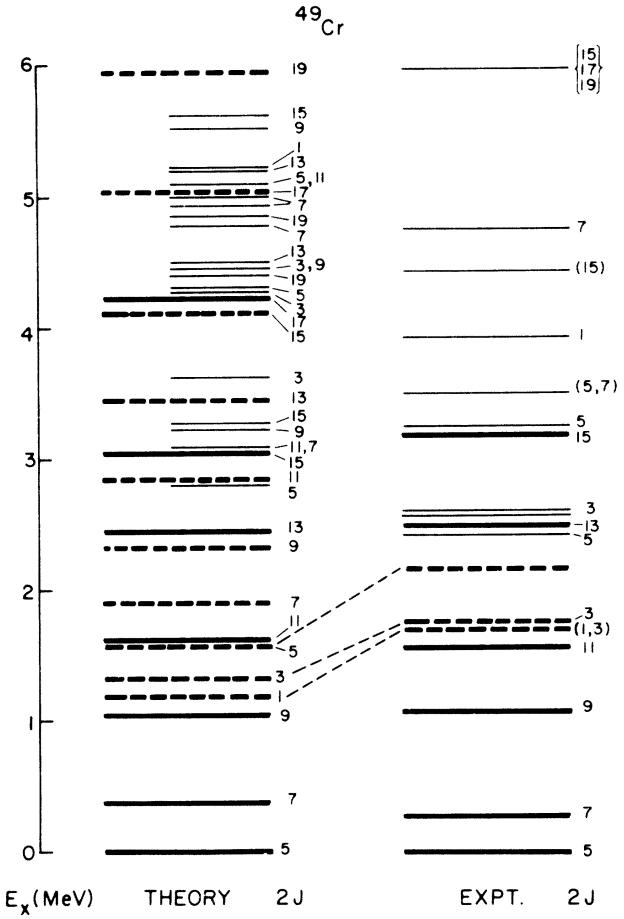

FIG. 1. Comparison of the calculated and experimental spectrum of ^{49}Cr. The states drawn in thick lines are the members of the ground state band; those in dotted lines, the members of the $K=\frac{1}{2}$ band. More complex states are drawn by thin half lines.

band. Except for the $J=\frac{15}{2}$ state at 3.05 MeV the average band mixing in the calculated ground state band up to the $J=\frac{17}{2}$ state at 4.23 MeV is only about 2%. For the $J=\frac{15}{2}$ and $\frac{19}{2}$ states at 3.05 and 4.40 MeV the intensity of the $J=\frac{15}{2}$ and $\frac{19}{2}$ states projected from the $K=\frac{5}{2}$ HF state is about 62 and 29%, respectively.

The states drawn in thick dotted lines in the calculated spectrum belong to the $K=\frac{1}{2}$ band. The band mixing due to Hamiltonian is extremely small for all the members of this band up to $J=\frac{19}{2}$. The other states drawn in thin lines have a complex structure with large band mixing.

The spectrum of the experimental ground state band observed by Sawa, Blomqvist, and Gullholmer[1] and Blasi *et al.*,[2] drawn in thick lines in Fig. 1, agrees very well with our calculated one. It is surprising that although Blasi *et al.*[2] have observed high-spin states up to about 6 MeV, they have not reported the $J=\frac{17}{2}$ member of the ground state band expected to occur at 4.23 MeV.

It is likely that the observed $J=\frac{1}{2}$ and $\frac{3}{2}$ states at 1.70 and 1.74 MeV, drawn in thick dotted lines, may correspond to the calculated $J=\frac{1}{2}$ and $\frac{3}{2}$ members of the $K=\frac{1}{2}$ band. The decay properties of the observed state at 2.17 MeV, which we shall soon discuss, suggest that this state may be the $J=\frac{5}{2}$ member of the $K=\frac{1}{2}$ band. It thus appears that the calculated $K=\frac{1}{2}$ band is shifted downwards by about 500 keV compared to the experiment.

There is no experimental information which allows us to identify in the observed spectrum the other members of the $K=\frac{1}{2}$ band. For the same reason it is not possible to suggest a correspondence between the remaining calculated and experimental states, except for the states observed[2] at 4.37 and 5.97 MeV with $J=\frac{15}{2}^-$ and $(\frac{15}{2}^-, \frac{17}{2}^-, \frac{19}{2}^-)$ as probable spin assignments.

