PHYSICAL REVIEW C VOLUME 36, NUMBER 6 DECEMBER 1987

Coexistence and $B(E2)$'s in even Ge nuclei

H. T. Fortune and M. Carchidi*
Physics Department, Univeristy of Pennsylvania, Philadelphia, Pennsylvania 19104
(Received 3 August 1987)

Values of $B(E2)$ strengths connecting low-lying 0^+ and 2^+ states in ^{70,72,74,76}Ge are examined in the context of an earlier coexistence model previously applied to two-neutron transfer.

I. INTRODUCTION

Evidence is overwhelming[1–3] that some sort of structural change takes place between the light ($A \leq 70$) and heavy ($A \geq 74$) Ge nuclei. The effect is observed as an irregularity in the A dependence of several different observables: (i) absolute ground state (g.s.) (t,p) cross sections (Refs. 4–6), (ii) ratios[2] of excited 0^+ to g.s. cross sections, (iii) excitation energy of the first excited 0^+ state, (iv) proton occupancies (Refs. 7 and 8), (v) $B(E2)$'s connecting low-lying 2^+ and 0^+ states (Refs. 9–12), (vi) their ratios, (vii) alpha-transfer ratios (Refs. 13–15), and (viii) inelastic scattering (Refs. 16 and 17).

Several different explanations have been given for this transition, including shape coexistence, neutron particle-hole (ph) excitation, and proton ph excitation. It does appear[2,3] that the structure of the ground states of the heavier Ge nuclei is contained in excited 0^+ states in the light Ge's and vice versa. As of this date, there are three surviving candidates for a simple explanation: (i) vibrational-rotational mixing, (ii) proton 2p-2h mixing,[18] and (iii) coexistence in a generalized basis.[3] These are not necessarily conflicting ideas, but they are certainly not equivalent.

In (i), the light Ge's are vibrational, the heavy ones rotational. A natural extension is that the states of the other type exist at quite low excitation energy (shape coexistence). In perhaps the best of the inelastic-scattering studies,[16] "within the framework of coupled-channels calculations, inelastic data can be reproduced only by assuming ^{70,72}Ge are vibrational and that ^{74,76}Ge are rotational." The concept[18] involving proton 2p-2h excitations was suggested primarily to explain the jump[7] in ground state $0f_{5/2}$ proton occupancies between ^{72}Ge and ^{74}Ge. It also quite naturally *qualitatively* explains the jump[4–6] in absolute g.s. (t,p) cross sections, and the peaking in (t,p) and (p,t) 0_2^+/g.s. cross-section ratios for 72↔74. And, of course, it is not surprising that rotational states in an otherwise vibrational spectrum should contain excitations from the proton core.

However, much of the success of the proton coexistence idea[18] depends only on the "smoothness' assumption[3]—i.e., that the unmixed basis states behave smoothly with A—rather than on the details of their structure. Also, the proton coexistence picture is not *quantitatively* correct in the details, but only gets the general trends. In fact, several observables are inconsistent with the basic assumptions of that model.

These considerations have led to a description[3] in terms of two-state mixing between generalized basis states. With as few assumptions as possible (and all of a smoothness variety) it has been possible[3,8,15] to parametrize existing one-, two-, and four-particle transfer data[2,7,13,14,19–22] in terms of the one independent parameter that describes the generalized basis. We now address, in that model, the $E2$ strengths between low-lying 2^+ and 0^+ states.

II. THE EXPERIMENTAL $B(E2)$ DATA IN THE Ge ISOTOPES

Existing information[10–12,23–25] on $E2$ strengths connecting low-lying 2^+ states to the g.s. and first-excited 0^+ states in $^{68-76}$Ge is listed in Table I. Various com-

TABLE I. Experimental $E2$ strengths in even Ge nuclei.[a] ($|M(E2)| = [(2J_i+1)B(E2;J_i^\pi \to J_f^\pi)]^{1/2}$.)

