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IS COLLECTIVE MOTION SYMMETRIC IN THE NEUTRON-PROTON DEGREES OF FREEDOM?

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ABSTRACT

The purity of intrinsic states of nuclei with respect to a proton-neutron boson symmetry (F-spin) is shown to be largely determined by the difference between proton and neutron deformations and not by whether the Hamiltonian is an F-spin scalar. Upper and lower bounds on F-spin mixing in the ground state band of ¹⁶⁵Ho are estimated using recent pion single-charge-exchange data.

INTRODUCTION

Shortly after the introduction of the interacting-boson model¹ as a phenomenologically successful description of low-lying collective spectra of medium to heavy nuclei, it was proposed that a microscopic, shell-model-based interpretation of the model required distinguishing between neutron and proton bosons.²⁻³ The resulting proton-neutron interacting-boson model (called IBM-2 to distinguish it from the original IBM-1 with only a single type of boson) contains a natural additional algebraic structure, based on the two-valued proton-neutron degree of freedom. This SU(2) structure, denoted F-spin,² holds out the possibility of an additional, possibly-conserved quantum number in nuclear spectroscopy. Although the same microscopic arguments which led to the introduction of IBM-2 support a model Hamiltonian which is not an F-scalar, apparently implying that nuclear collective states do not have well-defined F-spin, data on M1 transitions between low-lying collective states have been argued to require a high degree of F-spin purity in these nuclear levels.^{4,5} It will be shown here that the intrinsic-state picture recently developed for interacting-boson models,⁶ and the associated geometrical description of nuclear spectra in terms of intrinsic deformations with superimposed collective motion,⁷⁻⁸ may be capable of bridging these two superficially incompatible claims, and can open the way to the use of additional experimental information to pin down the F-spin purity of nuclear energy levels.

IBM-2 AND F-SPIN

The basic building blocks of IBM-2 are monopole and quadrupole proton ($\rho = \pi$) and neutron ($\rho = \nu$) creation and destruction operators: $s_\rho^\dagger, s_\rho$ ($J^\pi = 0^+$), $d_{\rho\mu}^\dagger$, $\tilde{d}_{\rho\mu} \equiv (-)^\mu d_{\rho-\mu}$ ($J^\pi = 2^+$). The boson number operator $\hat{N}_\rho$ has eigenvalue N_ρ

where $N_\pi(N_\nu)$ is one-half the number of valence protons (neutrons). The basic F-spin doublets are $(s_\pi^\dagger, s_\nu^\dagger)$, and $(d_{\pi\mu}^\dagger, d_{\nu\mu}^\dagger)$, with the convention that proton bosons have F-spin projection $+1/2$, neutron bosons $-1/2$. The F-spin raising and lowering operators are

$$\hat{F}_+ = s_\pi^\dagger s_\nu + \sum_\mu d_{\pi\mu}^\dagger d_{\nu\mu}, \quad \hat{F}_- = (\hat{F}_+)^\dagger \quad (1)$$

and the operator defining the z-component of F-spin is $\hat{F}_0 = \frac{1}{2}(\hat{N}_\pi - \hat{N}_\nu)$. These three operators form an $SU(2)$ Lie algebra analogous to isospin. In a given nucleus, with fixed N_π, N_ν , all states have the same value of $F_0 = \frac{1}{2}(N_\pi - N_\nu)$, while the allowed values of the F-spin quantum number F range from $|F_0|$ to $F_{MAX} \equiv \frac{1}{2}(N_\pi + N_\nu)$ in unit steps. F-spin measures the extent to which the states are symmetric in the neutron and proton degrees of freedom. The states with maximum F-spin, F_{MAX} , have the highest symmetry and are the lowest in the energy spectrum in general.