A significant discrepancy between the experimental and calculated spectrum is that the calculated spectrum does not have a $J=\frac{3}{2}$ state corresponding to the observed $\frac{3}{2}$ state at 2.61 MeV. This discrepancy may be removed if the configuration space is enlarged to include about ten intrinsic states for each J. This expectation is supported by the fact that in ^{47}Ti a calculation[8] in the space of ten projected states for each J reproduces quite well the spectrum of the $J=\frac{1}{2}$ and $\frac{3}{2}$ states up to 6 MeV excitation.

The experimental[16] binding energy of ^{49}Cr relative to ^{40}Ca is -80.06 MeV. Assuming the $f_{7/2}$ single particle energy to be -8.36 MeV, the Coulomb corrected[17] calculated binding energy of ^{49}Cr is obtained to be -76.8 MeV. This is in reasonable agreement with the experiment.

We have also estimated[18] the contribution to the energy arising from 2p-2h excitations, *within* the f-p shell, to the lowest energy HF state of ^{49}Cr by performing the second order perturbation calculation. This contribution is found to be -2.1 MeV.

It is therefore expected that if the angular momentum projection were carried out from a 2p-2h correlated intrinsic state, the energy of the $J=\frac{5}{2}$ ground state might be lowered by about 2.1 MeV compared to the energy of the $J=\frac{5}{2}$ state obtained in the above calculation. This would therefore then result in a better agreement with the experiment. It is, however, likely that because of the very good agreement with the experimental binding energy at the HF calculation stage itself, the chosen effective interaction might lead to overbinding if exact shell model calculations for ^{49}Cr were performed.

III. ELECTROMAGNETIC PROPERTIES

We shall compare the results of our calculation on electromagnetic properties obtained by using a full band-mixed wave function (listed as the DCM result) with the available experimental data and also with those of the RPC calculations.

A. Ground state band

The experimental and theoretical information on the $B(E2)$, $B(M1)$, $(E2/M1)$ mixing ratio, branching ratio, and lifetimes for transitions within this band are summarized in Tables I to IV. In addition to our DCM results, we have also given for comparison the $B(E2)$ and $B(M1)$ values obtained with the wave functions projected from the $K=\frac{5}{2}$ state. These results are listed as PHF (projected Hartree-Fock) in the tables.

1. B(E2) values

These are listed in Table I. The observed values in column 3 are of Zurmühle *et al.*[4] The DCM values, in column 4, obtained with the effective charges $e_p=1.32e$ and $e_n=0.89e$, are a little larger than the observed values, which have large errors. On the other hand, the DCM values obtained by using $e_p=1.5e$ and $e_n=0.5e$ listed in column 6 appear to be in better agreement with the experimental values. The RPC-calculated $B(E2)$ values obtained by Haas *et al.*[7] are somewhat smaller than our values, while those of Zurmühle *et al.*[4] are quite similar to our values. It may, however, be mentioned that in these RPC calculations intrinsic states corresponding to deformation $\delta\simeq 0.24$ have been found to give optimum agreement for the observed spectrum and $B(E2)$ values. In contrast, our intrinsic states correspond to $\delta\simeq 0.15$.

2. B(M1) values

These are listed in Table II. The experimental values are given by Zurmühle *et al.*[4] The calculated $B(M1)$ values are large and therefore it is expected that the members of the ground state band of ^{49}Cr would decay preferentially by $M1$ mode. This is in agreement with the heavy-ion reaction measurements of Blasi *et al.*,[2] who found that all the γ rays emitted up to the 3.19 MeV $J=\frac{15}{2}$ state showed a $M1$ shape. The calculated $B(M1)$ value of $0.36\mu_N{}^2$ for the $\frac{7}{2}\rightarrow\frac{5}{2}$ transition is almost twice its observed value.[4] Otherwise the agree-

TABLE I. $B(E2, J_i \rightarrow J_f)$ values in (e^2 fm^4) for transitions from the state J_i to J_f of the ground state band in ^{49}Cr. Calculated results using deformed configuration mixed wave functions and the wave functions projected only from the HF state are listed under the columns labeled as DCM and PHF. The results of rotation-particle-coupling calculations are labeled as RPC.