Nucleus	$J_i^\pi \to J_f^\pi$	$B(E2)$ (10^{-2} e^{-2} e^2b^2)	$\vert M(E2)\vert$ (e b)
^{68}Ge	$2_1^+ \to$ g.s.	2.80 ±0.42[b]	0.374±0.028
^{70}Ge	$2_1^+ \to$ g.s.	3.57 ±0.06	0.422±0.004
	$0_2^+ \to 2_1^+$	6.0 ±1.5	0.245±0.031
	$2_2^+ \to$ g.s.	0.026 ±0.020	0.036±0.014
	$2_2^+ \to 0_2^+$	2.51 ±1.1 W.u.[c]	0.146±0.032
			0.134±0.058[d]
^{72}Ge[e]	$2_1^+ \to$ g.s.	4.14 ±0.10	$0.455^{+0.009}_{-0.006}$
	$2_1^+ \to 0_2^+$	2.59 ±0.58	0.36 ±0.04
	$2_2^+ \to$ g.s.	0.018 ±0.004	$0.030^{+0.003}_{-0.005}$
	$2_2^+ \to 0_2^+$	0.0072±0.0008	$0.019^{+0.004}_{-0.005}$
^{74}Ge	$2_1^+ \to$ g.s.	6.09 ±0.06	0.552±0.003
	$0_2^+ \to 2_1^+$	<4.0	<0.20
	$2_2^+ \to$ g.s.	0.13 ±0.05	0.081±0.016
	$2_2^+ \to 0_2^+$		
^{76}Ge	$2_1^+ \to$ g.s.	5.56 ±0.06	0.527±0.003
	$0_2^+ \to 2_1^+$	<1.7	<0.13
	$2_2^+ \to$ g.s.	0.17 ±0.03	0.092±0.008
	$2_2^+ \to 0_2^+$		

[a]Reference 10 unless otherwise noted.
[b]Reference 24.
[c]Reference 11.
[d]Reference 23.
[e]Reference 12.

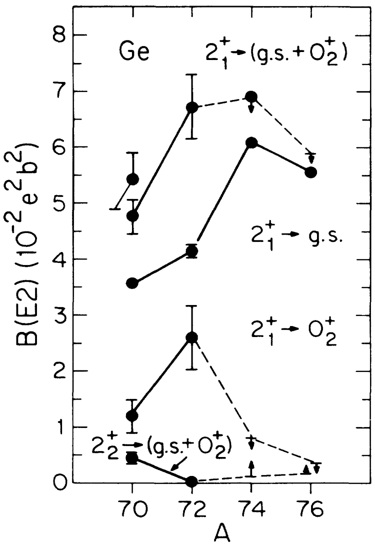

FIG. 1. Absolute $B(E2)$'s connecting low-lying 0^+ and 2^+ states in $^{70-76}$Ge.

binations of these data are plotted versus mass number A in Figs. 1–3. First, in Fig. 1, it can be seen that the A dependence of the $2_1^+ \to$g.s. $B(E2)$'s is very similar to the A dependence observed previously[7] for the g.s. $0f_{5/2}$ proton occupancies. Further, the $E2$ value between 2_1^+ and 0_2^+ sharply peaks at ^{72}Ge. [Actually, this $B(E2)$ value is not known in ^{74,76}Ge, but stringent limits exist.] Figure 2 shows the plot of the ratio of these two $B(E2)$'s versus A as well as the ratio for the two 2^+ states decaying to the ground state. In a vibrational nucleus, we expect $B(E2;0_2^+ \to 2_1^+) = 2B(E2;\, 2_1^+ \to \text{g.s.})$, giving 0.4 for the ratio plotted here. We note that the values for ^{70,72}Ge are roughly consistent with the vibrational expectation, but those for ^{74,76}Ge are not even close. In all

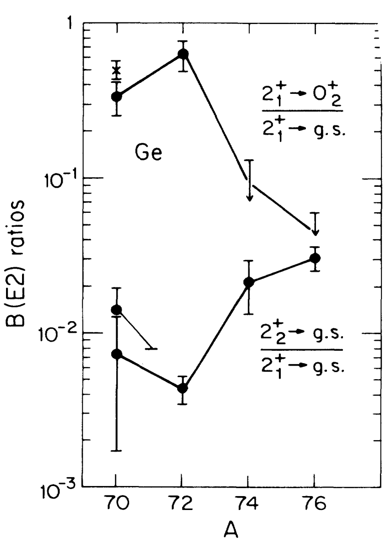

FIG. 2. $E2$ ratios vs A for 2_1^+ to both 0^+ states (top) and both 2^+ states to ground state (bottom).

