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Doorway state approximation and sign correlations in parity nonconservation in compound neutron resonances

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The nonzero average parity-nonconserving longitudinal analyzing powers for p-wave neutron resonances in compound nuclear systems are analyzed within the giant $J=0^-$ resonance doorway model. Assuming that the parity-nonconservation interaction can be approximated by a one-body operator of the type $\boldsymbol{\sigma}\cdot\mathbf{p}$, we find that the observed fixed sign of the asymmetry arises naturally within the doorway model. The $J=0^-$ giant resonance does not enhance the size of the constant asymmetry. The model prediction for the average symmetry is shown to be similar to that obtained in the single-particle model. In particular, if one retains only the first-order contribution to the analyzing power, a very large single-particle matrix element $\langle 4p_{1/2}|V_{\rm pv}|5s_{1/2}\rangle \simeq 75\pm 50$ eV is needed to reproduce the observed average asymmetry. This large value is in contradiction with the value of 2 eV estimated from the experimentally measured spreading width of the parity-violating interaction using the doorway model.

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I. INTRODUCTION

It is now well established that neutron resonances in compound nuclear (CN) systems exhibit large parity-nonconserving (PNC) asymmetries. In these systems PNC analyzing powers P, measured [1] in polarized neutron transmission experiments, can be as large as 10%. However, extracting information on the weak interaction from these measurements requires knowledge of the nuclear many-body levels involved. The very complex nature of compound nuclear states precludes microscopic descriptions of the wave functions in terms of shell-model states, for example. On the other hand, statistical models of the nucleus, in which the expansion coefficients of the CN states in a particle-hole basis are assumed to be Gaussian-distributed independent random variables, provide a good description of the properties of CN systems. For this reason theoretical analyses of parity nonconservation in CN systems have been developed mainly within the statistical framework. It had been assumed that the statistical model of the CN implied that the mean value of the PNC asymmetry was zero [2], and that the sign of the parity-violating longitudinal analyzing power, if measured for sufficiently many p-wave resonances, should be found to have random sign. This result simply reflects the fact that the parity-mixing matrix elements and neutron reduced width amplitudes which determine the value of P are themselves expected to be uncorrelated random variables with mean zero. In strong contrast to this expectation, a recent measurement [3] at LAMPF of PNC in p-wave neutron resonances in ^{232}Th found that all analyzing powers of greater than 2σ statistical significance have positive sign.

The purpose of this paper is to examine the correlations between the neutron reduced width amplitudes and the parity-mixing matrix elements which must be responsible for the very nonrandom nature of the sign of P. Some of the material presented here has appeared elsewhere in briefer form [4,5]. However, we recapitulate and expand it here for the purposes of a coherent presentation of our new results. Recently a doorway state approach was introduced [4] to describe the parity violation in compound nuclear states. In the framework of such an approach phase correlations are inherent. Also recently, a single-particle model (which could be viewed as a special case of the doorway model) was discussed, and an analysis in the framework of this model showed [5] that the common sign could be understood as arising from contributions to the analyzing power from the $s_{1/2}$ single-particle components of states approximately $\hbar\omega$ distant in energy. The observed magnitude of the average asymmetry could then be explained if a single-particle matrix element of the PNC interaction of about 50 eV is allowed. The role of such distant (~ 5 MeV) states is generally assumed in statistical models to be very small because of the large difference in the energy denominator compared to neighboring s-wave resonance where $E_{S_{1/2}}-E_{p_{1/2}}$ is typically ~ 10 eV. The doorway state approach [4] to parity mixing in compound states, which also emphasizes the importance of distant states, is that of the $J=0^-$ resonance model, where it is proposed that the $J=0^-$ giant resonance acts as a doorway state for the reaction. The doorway nature of this state arises because the one-body approximation to the PNC interaction involves the operator $\boldsymbol{\sigma}\cdot\mathbf{p}$, which is closely related to the

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operator $\boldsymbol{\sigma}\cdot\mathbf{r}$, which is responsible for the spin-flip dipole resonance in nuclei.

A microscopic shell-model calculation of the $\boldsymbol{\sigma}\cdot\mathbf{p}$ and neutron strength distributions contributing to the asymmetry would be neither elucidative nor possible, as it would require diagonalization of the strong Hamiltonian in a basis containing at least 10^5 states—the average energy spacing between p-wave resonances is ~ 10 eV. It is the purpose of this work to demonstrate that sign correlations in the longitudinal asymmetry coefficient emerge naturally from the doorway state picture. (One should keep in mind, however, that the type of contribution we consider here is only one among a few processes that might contribute to the value of the asymmetry.) In order to see how the doorway contributes to the sign correlations, we must first summarize some of the main points of the doorway state approach applied to the problem of parity mixing in compound nuclear states.