J_i	J_f	Expt[a]	Present DCM[b]	Present PHF[b]	RPC DCM[c]	RPC Hass *et al.*[d]	RPC Zurmühle *et al.*[a]
$\frac{7}{2}$	$\frac{5}{2}$	302 ± 79	432	462	354	290	377
$\frac{9}{2}$	$\frac{5}{2}$	160	124	128	103	86	129
	$\frac{7}{2}$	310^{+260}_{-110}	349	384	289	251	379
$\frac{11}{2}$	$\frac{7}{2}$	133^{+66}_{-44}	207	214	172	150	185
	$\frac{9}{2}$	505^{+620}_{-230}	251	291	204	189	293
$\frac{13}{2}$	$\frac{9}{2}$		254	265	210	191	
	$\frac{11}{2}$		182	218	149	145	
$\frac{15}{2}$	$\frac{11}{2}$		204	295	170	243	
	$\frac{13}{2}$		81	169	63	108	
$\frac{17}{2}$	$\frac{13}{2}$		305	309	249	241	
	$\frac{15}{2}$		63	129	50	86	
$\frac{19}{2}$	$\frac{15}{2}$		92	317	78		
	$\frac{17}{2}$		18	105	14		

[a] Reference 4.
[b] Effective charges $e_p=1.32e$, $e_n=0.89e$.
[c] Effective charges $e_p=1.5e$, $e_n=0.5e$.
[d] Reference 7.

TABLE II. $B(M1, J_i \rightarrow J_f)$ values in μ_N^2 for transitions from the state J_i to J_f of the ground state band in ^{49}Cr. For other details see caption for Table I.

J_i	J_f	Expt [a]	DCM	PHF	RPC Hass *et al.* [b]	RPC Zurmühle *et al.* [a]
$\frac{7}{2}$	$\frac{5}{2}$	0.15 ± 0.04	0.36	0.40	0.15	0.06
$\frac{9}{2}$	$\frac{7}{2}$	$0.40^{+0.20}_{-0.10}$	0.59	0.58	0.24	0.18
$\frac{11}{2}$	$\frac{9}{2}$	0.57 ± 0.20	0.70	0.69	0.38	0.34
$\frac{13}{2}$	$\frac{11}{2}$		0.72	0.72	0.34	
$\frac{15}{2}$	$\frac{13}{2}$		0.74	0.80	0.54	
$\frac{17}{2}$	$\frac{15}{2}$		0.35	0.74	0.36	
$\frac{19}{2}$	$\frac{17}{2}$		0.43	0.86		

[a] Reference 4.
[b] Reference 7.

ment between our DCM results and the experiment is good.

3. *(E2/M1) mixing ratios*

These are given in Table III. The observed values are of Sawa *et al.*[1] and of Zurmühle *et al.*[4] The agreement between the DCM calculated and observed values is, on the whole, good. That the mixing ratios for all the transitions is less than +0.20 is also supported by the observations of Blasi *et al.*[2] The calculated value of +0.07 in comparison to the observed value of $+0.14 \pm 0.02$ for the $\frac{7}{2} \rightarrow \frac{5}{2}$ transition is because our calculated $B(M1)$ value for this transition is about twice the observed $B(M1)$ value. For the $\frac{13}{2} \rightarrow \frac{11}{2}$ transition the experimental value is smaller than the calculated value.

TABLE III. $(E2/M1)$ mixing ratios (σ) for the transitions between the members of the ground state band in ^{49}Cr.

J_i	J_f	Expt [a]	$(E2/M1)$ DCM	RPC [b]
$\frac{7}{2}$	$\frac{5}{2}$	$+0.14 \pm 0.02$	+0.08	+0.10
$\frac{9}{2}$	$\frac{7}{2}$	$+0.21 \pm 0.03$ $+0.19 \pm 0.04$ [c]	+0.17	+0.22
$\frac{11}{2}$	$\frac{9}{2}$	$+0.05 \pm 0.03$ $+0.12 \pm 0.03$ [c]	+0.08	+0.09
$\frac{13}{2}$	$\frac{11}{2}$	$+0.03 \pm 0.04$	+0.12	+0.16
$\frac{15}{2}$	$\frac{13}{2}$		+0.06	+0.08
$\frac{17}{2}$ [d]	$\frac{15}{2}$		+0.12	
$\frac{19}{2}$ [d]	$\frac{17}{2}$		+0.01	

[a] Reference 2.
[b] Reference 7.
[c] Reference 4.
[d] Theoretical excitation energy.