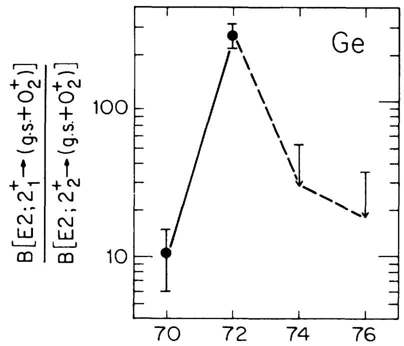

FIG. 3. $E2$ ratio vs A for the first two 2^+ states to summed strength to both 0^+ states.

four nuclei, 2_2^+ is barely connected to the ground state—though this $B(E2)$ is about a factor of 10 larger in ^{74,76}Ge than in ^{70,72}Ge.

III. MODEL ANALYSIS OF THE ELECTROMAGNETIC DATA

A. Without mixing in the 2^+ states

Figure 3 contains the ratio of summed (g.s. and 0_2^+) $B(E2)$'s for the first two 2^+ states. In a two-state model for the 0^+ states, these quantities are independent of the 0^+ mixing. Specifically, if (as in Ref. 3) one lets

$$\Psi^A(\text{g.s.}) = \alpha_A \phi_{g0}^A + \beta_A \phi_{e0}^A$$

and (1)

$$\Psi^A(0_2^+) = \beta_A \phi_{g0}^A - \alpha_A \phi_{e0}^A$$

represent the physical ground state and 0_2^+ state in ^{A}Ge (with ϕ_{g0}^A and ϕ_{e0}^A denoting the 0^+ basis states), then the square of the $E2$ amplitude $M^2(E2;\, J_i^\pi \to J_f^\pi)$, satisfying

$$M^2(E2;J_i^\pi \to J_f^\pi) = (2J_i+1)B(E2;J_i^\pi \to J_f^\pi)$$

becomes

$$M_A^2(E2;2_1^+ \to \text{g.s.}) = \langle \Psi^a(2_1^+) \,|\, E2 \,|\, \alpha_A \phi_{g0}^A + \beta_A \phi_{e0}^A \rangle^2 = (\alpha_A U_{gA} + \beta_A V_{eA})^2 \quad (2a)$$

$$M_A^2(E2;2_1^+ \to 0_2^+) = \langle \Psi^A(2_1^+) \,|\, E2 \,|\, \beta_A \phi_{g0}^A - \alpha_A \phi_{e0}^A \rangle^2 = (\beta_A U_{gA} - \alpha_A V_{eA})^2 \quad (2b)$$

$$M_A^2(E2;2_2^+ \to \text{g.s.}) = \langle \Psi^A(2_2^+) \,|\, E2 \,|\, \alpha_A \phi_{g0}^A + \beta_A \phi_{e0}^A \rangle^2 = (\alpha_A V_{gA} + \beta_A U_{eA})^2 \quad (2c)$$

$$M_A^2(E2;2_2^+ \to 0_2^+) = \langle \Psi^A(2_2^+) \,|\, E2 \,|\, \beta_A \phi_{g0}^A - \alpha_A \phi_{e0}^A \rangle^2 = (\beta_A V_{gA} - \alpha_A U_{eA})^2 \,, \quad (2d)$$

so that

$$M_A^2(E2;2_1^+ \to \text{g.s.}) + M_A^2(E2;2_1^+ \to 0_2^+) = U_{gA}^2 + V_{eA}^2$$

and (3)

$$M_A^2(E2;2_2^+ \to \text{g.s.}) + M_A^2(E2;2_2^+ \to 0_2^+) = V_{gA}^2 + U_{eA}^2 \,,$$

where

$$U_{gA} = \langle \Psi^A(2_1^+) | E2 | \phi_{g0}^A \rangle, \quad V_{eA} = \langle \Psi^A(2_1^+) | E2 | \phi_{e0}^A \rangle ,$$

$$V_{gA} = \langle \Psi^A(2_2^+) | E2 | \phi_{g0}^A \rangle, \quad U_{eA} = \langle \Psi^A(2_2^+) | E2 | \phi_{e0}^A \rangle .$$

As can be seen from Fig. 3, the peaking of the summed data at ^{72}Ge is dramatic. In this nucleus, the second 2^+ state has extremely weak $E2$'s to both 0^+ states. Is this an accidental cancellation, or something more profound? We return to this point later. As mentioned, the ground state and 0_2^+ wave function is represented by Eq. (1). As in Ref. 3, the generalized basis states are determined by a single continuous variable R which represents the $(e \to e)/(g \to g)$ 2n-transfer overlap ratios between the 0^+ basis states. The experimental (t,p) and (p,t) 0_2^+/g.s. cross-section ratios can be used to obtain α_A and β_A as functions of that variable, R. The quantities $x_A = \alpha_A / \beta_A$ are plotted versus R (as error bands) in Figs. 4 and 5.