II. THE DOORWAY STATE APPROACH

In the doorway approach introduced in Ref. [4], it is assumed that parity mixing in compound nuclear states is determined by a *one-body* potential. This assumption is supported by a number of theoretical studies [6]. The one-body parity-violating, but time-reversal preserving, potential in its simplest form can be written as

$$V_{\mathrm{pv}}=[g_0(r)+g_1(r)\tau_z]\boldsymbol{\sigma}\cdot\mathbf{p} \ , \tag{1}$$

where $g_0(r)$ and $g_1(r)$ are functions of the radius for the isoscalar and isovector parts of the parity-violating potential and $\boldsymbol{\sigma}$ and $\mathbf{p}$ are the spin and momentum of the nucleon.

If we deal now with a compound nuclear state $|m\rangle$, we will define as its doorway a state that couples strongly via the one-body potential in Eq. (1) to state $|m\rangle$. We will denote such a doorway as $|D_m\rangle$. It was pointed out [4] that the $J=0^-$ spin-dipole state (i.e., $L=1,S=1,J=0^-$) is the proper doorway in the case of parity mixing. This doorway may be written in the form

$$|D_m\rangle=\frac{1}{N_0}\sum_{i=1}^{A}(\boldsymbol{\sigma}\cdot\mathbf{r})_i|m\rangle \ , \tag{2a}$$

$$|D_m\rangle=\frac{1}{N_1}\sum_{i=1}^{A}(\boldsymbol{\sigma}\cdot\mathbf{r})_i\tau_3(i)|m\rangle \ , \tag{2b}$$

where the sum is over all nucleons and the constants $1/N_i$ are normalization factors. The state $|D_m\rangle$ is a spin-dipole state built on the compound state $|m\rangle$. It could be both an isoscalar [Eq. (2a)] or isovector [Eq. (2b)] type of excitation. The points we should emphasize are the following: (1) Spin-dipole excitations with respect to the ground state have been observed in several types of experiments, and concentration of isovector spin-dipole strength was established [7]. (2) The recent studies of giant resonances in "hot" nuclei have shown [8] that a giant dipole built on an excited state is a meaningful concept up to very high excitation energies of the nucleus. This lends support to our assumption concerning a dipole-doorway state built on a compound nuclear state. (3) The doorways $|D_m\rangle$ are of course not eigenstates of the Hamiltonian. The physical dipole excitations have a distribution of strength characterized by a spreading width of a few MeV. (4) The *centroids* of the isovector, as well as isoscalar spin-dipole states, are removed from the states $|m\rangle$, and only the tails of the distributions reach the energy position of the state $|m\rangle$. (5) In the case of an odd-even nucleus, the spin-dipole operator, when acting on a $J=\frac{1}{2}^-$ state $|m\rangle$, excites a $p_{1/2}$ single-particle (s.p.) neutron to an $s_{1/2}$ orbit. We emphasize, however, that in addition the spin-dipole operator produces many $J=0^-$ particle-hole configurations to which the $p_{1/2}$ neutron couples. The doorway state $|D_m\rangle$ is then a linear combination of these two types of configurations. (6) The action of the $\sum_i(\boldsymbol{\sigma}\cdot\mathbf{r})_i$ operator is to produce a coherent $|D_m\rangle$ state which carries much more strength than just a s.p. spin-dipole transition. Therefore the matrix element which couples the state $|m\rangle$ to $|D_m\rangle$,

$$M=\langle m|V_{\mathrm{pv}}|D_m\rangle \ , \tag{3}$$

is considerably larger than the s.p. matrix element

$$M_{\mathrm{s.p.}}=\langle p_{1/2}|V_{\mathrm{pv}}|s_{1/2}\rangle \tag{4}$$

III. SIGN CORRELATIONS IN P_m IN THE DOORWAY APPROACH

We will now proceed and show that in the present doorway state model, one expects a nonzero average value of the longitudinal asymmetry coefficient which is defined as

$$P=\frac{\sigma_+-\sigma_-}{\sigma_++\sigma_-} \ , \tag{5}$$

where σ_+ and σ_- denote the resonance cross sections for neutrons with positive and negative helicity, respectively.