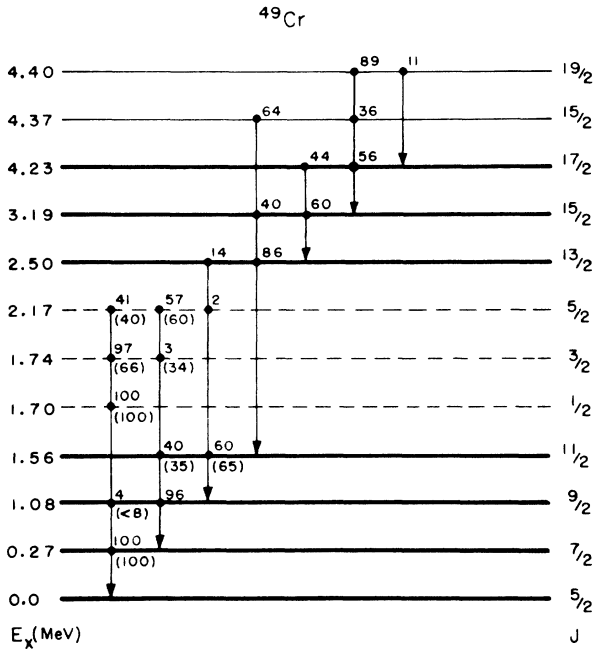

FIG. 2. Branching intensities in ^{49}Cr. The states drawn in thick lines belong to the ground state band. Those shown by dotted lines are the possible low-lying members of the $K = \frac{1}{2}$ excited band that is predicted by our calculations. The vertical lines indicate the transitions originating from the state with a filled circle to the state where the arrow ends. The numbers on top of these states are the corresponding calculated decay intensities. Those below in parentheses are the experimental values.

4. *Branching ratio*

In Fig. 2 are compared the experimental[3,4] and calculated branching ratios for the low-lying states of ^{49}Cr. The DCM-calculated branching ratios are given on top of the level from which the transition are considered. The corresponding experimental ratios are given in parentheses below the level. Of interest here are the branching ratios for transitions between the members of the ground state band drawn in thick lines in Fig. 2. The observed branching ratios for some of these transitions are measured by Blumenthal, Zurmühle, and Balamuth.[3]

The agreement between the calculated and observed branching ratios for the decays up to $J = \frac{11}{2}$ at 1.56 MeV is very good. It is seen that the dominant decay mode of all the members of the ground state band is of $M1$ character. This is in qualitative concurrence with the measurements of Blasi

et al.[2] The branching ratios obtained by the RPC calculations[7] are similar to ours.

5. *Mean lifetimes*

The lifetimes of some of the transitions between the low-lying states of ^{49}Cr have been measured by Zurmühle *et al.*[4] In Table IV are compared our DCM-calculated mean lifetimes with the observed and RPC results. For the $\frac{7}{2}\rightarrow\frac{5}{2}$ transition our calculated value is very small compared to the RPC or experimental value. This is because our $B(M1)$ value for this transition is larger than the observed $B(M1)$ value.

6. *Static moments*

In Table V are given the static electric quadrupole and magnetic dipole moments of the first three states of ^{49}Cr. Experimental measurements of the quadrupole moments are not yet available.

The magnitude of the ground state magnetic moment is measured by Sanner *et al.*[19] and Jonsson, Sanner, and Wannberg[20] using atomic beam resonance technique. Our calculated value is in very good agreement with the observed value. RPC model results of Haas *et al.*[7] and Zurmühle *et al.*[4] give a considerably larger value. It would be interesting to measure the sign of the ground state magnetic moment and its quadrupole moment. For the $J=\frac{7}{2}$ state at 0.27 MeV, our calculation predicts a positive magnetic moment of $0.45\mu_N$. This is in contrast to the predictions of RPC model calculations.[7]

B. Excited $K=\frac{1}{2}$ band

In Fig. 3 we present the results of our DCM calculations of the $B(E2)$ and $B(M1)$ values for the transitions between the members of the $K=\frac{1}{2}$ band.