If we assume for the moment, that each of the *physical* 2^+ states is connected via an $E2$ transition to only one of the 0^+ *basis* states (i.e., either U_{gA} or V_{eA} above is zero), then in ^{A}Ge, the $E2$ ratios are given solely in terms of the x_A's, i.e.,

$$\frac{B(E2;2_1^+ \to 0_2^+)}{B(E2;2_1^+ \to \text{g.s.})} = x_A^2 \quad \text{for } U_{gA} = 0 , \tag{4a}$$

or

$$\frac{B(E2;2_1^+ \to 0_2^+)}{B(E2;2_1^+ \to \text{g.s.})} = 1/x_A^2 \quad \text{for } V_{eA} = 0 . \tag{4b}$$

The $E2$ ratio data are plotted as horizontal error bands in Figs. 4 and 5. In ^{74,76}Ge, only limits exist, but they are consistent with the above simple assumption for values of R greater than about 1.14—*provided that in* ^{74,76}*Ge, it is* ϕ_e^A *that is connected to* 2_1^+ *by an E2 amplitude (i.e.,* $U_{gA} = 0$*).* In ^{70}Ge, the $E2$ amplitude ratio is 1.72 ± 0.22, suggesting R values in the range $1.13 \le R \le 1.24$, and that *in* ^{70}*Ge it is* ϕ_g^{70} *that is connected to* 2_1^+ *by an E2 amplitude (i.e.,* $V_{eA} = 0$*).* In ^{72}Ge, the newer $E2$ measurements slightly favor ϕ_g^{72} as "belonging" to 2_1^+, though the data are barely consistent with the other pairing. We note that the earlier[11] $E2$ ratio is about unity in ^{72}Ge—consistent with either and requiring roughly equal g,e mixing.

For ^{70,72}Ge we can eliminate the parameter R and simply plot the x_{70} vs x_{72} contour that is required by two-nucleon transfer ratios, as done in Fig. 6. Any point within this error band will fit the (t,p) and (p,t) ratios involving ^{70,72}Ge. We also plot in Fig. 6 as a vertical band the value of x_{72} predicted [via Eq. (4b)] from the $E2$ amplitude ratio in ^{72}Ge and as a horizontal band, the value of x_{70} predicted [via Eq. (4b)] from that ratio in ^{70}Ge. We note that there *is* an overlap, i.e., the two-nucleon

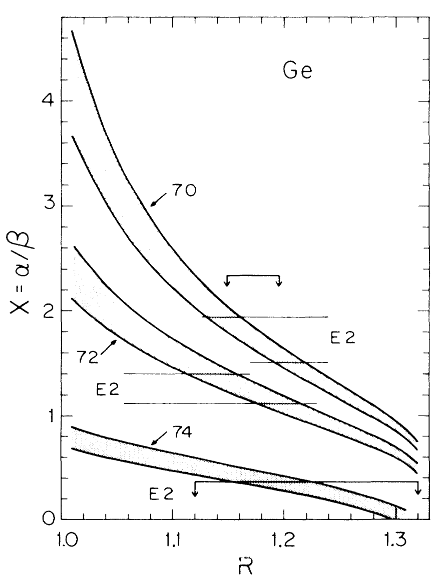

FIG. 4. As curved bands, the values from Ref. 3 of $x_A = \alpha_A / \beta_A$ ($A = 70$, 72, 74) vs R required to fit two-neutron transfer data. Horizontal bands are deduced from $E2$ ratios assuming each *physical* 2^+ state is connected (via an $E2$ transition) to only one 0^+ *basis* state.

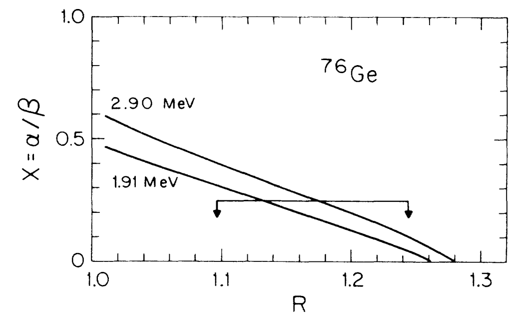

FIG. 5. As in Fig. 4, but for ^{76}Ge without uncertainties, with two different assumptions about which excited 0^+ state to use.