It has been shown⁹ that for states with good F-spin, there are no M1 transitions between states with $F = F_{MAX}$. This, together with the observed weakness of B(M1)'s between low-lying collective states in nuclei, is the basis of the claim that F-spin breaking must be small in these nuclei,^{4,5} though it has subsequently been realized that selection rules due to symmetries other than F-spin (such as $SO(5)$ and $SU(3)$) can also lead to vanishing M1 matrix elements.¹⁰

The general Hamiltonian of IBM-2 has many free parameters, and different forms have been used to fit spectra and E2 transition rates in nuclei. Forms based on microscopic arguments, and hence not F-scalars, can produce F-spin mixing as high as 18% in states of the ground band while fitting spectra and E2 transitions well.¹¹ (The goodness of the fit to B(M1) depends critically on the poorly-determined boson g-factors.) On the other hand, equally good fits are obtained with near F-scalar Hamiltonians or with interactions which push up in energy states with lower F-spin, resulting in F-spin mixing of 2-4% which suffices to reproduce the B(M1)'s.¹² It is clearly desirable to find alternate experimental criteria to try to pin down more precisely the F-spin purity of nuclear collective states.

AN INTRINSIC STATE

A geometrical description of IBM-2 states can be based on the concept of an intrinsic state which is a condensate of deformed bosons, which do not have well-defined angular momenta.⁶⁻⁸ The most general such condensate, in which proton and neutron boson numbers are separately conserved, can be written in the form

$$|c\rangle \equiv (N_\pi! N_\nu!)^{-1/2} [b_{c\pi}^\dagger(\beta_\pi, \gamma_\pi)]^{N_\pi} [b_{c\nu}^\dagger(\beta_\nu, \gamma_\nu, \Omega)]^{N_\nu} |0\rangle \quad (2a)$$

where $|0\rangle$ is the boson vacuum,

$$b_{c\rho}^\dagger(\beta_\rho, \gamma_\rho) = (1 + \beta_\rho^2)^{-1/2} [s_\rho^\dagger + \beta_\rho \cos \gamma_\rho \cdot d_{\rho 0}^\dagger + \beta_\rho \sin \gamma_\rho \cdot \frac{1}{\sqrt{2}}(d_{\rho 2}^\dagger + d_{\rho, -2}^\dagger)] \quad (2b)$$

$$b_{c\nu}^\dagger(\beta_\nu, \gamma_\nu, \Omega) = R(\Omega) b_{c\nu}^\dagger(\beta_\nu, \gamma_\nu) R^{-1}(\Omega), \quad (2c)$$

and where $R(\Omega)$ rotates the condensate boson through the Euler angles ϕ, θ, ψ which are collectively denoted as Ω . This condensate depends on seven intrinsic

shape parameters: the total deformations β_ρ , the axiality parameters γ_ρ , and the Euler angles ϕ, θ, ψ of relative orientation. The values of the shape parameters $\beta_\rho, \gamma_\rho, \Omega$ are determined by minimizing the expectation value of the Hamiltonian in the condensate $|c\rangle$. Whenever $\beta_\rho > 0$, the resulting equilibrium condensate is deformed, and a rotational ground-state band is projected from this intrinsic state. The IBM boson deformation parameter β_ρ differs in numerical value from the familiar Bohr and Mottelson definition¹³ since the boson model involves a truncation of nuclear collective motion^{1-3,6} to the shell model valence space of monopole and quadrupole pairs of fermions.