TABLE IV. Lifetime (τ) of some of the transitions in the ground state behind in ^{49}Cr.

J	τ (ps) Expt[a]	DCM	RPC[b]
$\frac{7}{2}$	19 ± 5[c]	8	19
$\frac{9}{2}$	0.26 ± 0.09	0.17	0.40
$\frac{11}{2}$	$0.59^{+0.30}_{-0.12}$	0.44	0.72
$\frac{13}{2}$		0.08	0.16
$\frac{15}{2}$		0.14	0.16
$\frac{17}{2}$[d]		0.08	0.03

[a] Reference 2.
[b] Reference 7.
[c] See also Reference 4.
[d] Theoretical excitation energy.

TABLE V. Electric quadrupole and magnetic dipole moments of the first few states of ^{49}Cr.

J	E_J (MeV)	Q (e fm^2) DCM	RPC[a]	Expt[b]	μ (μ_N) DCM	RPC[a]
$\frac{5}{2}$	0.0	39.3	32	$\pm0.48\pm0.01$	−0.52	−1.22[c]
$\frac{7}{2}$	0.27	7.7	5.6		0.45	−0.92
$\frac{9}{2}$	1.08	−10.4			1.51	

[a] Reference 7.
[b] References 19, 20.
[c] See also Reference 4.

The band splits into two bands: one with spins $J=\frac{1}{2}$, $\frac{5}{2}$, $\frac{9}{2}$, $\frac{13}{2}$, and $\frac{17}{2}$ and the other with $J=\frac{3}{2}$, $\frac{7}{2}$, $\frac{11}{2}$, $\frac{15}{2}$, and $\frac{19}{2}$. The $B(E2)$ values for transitions between the members of these subbands are large and have roughly the same value except the $B(E2)$ for the $\frac{5}{2}\rightarrow\frac{1}{2}$ transition. The $E2$ as well as $M1$ transitions between these two subbands are weak.

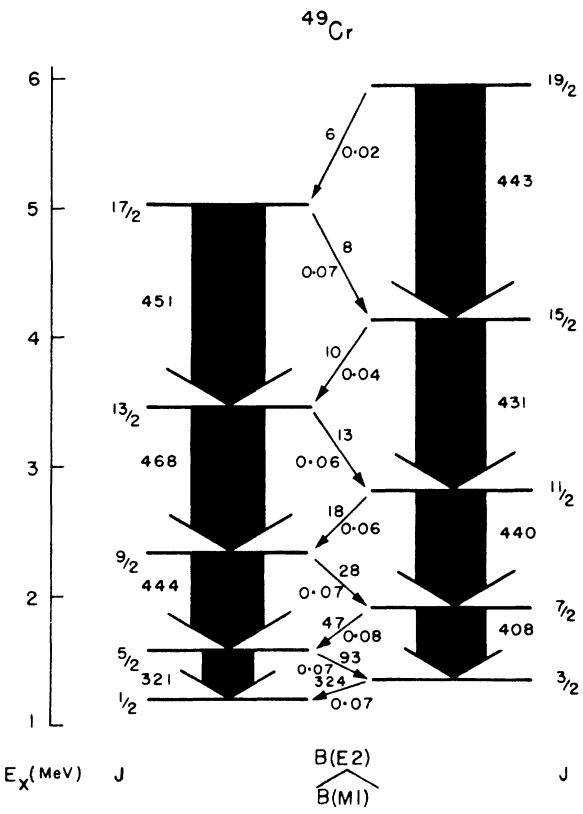

FIG. 3. Spectrum and transitions within the $K=\frac{1}{2}$ band in ^{49}Cr. This band is split into two subbands on the basis of pure $E2$ transitions. The magnitude of $B(E2)$ values (in e^2 fm^4) obtained in the DCM calculations are given alongside of the thick arrows. The $B(E2)$ and $B(M1)$ (in μ_N^2) values for the transitions between these subbands are given above and below the thin arrows, respectively.