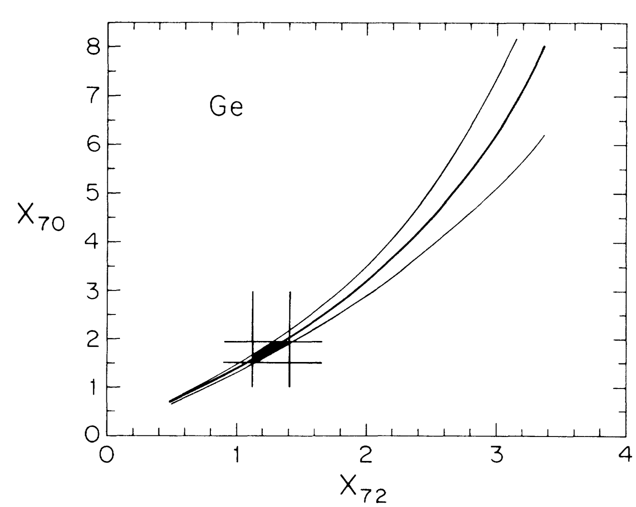

FIG. 6. Relationship between x_{70} and x_{72} from two-neutron transfer (curved band), compared with values of x_{70} and x_{72} deduced from $E2$ ratios (with $V_{eA} = 0$), as in Fig. 4.

transfer data are consistent with ^{70,72}Ge $E2$ data within the simple assumption that each of the physical 2^+ states is connected to only one of the basis 0^+ states. Furthermore, this assumption then puts severe limits on the allowed value of x_{70}, x_{72} (and hence on R and the 0^+ mixing amplitudes for all other Ge isotopes).

The analysis can be expanded to include the 2_2^+ state in ^{70}Ge and ^{72}Ge, in both of which all four $B(E2)$'s are known. Hence, for any value of the parameter R, the four experimental quantities can be used to calculate the four $E2$ matrix elements (U_{gA}, U_{eA}, V_{gA}, V_{eA}) connecting the two *physical* 2^+ states with the two *basis* 0^+ states. (It turns out that the possibility of a sign ambiguity in the $E2$ amplitude—i.e., $M(E2)=[(2J_i+1)B(E2;J_i^\pi \to J_f^\pi)]^{1/2}$, poses no problem.) These are plotted versus R in Figs. 7 and 8. We note that U_{gA} [i.e., $M(E2;2_1^+ \to \phi_{g0}^A)$] is large and roughly constant, in both ^{70,72}Ge, over most of the allowed range of R, whereas in both nuclei the matrix element V_{eA} [i.e., $M(E2;2_1^+ \to \phi_{e0}^A)$], changes rapidly—going through zero near $R=1.17$.

In ^{72}Ge, both $M(E2;2_2^+ \to \phi_{e0}^{72}, \phi_{g0}^{72})$ matrix elements (i.e., U_{e72} and V_{g72}, respectively) are small, and U_{e72} (through very small everywhere) passes through zero near $R=1.1$. In ^{70}Ge, both $M(E2;2_2^+ \to \phi_{e0}^{70}, \phi_{g0}^{70})$ matrix elements (i.e., U_{e70} and V_{g70}, respectively) are larger (in magnitude) but of opposite sign. In fact, within the uncertainties, for R in the range 1.1–1.2, three of the four matrix elements in ^{72}Ge are zero (i.e., all but U_{g72}), implying a "spherical" nature for the intruder ϕ_e^{72}.

In ^{70}Ge, the vanishing of V_{e70} near $R=1.17$ agrees with the earlier assumption discussed in connection with Figs. 4–6. However, 2_2^+ is then connected to both 0^+ basis states, although by small matrix elements in comparison to that of 2_1^+. Perhaps the most striking feature of the raw data is that the summed strength from 2_2^+ in ^{72}Ge is only about 3.7×10^{-3} of that for 2_1^+. Even in ^{70}Ge, the summed strength from 2_2^+ is only about 10% as strong as that for 2_1^+.