The intrinsic state will have well-defined F-spin, F , when $|c\rangle$ is an eigenstate of $\hat{F}^2 = \hat{F}_+ \hat{F}_- + \hat{F}_0^2 - \hat{F}_0$, with eigenvalue $F(F+1)$. Since $|c\rangle$ is, by construction, an eigenstate of $\hat{F}_0$, the condition for it to have good F-spin is $\hat{F}_+ \hat{F}_- |c\rangle \propto |c\rangle$. Because the effect of $\hat{F}_-$ on the deformed proton boson $b_{c\pi}^\dagger(\beta_\pi, \gamma_\pi)$ is to turn it into a deformed neutron boson $b_{c\nu}^\dagger(\beta_\pi, \gamma_\pi)$, while $\hat{F}_+$ turns $b_{c\nu}^\dagger(\beta_\nu, \gamma_\nu, \Omega)$ into $b_{c\pi}^\dagger(\beta_\nu, \gamma_\nu, \Omega)$, $\hat{F}_+ \hat{F}_- |c\rangle$ will have one component proportional to $|c\rangle$, and a second component in which one proton condensate boson and one neutron condensate boson have exchanged expansion coefficients. Thus $\hat{F}_+ \hat{F}_- |c\rangle$ can be proportional to $|c\rangle$ only if the expansion coefficients are equal. Since the representation of the expansion coefficients in terms of shape parameters β, γ and Euler angles ϕ, θ, ψ is unique, this means that $\beta_\pi = \beta_\nu, \gamma_\pi = \gamma_\nu$, and the relative Euler angles must vanish in order for $|c\rangle$ to be an eigenstate of $\hat{F}^2$. It is then easy to show that the corresponding eigenvalue is $F_{MAX}(F_{MAX} + 1)$.

These conditions ($\beta_\pi = \beta_\nu, \gamma_\pi = \gamma_\nu, \Omega = 0$) translate into relatively mild constraints on the parameters of the IBM-2 Hamiltonian which need not be an F-scalar. The members of the ground-state band are expected to be well approximated by the projections of states of good angular momentum from the deformed equilibrium condensate. Since the angular-momentum projection operator is an F-scalar, these projected states will also have $F = F_{MAX}$. Thus it is possible for a non-F-scalar IBM-2 Hamiltonian to have a ground-state band of states with nearly pure F-spin, $F = F_{MAX}$, provided only that its equilibrium intrinsic state consists of aligned proton and neutron condensates, of equal deformation.

F-SPIN ADMIXTURES

In order to explore the consequences of different proton and neutron deformations for F-spin breaking, it is convenient to restrict attention to the most likely situation, namely aligned, axially-symmetric but differently-deformed condensates (2) with $\beta_\pi \neq \beta_\nu, \gamma_\pi = \gamma_\nu = \Omega = 0$, which we denote by $|c_a\rangle$. It is straightforward to evaluate

$$\langle c_a | \hat{F}^2 | c_a \rangle = F_{MAX}(F_{MAX} + 1) - N_\pi N_\nu (\beta_\pi - \beta_\nu)^2 / (1 + \beta_\pi^2)(1 + \beta_\nu^2), \quad (3)$$

from which it is again evident that $F = F_{MAX}$ for $\beta_\pi = \beta_\nu$. This condensate can, in general, be expanded in terms of states of well-defined F-spin, as $|c_a\rangle = \sum_F \alpha_F |F\rangle$, where $|F\rangle$ is the component with the F-spin quoted and α_F is the amplitude of that component in the condensate $|c_a\rangle$. Using the normalization condition $\sum_F |\alpha_F|^2 = 1$ and (3), it follows that

$$NP_{MAX} \equiv N_\pi N_\nu \frac{(\beta_\pi - \beta_\nu)^2}{(1 + \beta_\pi^2)(1 + \beta_\nu^2)} = \sum_{F=|F_0|}^{F_{MAX}-1} |\alpha_F|^2 [F_{MAX}(F_{MAX} + 1) - F(F + 1)] \quad (4)$$

where $N = N_\pi + N_\nu$. Both upper and lower bounds on the admixtures of lower F-spin in the intrinsic condensate can be derived by putting $F = F_{MAX} - 1$ and $|F_0|$, respectively, in the sum in (4). That is

$$P_{MIN} = \frac{N}{N_<(N_> + 1)} P_{MAX} \leq 1 - |\alpha_{F_{MAX}}|^2 \leq P_{MAX} \quad (5)$$

where $N_<(N_>)$ is the lesser (greater) of (N_π, N_ν) . Thus by knowing the IBM deformation parameters β_ρ an upper and lower bound on the F-spin admixtures can be obtained. For large N_ρ these parameters can be determined from the measured neutron and proton quadrupole moments or $B(E2)$ transition rates.