Here the $B(M1)$ values are approximately the same for all the transitions except for the $\frac{19}{2} \rightarrow \frac{17}{2}$ and the $\frac{15}{2} \rightarrow \frac{13}{2}$ transitions. Another significant exception is the large $B(E2)$ value of 324 e^2 fm^4 for the $\frac{3}{2} \rightarrow \frac{1}{2}$ transition.

Unfortunately, no experimental information on these transitions is yet available. It is not possible, therefore, to identify the members of this band on the basis of their intraband transitions.

C. Interband transitions

In this section we attempt to identify in the experimental spectra the states belonging to the $K = \frac{1}{2}$ band on the basis of their decay properties to the members of the ground state band. According to our calculations these decays should be highly hindered. In Table VI we have listed the $B(E2)$ and $B(M1)$ values for transitions from the $J = \frac{1}{2}-\frac{9}{2}$ states of the $K = \frac{1}{2}$ band to the $J = \frac{5}{2}-\frac{11}{2}$ states of the $K = \frac{5}{2}$ ground state band.

Zurmühle *et al.*[4] have found that the 1.70, 1.74, and 2.17 MeV levels (indicated by dotted line in Fig. 1) decay weakly to the $\frac{5}{2}$ and $\frac{7}{2}$ members of the ground state band, which we now discuss. The decay properties of these states are similar to those of the calculated $J = \frac{1}{2}$, $\frac{3}{2}$, and $\frac{5}{2}$ members of the $K = \frac{1}{2}$ band.

The 1.70 MeV state decays only to the $J = \frac{5}{2}$ ground state. If a $J = \frac{1}{2}$ assignment is assumed for this level, Zurmühle *et al.*[4] find that $B(E2)$ value is less than 0.95 Weisskopf units (W.u.). Our calculated $B(E2)$ value for the transition from the $J = \frac{1}{2}$ state of the $K = \frac{1}{2}$ band to the $J = \frac{5}{2}$ ground state is 0.2 W.u.

The $J = \frac{3}{2}$ state at 1.74 MeV decays both to the $J = \frac{5}{2}$ and $\frac{7}{2}$ members of the ground state band with 66 : 34 branching. Zurmühle *et al.*[4] have observed a retardation of about 10^{-4} or 10^{-5} in the $B(M1)$ values for the $\frac{3}{2} \rightarrow \frac{5}{2}$ ground state transition. Similarly, in case of the $B(E2)$ value the retardation of either about 7×10^{-4} or about 0.75 W.u. is observed. The calculated $B(M1)$ and $B(E2)$ values for the corresponding decays of the $J = \frac{3}{2}$ member of the $K = \frac{1}{2}$ band are about 10^{-3} and 0.08 W.u.

It may, however, be pointed out that in contrast to the observed[4] branching ratios from the $J = \frac{3}{2}$ state at 1.742 MeV, our calculated $J = \frac{3}{2}$ state, at that energy, decays with a 97% branch to the $J = \frac{5}{2}$ ground state. This discrepancy is, however, not serious since the $B(M1)$ and $B(E2)$ values are extremely hindered and such hindered transitions would not be reproduced very accurately by our calculations. In order to reproduce the observed 66 and 34% branches of the $J = \frac{3}{2}$ level the calculated $B(M1)$ value for the $\frac{3}{2} \rightarrow \frac{5}{2}$ transition should be $0.0001\mu_N{}^2$ compared to our value of $0.0041\mu_N{}^2$. The mean lifetime of the calculated $J = \frac{3}{2}$ state is obtained to be 2.5 ps. This compares well with the observed lifetime of about 4 ps.

Zurmühle *et al.*[4] have observed a state of unassigned spin at 2.17 MeV. This state is observed to decay with a 40 and 60% branch to the ground and first excited state of ^{49}Cr. The mean lifetime of this state is measured to be about 4.5 ps. The *only* calculated state that fits well with the decay modes of the 2.17 MeV is the $J = \frac{5}{2}$ member of the $K = \frac{1}{2}$ band. As shown in Fig. 2, this state at that energy decays with 41 and 57% branches in excellent agreement with the experiment. The calculated mean lifetime of this state is 1.1 ps. We therefore suggest that the 2.17 MeV observed level has $J = \frac{5}{2}$ and is the third member of the $K = \frac{1}{2}$ band.