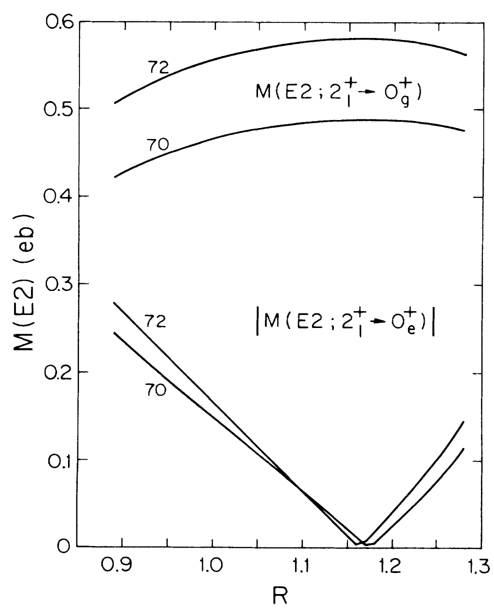

FIG. 7. Physical $2_1^+ \to$basis 0^+ $E2$ matrix elements $M(E2;2_1^+ \to 0_g^+, 0_e^+)$ vs R for ^{70,72}Ge deduced from $E2$ strengths in Table I and x_A vs A curves of Fig. 4.

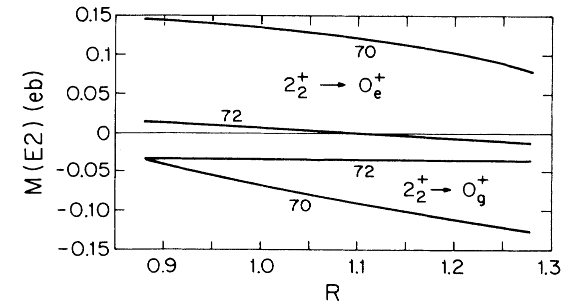

FIG. 8. As in Fig. 7, but for 2_2^+.

B. With mixing in the 2^+ states

We now go one step further and assume that the physical 2^+ states are mixtures of two basis states, each of which is connected to only one 0^+ basis state. Specifically, we write for ^{A}Ge

$$\Psi^A(2_1^+)=\gamma_A \phi_{g2}^A + \delta_A \phi_{e2}^A$$

and (5)

$$\Psi^A(2_2^+)=\delta_A \phi_{g2}^A - \gamma_A \phi_{e2}^A ,$$

and then (see Fig. 9) define

$$u_{gA}=\langle \phi_{g2}^A | E2 | \phi_{g0}^A \rangle, \quad u_{eA}=\langle \phi_{e2}^A | E2 | \phi_{e0}^A \rangle ,$$

$$v_{gA}=\langle \phi_{e2}^A | E2 | \phi_{g0}^A \rangle, \quad v_{eA}=\langle \phi_{g2}^A | E2 | \phi_{e0}^A \rangle .$$

Note that in terms of these $E2$ basis-state overlaps, we

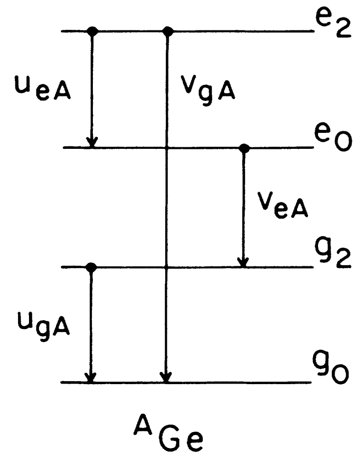

FIG. 9. The schematic representation of basis 0^+ and 2^+ states, and $E2$ matrix elements connecting them. For results in Table II, the off-diagonal amplitudes v_{gA} and v_{eA} were assumed to be zero.

TABLE II. The calculated values of α_A^2, γ_A^2, u_{gA}, and u_{eA} for ^{70,72}Ge. The sign combinations[a] are for $M(2101)$, $M(2102)$, $M(2201)$, and $M(2202)$ where $M(2i0j)=[5B(E2;2_i^+\rightarrow 0_j^+)]^{1/2}$ $=[B(E2;0_j^+\rightarrow 2_i^+)]^{1/2}$.