An explicit form for the F-spin decomposition of the condensate $|c_a\rangle$ can be obtained in the limit of large N_ρ . Introducing a fixed reference value $\bar{\beta}$ of the deformation parameter, the condensate boson $b_{c\rho}^\dagger$ (with $\gamma_\rho = \Omega = 0$) can be expressed as a linear combination of the mutually-orthogonal condensate boson and β -vibration boson for that value, as follows:

$$B_{c\rho}^\dagger \equiv (1 + \bar{\beta}^2)^{-1/2} (s_\rho^\dagger + \bar{\beta} a_{\rho 0}^\dagger), \quad B_{\beta\rho}^\dagger \equiv (1 + \bar{\beta}^2)^{-1/2} (d_{\rho 0}^\dagger - \bar{\beta} s_\rho^\dagger) \quad (6a)$$

$$b_{c\rho}^\dagger = [(1 + \beta_\rho^2)(1 + \bar{\beta}^2)]^{-1/2} [(1 + \bar{\beta}\beta_\rho) B_{c\rho}^\dagger + (\beta_\rho - \bar{\beta}) B_{\beta\rho}^\dagger] \quad (6b)$$

The condensate $|c_a\rangle$ can then be expanded in terms of the form $(B_{c\rho}^\dagger)^{N_\rho - K_\rho} (B_{\beta\rho}^\dagger)^{K_\rho}$. Using the facts that for any n_π , n_ν , $(B_{c\pi}^\dagger)^{n_\pi} (B_{c\nu}^\dagger)^{n_\nu}$ has well defined F-spin, equal to $\frac{1}{2}(n_\pi + n_\nu)$, with projection $\frac{1}{2}(n_\pi - n_\nu)$, while $B_{\beta\pi}^\dagger$ and $B_{\beta\nu}^\dagger$ have F-spin 1/2, with projections +1/2 and -1/2 respectively, and applying SU(2) vector-coupling coefficients, each term in the expansion is expressed in terms of components of well-defined F-spin. The leading terms resulting from this procedure are $(B_{c\pi}^\dagger)^{N_\pi} (B_{c\nu}^\dagger)^{N_\nu}$ with $F = F_{MAX}$, and $B_{\beta\pi}^\dagger (B_{c\pi}^\dagger)^{N_\pi - 1} (B_{c\nu}^\dagger)^{N_\nu}$, $B_{\beta\nu}^\dagger (B_{c\pi}^\dagger)^{N_\pi} (B_{c\nu}^\dagger)^{N_\nu - 1}$, which contain components $F = F_{MAX}$ and $F = F_{MAX} - 1$. If, at this point, the value of $\bar{\beta}$ is chosen so that the coefficient of the F_{MAX} component of the $B_{\beta\rho}^\dagger$ terms vanishes, then only the $F_{MAX} - 1$ component survives, with coefficient

$$x = \sqrt{N_\pi N_\nu / N} (\beta_\pi - \beta_\nu) (1 + \bar{\beta}^2) / (1 + \beta_\pi \bar{\beta}) (1 + \beta_\nu \bar{\beta}) \quad (7)$$

relative to the leading F_{MAX} term. The equation defining $\bar{\beta}$ is

$$(N_\pi \beta_\nu + N_\nu \beta_\pi) \bar{\beta}^2 + N(1 - \beta_\pi \beta_\nu) \bar{\beta} - (N_\pi \beta_\pi + N_\nu \beta_\nu) = 0 \quad (8)$$

and has one positive root. For almost-equal deformations, $|\beta_\pi - \beta_\nu| \ll 1$, $\bar{\beta} = (N_\pi \beta_\pi + N_\nu \beta_\nu) / N + O((\beta_\pi - \beta_\nu)^2)$; i. e., a boson-number weighted deformation. By inspection of the remaining terms in the expansion, it can be seen that, with this choice of $\bar{\beta}$, the condensate can be written approximately in the form

$$|c_a\rangle \approx e^{-x^2/2} \sum_{k=0}^{\infty} (x^k / \sqrt{k!}) |F = F_{MAX} - k\rangle, \quad (9)$$

for large N_ρ .