In an experiment [3] performed recently the parity-violating asymmetries P_m were measured in the scattering of 1–400 eV neutrons from ^{232}Th. The asymmetries were measured for a large number of compound $p_{1/2}$ resonances in ^{232}Th and found to be predominantly of positive sign. (In Ref. [5] the tendency of the asymmetries to have a fixed sign is shown to result from a nonzero average value of PkR.) We will refer to this as sign correlations.

Under the assumption of narrow resonances, in the first-order perturbation theory [9], the parity-violating asymmetry coefficient P for a given state $|m\rangle$ is

$$P_m=2\sum_n\frac{\langle n|V_{\mathrm{pv}}|m\rangle}{E_m-E_n}\frac{\gamma_n}{\gamma_m} \ , \tag{6}$$

where the sum is, in principle, over all state $|n\rangle$ having opposite parity to that of the state $|m\rangle$. The quantities γ_m and γ_n are the neutron decay amplitudes of states $|m\rangle$ and $|n\rangle$, respectively, and E_m and E_n refer to the energies of these states. In order to derive an expression for P_m in our doorway state approach, we note, in the absence of $2h\omega$ correlations, the relation

$$\langle n|V_{\mathrm{pv}}|m\rangle=\langle n|D_m\rangle\langle D_m|V_{\mathrm{pv}}|m\rangle \ , \tag{7}$$

where $\langle n|D_m\rangle$ is the overlap of states $|n\rangle$ and $|D_m\rangle$. This relation is the essence of the doorway state hypothesis. The parity-violating coupling of the compound state $|m\rangle$ to the compound state $|n\rangle$ is via the coupling of the admixture of $|D_m\rangle$ in $|n\rangle$. This last admixture is the result of the parity-conserving strong-interaction coupling of $|D_m\rangle$ and $|n\rangle$.

As in the case of the $E1$ operator, $2\hbar\omega$ configurations in the wave function of the compound state $|m\rangle$ are expected to lead to destructive interference in the resonance region for the operator $\boldsymbol{\sigma}\cdot\mathbf{r}$. The relative sign between the (0 to 1)$\hbar\omega$ and (2 to 1)$\hbar\omega$ single-particle matrix elements is opposite for $\boldsymbol{\sigma}\cdot\mathbf{r}$ and $\boldsymbol{\sigma}\cdot\mathbf{p}$. Thus, in the case of the operator $\boldsymbol{\sigma}\cdot\mathbf{p}$, the $2\hbar\omega$ correlations generally lead to constructive interference in the resonance and destructive interference for low-lying states, and result in a somewhat different distribution of strength than for the operator $\boldsymbol{\sigma}\cdot\mathbf{r}$. Without a microscopic description of the compound nucleus, it is difficult to calculate accurately the effects of these $2\hbar\omega$ configurations on the PNC analyzing powers. However, such an extension of the doorway model is unlikely to change significantly the present estimate of the expected sign correlations.

We will also make use of the relations

$$\gamma_n=\gamma_s\langle 0^+s_{1/2}|n\rangle\ , \tag{8a}$$

$$\gamma_m=\gamma_p\langle 0^+p_{1/2}|m\rangle\ , \tag{8b}$$

where γ_p and γ_s are the single-particle *decay* amplitudes for a $p_{1/2}$ and $s_{1/2}$ neutron, respectively. The symbols $\langle 0^+s_{1/2}|n\rangle$ and $\langle 0^+p_{1/2}|m\rangle$ denote the overlaps of a continuum $s_{1/2}$ ($p_{1/2}$) neutron s.p. state and the target in the ground state with the state $|n\rangle$ ($|m\rangle$).

Using Eq. (7) and the definitions above, we may write Eq. (6) in the form

$$P_m=\frac{2\gamma_s}{\gamma_p\langle 0^+p_{1/2}|m\rangle}\times\sum_n\frac{\langle 0^+s_{1/2}|n\rangle\langle n|D_m\rangle\langle D_m|V_{\rm pv}|m\rangle}{(E_m-E_n)}\ . \tag{9}$$

We now decompose Eq. (9) by writing

$$1=|D_m\rangle\langle D_m|+\sum|q_m\rangle\langle q_m|\ , \tag{10}$$

where $\sum_{q_m}|q_m\rangle\langle q_m|$ is the projection operator for the part of the Hilbert space complementary to $|D_m\rangle$.