Sign	α_A^2	γ_A^2	u_{gA} (e b)	u_{eA} (e b)
		^{70}Ge ($A=70$)		
+ + + +	0.706±0.051	0.952±0.005	0.500 ±0.017	0.106 ±0.028
+ + − +	0.724±0.054	0.991±0.0005	0.490 ±0.017	0.144 ±0.028
+ − + +	0.276±0.054	0.009±0.0005	0.144 ±0.028	0.490 ±0.017
+ − − +	0.294±0.051	0.048±0.005	0.106 ±0.028	0.500 ±0.017
		^{72}Ge ($A=72$)		
+ + + +	0.615±0.054	0.996±0.0001	0.581 ±0.025	−0.0037±0.0047
+ + + −	0.616±0.053	1.000±0.0000	0.580 ±0.025	−0.0335±0.0044
+ − − +	0.385±0.053	0.004±0.0001	−0.0037±0.0047	0.581 ±0.025
+ − − −	0.384±0.053	0.000±0.0000	−0.0335±0.0044	0.580 ±0.025

[a]Those sign combinations not present are discarded because they lead to solutions with negative values of γ_A/δ_A which are inconsistent with the assumed phase restrictions. (They are otherwise equivalent to the solutions shown in the table.)

have

$$U_{gA}=\gamma_A u_{gA}+\delta_A v_{gA} , \tag{6a}$$

$$V_{eA}=\gamma_A v_{eA}+\delta_A u_{eA} , \tag{6b}$$

$$V_{gA}=\delta_A u_{gA}-\gamma_A v_{gA} , \tag{6c}$$

$$U_{eA}=\delta_A v_{eA}-\gamma_A u_{eA} . \tag{6d}$$

We shall assume that $v_{gA}=v_{eA}=0$ and without any input from two-nucleon transfer, then, we have four unknown quantities in each nucleus, viz., u_{gA}, u_{eA}, the 0^+ mixing amplitude α_A, and the 2^+ mixing amplitude γ_A. In ^{70,72}Ge, there are four known $B(E2)$'s, so it is worthwhile to ask if they lead to specific solutions for the unknown parameters. Results of solving Eqs. (2) and (6) with $v_{gA}=v_{eA}=0$ for each A are given in Table II. It turns out that in ^{72}Ge, there exist two *independent* solutions (labeled + + + + and + + + − in Table II). The first solution has $\alpha_{72}^2\approx 0.615\pm 0.054$, $\gamma_{72}^2\approx 0.996\pm 0.0001$, $u_{g72}\approx 0.581\pm 0.025$ e b and $u_{e72}\approx -0.0037\pm 0.0047$ e b, while the second solution has $\alpha_{72}^2\approx 0.616\pm 0.053$, $\gamma_{72}^2\approx 1.000\pm 0.000$, $u_{g72}\approx 0.580$ ± 0.025 e b, and $u_{e72}\approx -0.0335\pm 0.0044$ e b. We note that the major difference between the two solutions is that the first is consistent with $u_{e72}=0$ while the second is not *and* the second solution has $\gamma_{72}^2=1$ (i.e., allows for no mixing between the 2^+ basis states) while the first solution requires some mixing, although very minute. (Note that the two solutions labeled + − − + and + − − − in Table II are equivalent to these via $\alpha_A^2\leftrightarrow\beta_A^2$, $\gamma_A^2\leftrightarrow\delta_A^2$, and $u_{eA}\leftrightarrow u_{gA}$, and that preference for one set over another would require some independent evidence as to whether the physical ^{72}Ge ground state is mostly ϕ_g^{72} or mostly ϕ_e^{72}.) In both solutions (+ + + + and + + + −), the value of α_{72}^2 is about 0.6155 which corresponds to $x_{72}\approx 1.265$.

In ^{70}Ge, there are also two *independent* solutions which very nearly overlap within the uncertainties. If we take averages, we have $\alpha_{70}^2\approx 0.715$, $\gamma_{70}^2\approx 0.972$, $u_{e70}\approx 0.125$ e b and $u_{g70}\approx 0.495$ e b. This value of α_{70}^2 corresponds to $x_{70}\approx 1.584$. If we put these together with the analysis of (p,t) and (t,p) (i.e., Fig. 6), we see that these values of x_{70} and x_{72} lie well within the (t,p)-(p,t) band for $x_{70}-x_{72}$. We note also that in both calculations, the 2^+ states are relatively pure, with virtually *no* mixing in ^{72}Ge and a small amount in ^{70}Ge, if we are to understand the basis states as having no "off-diagonal" $E2$'s.