It appears from these considerations that the observed states at 1.70, 1.74, and 2.17 MeV may be the $J = \frac{1}{2}$, $\frac{3}{2}$, and $\frac{5}{2}$ members of the $K = \frac{1}{2}$ band. As shown in Fig. 1, the calculated band is shifted downwards by about 500 keV compared to the observed band. Such relative shifts between the calculated and observed excited bands also occur[21] in the s-d shell.

The other members of the $K = \frac{1}{2}$ band do not yet have the experimental counterparts. It would be interesting to undertake an experimental investigation of this band of states built on the $K = \frac{1}{2}$ intrinsic state.

TABLE VI. Calculated $B(E2)$ and $B(M1)$ values for transitions between some of the members of the $K = \frac{1}{2}$ band and the ground state band of ^{49}Cr. For members of the $K = \frac{1}{2}$ band the calculated energies (E^{cal}), while for the ground band members the experimental energies (E^{expt}), are given.

E_i^{cal} (MeV)	E_f^{cal} (MeV)	J_i	J_f	$B(E2)$ (e^2 fm^4)	$B(M1)$ ($\mu_N{}^2$)
1.20	0.0	$\frac{1}{2}$	$\frac{5}{2}$	2.55	
1.34	0.0	$\frac{3}{2}$	$\frac{5}{2}$	0.88	0.0041
	0.27		$\frac{7}{2}$	1.53	
1.58	0.0	$\frac{5}{2}$	$\frac{5}{2}$	0.24	0.002
	0.27		$\frac{7}{2}$	1.20	0.004
	1.08		$\frac{9}{2}$	1.02	
1.90	0.0	$\frac{7}{2}$	$\frac{5}{2}$	0.01	0.000 006
	0.27		$\frac{7}{2}$	0.21	0.0066
	1.08		$\frac{9}{2}$	1.02	0.0093
2.33	0.27	$\frac{9}{2}$	$\frac{7}{2}$	0.17	0.001
	1.08		$\frac{9}{2}$	0.78	0.0069
	1.56		$\frac{11}{2}$	0.84	0.0083

D. Other states

Among the low-lying states of ^{49}Cr observed up to about 3 MeV (see Fig. 1) excitation, we have thus far discussed all the states except the ones observed[4] at 2.433 MeV with $J=\frac{5}{2}^-$, 2.504 MeV of unassigned spin and 2.614 MeV with $J=\frac{3}{2}^-$. Zurmühle *et al.*[4] have studied the decay properties of these states. Among the higher states, Blasi *et al.*[2] have observed γ decay from the levels at 4.367 MeV with tentative spin assignment $(\frac{15}{2}^-)$ and from the 5.966 MeV level with probable spin assignment $(\frac{15}{2}^-, \frac{17}{2}^-, \frac{19}{2}^-)$.

We attempted to identify in the calculated spectrum the states that have decay properties similar to the above observed states.

2.433 MeV level. Zurmühle *et al.*[4] have assigned $J=\frac{5}{2}$ for this level with an observed lifetime >4 ps. This state has branching values 43 : 17 : 40 for the decays to $J=\frac{5}{2}^-$ ground state, to $J=\frac{7}{2}^-$ at 0.272 MeV, and to $J=\frac{3}{2}^+$ at 1.982 MeV. Thus the decay intensities for transitions from this state to the negative parity states are in the ratio 2 : 5 : 1. It is tempting to associate the calculated $J=\frac{5}{2}$ state at 2.79 MeV with this observed level. A difficulty of this association is that the calculated state decays with 25 : 75 percent branches to the ground and first excited states of ^{49}Cr, with a lifetime of 31 fs.

2.504 MeV level. No spin assignment has been made for this level. A lifetime of less than 12 fs is measured.[4] This level has 80 : 20 percent branches to the ground and first excited states. The calculated $J=\frac{7}{2}$ state at 3.07 MeV has the corresponding branching ratios of 86 : 4 and a lifetime of 39 fs. In fact, this is the only state which provides a reasonable agreement with the decay properties of the observed 2.504 MeV level. Hence, we suggest a $J=\frac{7}{2}$ assignment to the 2.504 MeV observed level.