Inserting Eq. (10) into (9) we find

$$P_m=\frac{2\gamma_s}{\gamma_p\langle 0^+p_{1/2}|m\rangle}\times\sum_n\frac{\langle 0^+s_{1/2}|D_m\rangle\langle D_m|n\rangle^2\langle D_m|V_{\rm pv}|m\rangle}{E_m-E_n}+F_q\ , \tag{11}$$

where

$$F_q=\frac{2\gamma_s}{\gamma_p\langle 0^+p_{1/2}|m\rangle}\times\sum_{n,q_m}\frac{\langle 0^+s_{1/2}|q_m\rangle\langle q_m|n\rangle\langle D_m|n\rangle\langle D_m|V_{\rm pv}|m\rangle}{E_m-E_n}\ . \tag{12}$$

The matrix elements involving $|q_m\rangle$ have random phases with respect to the matrix elements involving $|m\rangle$ and $|n\rangle$, and therefore the various contributions in F_q have fluctuating signs and F_q averages to zero. We will drop this term in Eq. (11). The roles of the isoscalar and isovector states in Eqs. (2a) and (2b) in determining the sign correlations are exactly analogous, and so for the sake of simplicity we will restrict our discussion to a single resonance which includes both strengths N_0 and N_1. The energy of the "unified" doorway will be taken at an average of both. Accordingly, in Eq. (1) we will approximate the expression in the brackets by an isospin-independent constant G, so that

$$V_{\rm pv}\simeq g\boldsymbol{\sigma}\cdot\mathbf{p}\ . \tag{13}$$

Using the definition of the doorway, we may write

$$\langle 0^+s_{1/2}|D_m\rangle=\frac{1}{N}\langle 0^+s_{1/2}|\sum_i(\boldsymbol{\sigma}\cdot\mathbf{r})_i|m\rangle\ , \tag{14}$$

where N represents the combined strength of N_0 and N_1. Equation (14) can be expressed as

$$\langle 0^+s_{1/2}|D_m\rangle=\frac{1}{N}\langle 0^+s_{1/2}|\boldsymbol{\sigma}\cdot\mathbf{r}|0^+p_{1/2}\rangle\times\langle 0^+p_{1/2}|m\rangle+\Delta_f\ , \tag{15}$$

where Δ_f is again a fluctuating part which averages to zero. Inserting Eq. (15) into Eq. (11) and dropping F_q and Δ_f, we obtain

$$P_m=\frac{2\gamma_s}{\gamma_p}\frac{\langle D_m|V_{\rm pv}|m\rangle\langle 0^+s_{1/2}|\boldsymbol{\sigma}\cdot\mathbf{r}|0^+p_{1/2}\rangle}{N}\times\sum_n\frac{|\langle D_m|n\rangle|^2}{E_m-E_n}\ . \tag{16}$$

Note that the matrix element $\langle D_m|V_{\rm pv}|m\rangle$, with $V_{\rm pv}$ given by Eq. (13), is closely related to the normalization N which is the square root of the total $\boldsymbol{\sigma}\cdot\mathbf{r}$ strength for the state $|m\rangle$. For harmonic-oscillator wave functions, in fact, matrix elements of the operator $\boldsymbol{\sigma}\cdot\mathbf{p}$ are equal to matrix elements of $iM\omega\boldsymbol{\sigma}\cdot\mathbf{r}$. One can therefore write

$$\langle D_m|V_{\rm pv}|m\rangle=\frac{iM\omega g}{N}\langle m|\sum_i(\boldsymbol{\sigma}\cdot\mathbf{r})_i\sum_i(\boldsymbol{\sigma}\cdot\mathbf{r})_i|m\rangle\ . \tag{17}$$

The matrix element in Eq. (17) is the total spin-dipole strength and therefore equal to N^2. We find that

$$\langle D_m|V_{\rm pv}|m\rangle=iM\omega gN\ , \tag{18}$$

and Eq. (16) becomes

$$P_m=\frac{2\gamma_s}{\gamma_p}\langle 0^+s_{1/2}|V_{\rm pv}|0^+p_{1/2}\rangle\sum_n\frac{|\langle D_m|n\rangle|^2}{E_m-E_n}\ . \tag{19}$$

The distribution of strength $|\langle D_m|n\rangle|^2$ peaks around the spin-dipole giant resonance, which is far removed from the state $|m\rangle$. Assuming a monotonically decreasing distribution in the tail, one finds that the sum in Eq. (19) has a definite sign independent of $|m\rangle$. The other quantities appearing in Eq. (19) are single-particle quantities independent, of course, of $|m\rangle$ and having a definite sign. We find therefore that *P_m has a fixed sign for all $|m\rangle$ states*. Note that the asymmetry arising from the $J=0^-$ resonance is independent of N, i.e., independent of the total $\sigma\cdot\mathbf{p}$ strength in the resonance. This result reflects the fact that the very large value of the collective PNC matrix elements is compensated by the small $s_{1/2}$ neutron reduced width of the $J=0^-$ resonance. Consequently, the final result only depends on the single-particle $p_{1/2}-s_{1/2}$ matrix element. Secondly, P_m is independent of $\langle 0^+p_{1/2}|m\rangle$ and of the detailed structure of the $|m\rangle$ state. We note that the predictions of the doorway model are completely analogous with those of the single-particle model [4].