At this point it is clear that in well-deformed, rotational nuclei, the degree of F-spin mixing in the states of the nucleus is dependent mainly on the degree

of similarity of proton and neutron deformations, regardless of whether the IBM-2 Hamiltonian is F-scalar or not. It should be pointed out that non-F-scalar Hamiltonians with equal proton and neutron deformations are not hard to come by. As one example, consider the popular choice

$$H = \epsilon_\pi \hat{n}_{d\pi} + \epsilon_\nu \hat{n}_{d\nu} + \kappa Q_\pi \cdot Q_\nu + \kappa' L_\pi \cdot L_\nu + \alpha_2 (s_\pi^\dagger d_\pi^\dagger - s_\nu^\dagger d_\nu^\dagger) \cdot (s_\pi \tilde{d}_\nu - s_\nu \tilde{d}_\pi) \\ + \sum_{L=1,3} \alpha_L (d_\pi^\dagger d_\nu^\dagger)^{(L)} \cdot (\tilde{d}_\nu \tilde{d}_\pi)^{(L)}. \quad (10a)$$

Here

$$Q_\rho = s_\rho^\dagger \tilde{d}_\rho + d_\rho^\dagger s_\rho + \chi_\rho (d_\rho^\dagger \tilde{d}_\rho)^{(2)}, \quad (10b)$$

$\hat{n}_{d\rho}$ are the d_ρ -boson number operators, superscripts indicate coupling to well-defined spherical-tensor rank and dots denote scalar products. This is not an F-scalar. The necessary conditions for $\beta_\pi = \beta_\nu = \beta$, $\gamma_\pi = \gamma_\nu = 0$, $\Omega = 0$ to determine a ground-state condensate with well-defined $F = F_{MAX}$ are

$$\epsilon_\pi / N_\nu - \epsilon_\nu / N_\pi - \kappa \sqrt{\frac{2}{7}} (\chi_\pi - \chi_\nu) \beta = 0 \quad (11a)$$

$$\epsilon_\pi (1 + \beta^2) / N_\nu + 2\kappa (1 - \beta^2) - \kappa \sqrt{\frac{2}{7}} \beta [\chi_\nu (1 - \beta^2) + 2\chi_\pi] + \frac{2}{7} \kappa \chi_\pi \chi_\nu \beta^2 = 0, \quad (11b)$$

which may be regarded as one equation for determining β , and one constraint equation relating some of the nine parameters of the Hamiltonian. As long as band mixing is weak, the ground state band generated from this condensate will have good F-spin.

The class of Hamiltonians

$$H = \sum_\rho \{ A_\rho [d_\rho^\dagger \cdot d_\rho^\dagger - \beta^2 (s_\rho^\dagger)^2] [H. c.] + A'_\rho [\beta s_\rho^\dagger d_\rho^\dagger + \sqrt{\frac{7}{2}} (d_\rho^\dagger d_\rho^\dagger)^{(2)}] \cdot [H. c.] \} \\ + A_0 [d_\pi^\dagger \cdot d_\nu^\dagger - \beta^2 s_\pi^\dagger s_\nu^\dagger] [H. c.] + \sum_{L=1,3} A_L (d_\pi^\dagger d_\nu^\dagger)^{(L)} \cdot (\tilde{d}_\nu \tilde{d}_\pi)^{(L)} + A_2 [s_\pi^\dagger d_\nu^\dagger - s_\nu^\dagger d_\pi^\dagger] \cdot [H. c.] \\ + A'_2 [\beta s_\pi^\dagger d_\nu^\dagger + \sqrt{\frac{7}{2}} (d_\pi^\dagger d_\nu^\dagger)^{(2)}] \cdot [H. c.] + A''_2 [\beta s_\nu^\dagger d_\pi^\dagger + \sqrt{\frac{7}{2}} (d_\pi^\dagger d_\nu^\dagger)^{(2)}] \cdot [H. c.], \quad (12)$$