2.614 MeV level. This level is assigned[4] $J=\frac{3}{2}^-$. We do not have a corresponding $J=\frac{3}{2}^-$ state about 2.6 MeV in our calculated spectrum.

4.367 MeV level. This level with a tentative $J=(\frac{15}{2}^-)$ is observed by Blasi *et al.*[2] in the heavy-ion reaction measurements and is found to decay to $J=\frac{15}{2}^-$ and $\frac{13}{2}^-$ members of the ground state band. The latter decay is weak. The 4.367 MeV $\rightarrow J=\frac{15}{2}$ at 3.19 MeV transition is observed to have a large quadrupole component. Mean lifetime greater than 0.6 ps is measured for this level and on this basis Blasi *et al.*[2] suggest that the 4.367 MeV level is not a member of the ground state band.

In the calculated spectrum (Fig. 1) we have high-spin states with $J=\frac{15}{2}$, $\frac{17}{2}$, and $\frac{19}{2}$ within 4 to 5 MeV relative excitation energy. The $J=\frac{19}{2}$ assignment to the 4.367 MeV level is ruled out by the observed 4.367 MeV $\rightarrow J=\frac{13}{2}$ state decay. The $J=\frac{15}{2}$ state at 4.13 MeV, shown by dotted line, is the member of the $K=\frac{1}{2}$ band. It decays with a 75% branch to the $J=\frac{11}{2}$ state of the $K=\frac{1}{2}$ band with a mean lifetime of 0.15 ps. This is inconsistent with the observed decay pattern of the level under study. The 4.23 MeV $J=\frac{17}{2}$ state of the ground state band, drawn with a thick line, decays with 56 and 44% branches to the $J=\frac{15}{2}$ and $\frac{13}{2}$ members of the ground state band. The corresponding mean lifetime is 0.08 ps. Thus, although the branching ratios of the $J=\frac{17}{2}$ state calculated at 4.23 MeV are similar to that of the 4.367 MeV level, the lifetimes do not agree. It is thus not possible to associate the calculated $J=\frac{15}{2}$ or $\frac{17}{2}$ state uniquely with this observed $(\frac{15}{2}^-)$ state.

IV. DISCUSSION

The present deformed configuration mixing calculation provides an adequate description of the electromagnetic properties of the low-lying states of ^{49}Cr. It was hoped that the $E2$ transitions in this nucleus would show a preference for the effective charges $e_p=1.32e$ and $e_n=0.89e$ which give the best fit to the $B(E2;\ 2\rightarrow 0)$ values for a number of even-even f-p shell nuclei. This was indeed found[22] for ^{47}Ti, but for ^{49}Cr the charges $e_p=1.5e$ and $e_n=0.5e$ seem to give a slightly better fit to the experimental $B(E2)$ values. However, the experimental errors are somewhat larger in ^{49}Cr than in ^{47}Ti.

The effective interaction employed in the present calculation reproduces very well the spectrum of ^{49}Cr, but it gives rise to the excited $K=\frac{1}{2}$ band which is lower in energy than the experimental one by about 500 keV. In this band of states the odd neutron occupies the $k=\frac{1}{2}$ orbit having large admixtures of the $j=p_{3/2}$, $p_{1/2}$, and $f_{5/2}$ states. Hence, a reason for the above discrepancy may lie in the overbinding[23] of a $p_{3/2}$, $p_{1/2}$, and $f_{5/2}$ nucleon by the $f_{7/2}$ nucleons. As a matter of fact, the effective interaction employed in the present calculation, while giving a closed shell structure of ^{56}Ni, does not satisfactorily reproduce[24] the single particle and single hole energies of ^{57}Ni and ^{55}Ni. In particular, the $f_{5/2}$ state comes lower than the $p_{3/2}$ state. Hence the presently used interaction would need some modifications to properly describe the spectroscopic properties of nuclei with $A\gtrsim 50$.

The systematics of the observed[1,25,26] relative separation between the $K=\frac{7}{2}$ and $K=\frac{1}{2}$ bands in the nuclei with $N=27$ and 29, such as ^{51,53}Cr and ^{53}Fe, might help to determine the modification necessary in the interaction.

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