IV. AN ESTIAMTE OF THE PARITY-VIOLATING MATRIX ELEMENT

We use now the measured value of P_m and the doorway state contribution to evaluate the one-body parity-violating matrix element in Eq. (19).

Noting that the total strength $\sum|\langle D_m|n\rangle|^2=1$ and assuming a smooth distribution, we may write Eq. (19) in the form

$$P_m=\frac{2\gamma_s}{\gamma_p}\frac{\langle 0^+s_{1/2}|V_{\rm pv}|0^+p_{1/2}\rangle}{E_m-\bar{E}_{D_m}}\ , \tag{20}$$

where $\bar{E}_{D_m}$ is an energy representing the average position of the isoscalar and isovector $L=1$ spin-flip strength built on the state $|m\rangle$. The ratio γ_s/γ_p for low energies can be approximated by

$$\frac{|\gamma_s|}{|\gamma_p|}\simeq\frac{\sqrt{3}}{kR}\ , \tag{21}$$

where k is the neutron wave number. The value of $(kR)^{-1}$ for the experiments discussed here is typically of the order 10^3. For heavy nuclei the spin-flip strength distribution can be approximated by a Lorentzian distribution. The spin-flip particle-hole interaction is repulsive, so the centroids of both the isoscalar and isovector $J=0^-$ resonances are shifted above $1\hbar\omega$ in energy. However, to date there is no direct experimental information on their expected excitation energies, although a good guess can be made from the observed position of the total isovector spin-dipole strength and from theoretical considerations. As discussed in [4], a reasonable estimate of the parity-mixing matrix elements is obtained by replacing the two doorway states by a single resonance of a width of 3 MeV lying at about $1\hbar\omega$ above the p-wave state.

Thus far we have considered the $\frac{1}{2}^+$ spin-flip resonance $1\hbar\omega$ higher in energy. The transition strength from a given compound state $|m\rangle$ to a spin-flip dipole state $1\hbar\omega$ lower in energy is several orders of magnitude smaller than to the dipole $1\hbar\omega$ higher in energy. Therefore in the framework of the collective doorway state approach it may be neglected. However, as pointed out in [5], parity mixing from low-lying s.p. bound states can produce a contribution to the *average* analyzing power of equal magnitude. This contribution, which involves the 4s orbit, adds constructively [5], giving an approximate factor of 2 in Eq. (20).

The ^{233}Th data show an average asymmetry of $8.0^{+6.2}_{-6.0}$ for a 1-eV neutron [3]. If we treat the single-particle matrix element of $V_{\rm pv}$ as a parameter, we find that the $J=0^-$ doorway model requires a $\langle V_{\rm pv}\rangle\simeq 75^{+58}_{-50}$ eV. (The error bars are only due to the experimental uncertainty of the above asymmetry coefficient.) This value is clearly quite large, and would have consequences in other PNC observables. For example, in the framework of the same doorway state approach, the PNC spreading width of the observed resonance ($\Gamma^{\downarrow}_{m,\rm pv}$) was estimated [4]. It is given by

$$\Gamma^{\downarrow}_{m,\rm pv}\simeq\left|\frac{\langle m|V_{\rm pv}|D_m\rangle}{E_m-\bar{E}_{D_m}}\right|^2\Gamma^{\downarrow}_{D_m}\ , \tag{22}$$

where $\Gamma^{\downarrow}_{D_m}$ is the spreading width of the 0^- doorway. Using $1\hbar\omega\simeq 6.7$ MeV for the denominator, a typical number for the spreading width of a giant dipole of $\Gamma^{\downarrow}_{D_m}\simeq 3$ MeV, and the value 5×10^{-7} eV for $\Gamma^{\downarrow}_{m,\rm pv}$ (as deduced by Bowman *et al.* in Ref. [1]), one obtains for the PNC matrix element in the numerator of Eq. (22) a value of about 2 eV, in clear disagreement with the estimate above. One could question the use of the value $\Gamma^{\downarrow}_{D_m}=3$ MeV for the *spin-dipole* resonance and, in particular, of its $J=0^-$ component. It cannot be ruled out that this width for the 0^- spin mode is considerably smaller, say, in the range of few hundred keV. Then the estimate based on Eq. (22) would lead to a larger PNC matrix element of the order of 5 eV, still smaller than the estimate deduced from Eq. (20).