The value of x_{72} near 1.265 (i.e., R near 1.168) arose naturally in two independent considerations. It is at this value of R that the deduced potential matrix elements responsible for mixing the 0^+ states are nearly equal for all four stable even Ge nuclei.[3] It is also for this value of x_{72} that the ratio of α pickup strengths is equal to the reciprocal of the α stripping strengths in ^{72}Ge.[26]

IV. CONCLUSION

Remembering that R is a parameter labeling the generalized 0^+ basis states, we thus have what appears to be a "natural" choice of basis. It gives (i) mixing potential matrix elements nearly equal in $^{70-76}$Ge (the unperturbed basis-state separations are then roughly linear with A), (ii) no off-diagonal (or "cross-band") $E2$'s among low-lying 2^+ and 0^+ basis states (in fact, ϕ_e^{72} in ^{72}Ge is then not connected to *either* 2^+ basis states), and (iii) state ϕ_e^{72} in ^{72}Ge has properties of being an α particle-α hole excitation of state ϕ_g^{72} in that the α stripping and pickup ratios are inverses of one another. As of now, we have agreement for 2n transfer, α transfer, $0f_{5/2}$ proton occupancies, and $B(E2)$'s—though in ^{74,76}Ge the latter (so far) involve only 2_1^+ data. It would be extremely useful to have sufficient $E2$ data in ^{74,76}Ge to further test this choice of basis.

We acknowledge financial support from the National Science Foundation.

*Present address: Department of Physics and Atmospheric Science, Drexel University, Philadelphia, PA 19104.

[1]D. Ardouin *et al.*, Phys. Rev. C **12**, 1745 (1975).
[2]M. N. Vergnes *et al.*, Phys. Lett. **72B**, 447 (1978).
[3]M. Carchidi, H. T. Fortune, G. S. F. Stephans, and L. C. Bland, Phys. Rev. C **30**, 1293 (1984).
[4]S. Mordechai, H. T. Fortune, M. Carchidi, and R. Gilman, Phys. Rev. C **29**, 1699 (1984).
[5]C. Lebrun *et al.*, Phys. Rev. C **19**, 1224 (1979).
[6]D. Ardouin *et al.*, Phys. Rev. C **18**, 1201 (1978).
[7]G. Rotbard *et al.*, Phys. Rev. C **18**, 86 (1978).
[8]H. T. Fortune, M. Carchidi, and S. Mordechai, Phys. Lett. **145B**, 4 (1984).
[9]R. Lecomte *et al.*, Phys. Rev. C **22**, 1530 (1980); **25**, 2812 (1982).
[10]R. Lecomte *et al.*, Phys. Rev. C **22**, 2420 (1980).
[11]P. M. Endt, At. Data Nucl. Data Tables **23**, 547 (1979).
[12]D. Cline, private communication.
[13]A. M. Van den Berg *et al.*, Nucl. Phys. **A379**, 239 (1982).
[14]D. Ardouin, D. L. Hanson, and N. Stein, Phys. Rev. C **22**, 2253 (1980).
[15]M. Carchidi and H. T. Fortune, Phys. Rev. C **31**, 853 (1985).
[16]S. Sen *et al.*, Phys. Rev. C **31**, 787 (1985).
[17]L. H. Rosier *et al.*, Nucl. Phys. **A453**, 389 (1986).
[18]M. Vergnes, in *Proceedings of the Sixth European Physical Society Nuclear Divisional Conference on the Structure of Medium-Heavy Nuclei, Rhodes, Greece, 1979,* Institute of Physics Conference Series No. 49, edited by G. S. Anagnostatos, C. A. Kalfas, S. Kossionides, T. Paradellis, L. D. Skouras, and G. Vourvopoulos (IOP, Bristol, 1980), p. 25.
[19]S. Mordechai, H. T. Fortune, R. Middleton, and G. Stephans, Phys. Rev. C **19**, 1733 (1979).
[20]S. LaFrance, S. Mordechai, H. T. Fortune, and R. Middleton, Nucl. Phys. **A307**, 52 (1978).
[21]S. Mordechai, H. T. Fortune, R. Middleton, and G. Stephans, Phys. Rev. C **18**, 2498 (1979).
[22]J. F. Mateja *et al.*, Phys. Rev. C **17**, 2047 (1978).
[23]P. F. Hinrichsen, D. M. Van Patter, and M. H. Shapiro, Nucl. Phys. **A123**, 250 (1969).
[24]S. Raman *et al.*, At. Data Nucl. Data Tables **36**, 1 (1987), and references therein.
[25]M. R. Bhat, Nucl. Data Sheets **51**, 95 (1987).
[26]H. T. Fortune and M. Carchidi, J. Phys. G **11**, L193 (1985).