where $H. c.$ means Hermitian conjugate, have the remarkable property that the aligned prolate condensate with $\beta_\pi = \beta_\nu = \beta$ is an eigenstate, i.e. there is no band mixing and the ground-state band consists of states of pure $F = F_{MAX}$. (Specific examples of such Hamiltonians were given in the SO(6) and SU(3) dynamical symmetry limits¹⁴ of IBM-2.) However, the condensate is an eigenstate for the Hamiltonian (12) for any choice of the parameters $A_\rho, A'_\rho, A_0, A_1, A_2, A'_2, A''_2, A_3$, but the Hamiltonian is an F-scalar only when $A_\pi = A_\nu = \frac{1}{2} A_0$ and $A'_\pi = A'_\nu = A'_2 = A''_2$.

Similar techniques can be employed to investigate the F-spin decomposition of excited intrinsic bands, including symmetric and antisymmetric β - and γ -vibrations and scissors modes ($\gamma_\rho = \Omega = 0$, $\beta_\pi = \beta_\nu$ guarantee $F = F_{MAX} - 1$ for the scissors band). The F-spin mixing depends again on the proton and neutron

deformations, and generally also on the mixing parameters which determine the relative weights of proton and neutron bosons in the intrinsic normal modes.⁸ When the good F-spin of the ground-state band is not due to a symmetry of the Hamiltonian, the mixing in the excited bands can differ from that of the ground band, and from band to band. Similar methods can also be used to obtain the dependence of the F-spin mixing on $\gamma_\pi - \gamma_\nu$ when the axiality constraint is released. The fact that detailed IBM-2 calculations with non-F-scalar Hamiltonians, which have considerable F-spin mixing in the eigenstates, show rather similar F-spin decompositions for different members of the same band¹¹ strengthens the contention that the F-spin impurity is largely a function of the intrinsic structure underlying the rotational bands.

ESTIMATION OF F-SPIN ADMIXTURES

Recent pion single-charge-exchange experiments on ^{165}Ho at the Clinton P. Anderson Meson Physics Facility at Los Alamos (LAMPF) have measured the difference between the differential cross-section to the analog for the target oriented perpendicular to the pion beam and the differential cross section to the analog for an unoriented target.¹⁵ From this orientation asymmetry in the cross sections the authors extract the ratio of Bohr-Mottelson neutron to proton deformations¹⁵ for ^{165}Ho to be 0.84(8). Multiplying this ratio of deformations by N/Z for ^{165}Ho , the ratio R of the neutron quadrupole moment to the proton quadrupole moment is $R=1.23(12)$. Using the measured proton quadrupole moment of $q_\pi = 3.49(3)$ eb,¹⁷ the neutron quadrupole moment is then R times this moment.

Since the IBM is a model based on the truncation of the shell model space, the effective proton and neutron boson quadrupole transition operator $\hat{T}_\rho$ has a contribution from both the proton and neutron boson quadrupole operators Q_π and Q_ν given in (10b),

$$\hat{T}_\rho = e_B [(1 + \delta)Q_\rho + \delta Q_{\tilde{\rho}}], \quad (13)$$

where $\tilde{\rho} = \pi(\nu)$ for $\rho = \nu(\pi)$, and δ is the effective charge correction which is usually taken to have the value $\delta \simeq 0.5$ in the shell model. The boson strength e_B is taken to be equal to the phenomenologically determined value¹⁸ $e_B = 0.15$ eb, which happens to be twice the quadrupole single-particle unit.