Note also that the matrix element in Eq. (22), because of the collectivity of the doorway, should be enhanced with respect to the single-particle PNC matrix element entering Eq. (20). The corresponding single-particle PNC matrix element should be reduced by a factor $1/N'$, where N' is the square root of the collectivity coefficient of the doorway. For heavy nuclei, this factor is of the order of 10. Therefore we should expect the PNC s.p. matrix elements to be around 0.2 eV, two orders of magnitude smaller than the one obtained from Eq. (20). The source of the discrepancy giving rise to a large effective PNC matrix element resulting from Eq. (20) may come from the reaction theory employed in the calculation of the *decay* amplitude γ_m entering the expression from P_m. It is well known from the study of decay amplitudes of isobaric analog resonances [10,11] that the kind of contribution considered here (and termed the "compound amplitude" in Ref. [10], p. 81) is only one of several processes entering the calculation of an escape (decay) amplitude, and is actually not the dominant one [11]. Direct and channel coupling processes must also be considered. On these lines we note that very recently a mechanism proposed by Weidenmuller [12] suggests that an enhancement arising from a direct channel coupling between the $p_{1/2}$ and $s_{1/2}$ channels may contribute to the average asymmetry.

V. SUMMARY

We have shown that in the framework of a doorway state model one obtains an average asymmetry P_m which is fixed in sign and which is independent of the details of the p-wave resonance.

As opposed to the calculation of the spreading width, where the collectivity of the doorway plays a role, the physics determining the average asymmetry in the doorway model [4] and the single-particle model [5] is essentially the same. In both cases the sum over all s-wave states in Eq. (6) is dominated by the state consuming most of the $\sigma \cdot \mathbf{p}$ *or* $s_{1/2}$ neutron strength. *In both models, the single-particle [5] and the present model, to reproduce the observed average asymmetry requires anomalously large PNC single-particle matrix elements. These large single-particle matrix elements are in contradiction with the value of 2* eV *deduced from the experimentally measured parity-violating spreading width using the doorway state approach.*

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[1] V. P. Alfimenkov *et al.*, Nucl. Phys. **A398**, 93 (1983); J. D. Bowman *et al.*, Phys. Rev. Lett. **65**, 1192 (1990).

[2] H. A. Weidenmuller, in *Nuclear Physics in the 1990's*, Proceedings of the Symposium in Honor of Akito Arima, Santa Fe, NM, 1990, edited by D. H. Feng, J. N. Ginocchio, T. Otsuka, and D. D. Strottman (North-Holland, Amsterdam, 1990); V. E. Bunakov, E. D. Davis, and H. A. Weidenmuller, Phys. Rev. C **42**, 1718 (1990).

[3] C. M. Frankle *et al.*, Phys. Rev. Lett. **67**, 564 (1991).

[4] N. Auerbach, Phys. Rev. C **45**, R514 (1992).

[5] J. D. Bowman, G. T. Garvey, C. R. Gould, A. C. Hayes, and M. B. Johnson, Phys. Rev. Lett. **68**, 780 (1992).

[6] See, for example, E. G. Adelberger and W. C. Haxton, Annu. Rev. Nucl. Part. Sci. **35**, 501 (1985), and references therein.

[7] W. A. Sterrenburg, S. M. Austin, R. P. DeVito, and A. Galonsky, Phys. Rev. Lett. **45**, 1839 (1980); M. Moinester *et al.*, Phys. Lett. B **230**, 41 (1989).

[8] See, for example, G. F. Bertsch and R. A. Broglia, Phys. Today **39**, 44 (1986); K. Snover, Annu. Rev. Nucl. Part. Sci. **36**, 545 (1986).

[9] V. V. Flambaum and O. P. Sushkov, Nucl. Phys. **A412**, 13 (1983).

[10] N. Auerbach, J. Hufner, A. K. Kerman, and C. M. Shakin, Rev. Mod. Phys. **44**, 48 (1972).

[11] N. Auerbach and G. F. Bertsch, Phys. Lett. **43B**, 175 (1973).

[12] H. A. Weidenmuller (unpublished); private communication.