The estimation of the F-spin admixtures is very sensitive to the renormalization coefficient δ . The larger the value of δ taken, the larger the estimation of F-spin admixtures because the larger value of δ means that the transition operator (13) becomes more like an F-spin scalar, and hence a given difference in measured quadrupole moments must be explained by a larger difference in β_π and β_ν thereby implying larger F-spin admixtures in the ground state band. Sometimes very large δ 's are used in the IBM^{1,19}, for example as large as $\delta = 2.7$, but this may be due to the fact that only electromagnetic transition rates are used to determine δ . A better way to determine δ is to measure a collective proton and neutron transition rate. This can be done by measuring a collective transition for both π^+ and π^- inelastic scattering. The best determination of δ comes from fitting both $\pi^\pm$ scattering to the first 2^+ state in the Pd isotopes.²⁰ In this analysis the value $\delta = 0.69$ was extracted in IBM-1, independent of the IBM-1 Hamiltonian. This value is slightly larger than the shell model value of $\delta = 0.5$, but the use of IBM-1 may have the effect of making δ effectively larger. Since we are using IBM-2 in this paper, we expect a value of δ more consistent with the shell model to be the correct one to use.²¹

In the large N limit, the IBM quadrupole moments are given by a numerical factor relating the moment operator to the transition operator times a Wigner 3j symbol squared times an intrinsic matrix element of the IBM transition operator,

$$q_\rho = 4\sqrt{\frac{\pi}{5}}(2J+1) \begin{pmatrix} J & 2 & J \\ J & 0 & -J \end{pmatrix}^2 \langle c_a | \hat{T}_\rho | c_a \rangle, \quad (14a)$$

where the intrinsic matrix element of the boson quadrupole operators is

$$\langle c_a | \hat{T}_\rho | c_a \rangle = e_B [(1+\delta)N_\rho\beta_\rho + \delta N_{\bar{\rho}}\beta_{\bar{\rho}}] \quad (14b)$$

where we have used¹⁸ $\sqrt{\frac{2}{7}}\chi_\rho\beta_\rho = 1 - \beta_\rho^2$ and have ignored the contribution of the odd proton to the quadrupole moment.

Comparing these IBM moments to the measured values, we determine the IBM β_π, β_ν to be 1.0 and 1.3 respectively if we take $\delta = 0.5$, the shell model value. With these β_ρ 's, we estimate that the maximum of F-spin admixture in the ground state band of ^{165}Ho ($K = J = 7/2$) is $P_{MAX} = 8\%$ and the minimum is $P_{MIN} = 2\%$ with P_{MAX} and P_{MIN} defined in (4) and (5). On the other hand if we use a large value of $\delta = 2.7$, the β_π, β_ν are 0.13 and 0.57, respectively. These β 's imply very large F-spin admixtures, between 54% and 13%. However, for these latter relatively small IBM deformations, the intrinsic state may not produce an accurate approximation to the states of the ground band.

SUMMARY

We have shown that in deformed nuclei an F-spin violating Hamiltonian can produce states with pure F-spin provided the IBM neutron and proton deformations are equal, and, if they are not equal, upper and lower bounds on the F-spin admixtures can be estimated from the quadrupole properties of nuclei, as opposed to the M1 properties which are more sensitive to the underlying single-particle structure.

More experiments on a wide range of nuclei are needed to study the difference in proton and neutron quadrupole moments and transition rates in order to establish the quality of F-spin as a quantum number and to set constraints on IBM-2 and on other models of nuclear structure. Although ^{165}Ho is special as a target since it can be aligned, the same information can be obtained by pion single-charge exchange on collective unaligned even-even targets to the 2^+ analog state in the residual nuclei. This cross section is sensitive to the difference between the neutron and proton quadrupole transition densities. These transitions will be possible to detect with the new neutral meson spectrometer being constructed at LAMPF.

In short, we need AFFIRMATIVE ACTION for the other half of the nuclear matrix elements, the neutron matrix elements, so that they are determined to the same quality as the proton matrix elements.

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