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Kaup, U; Vorwerk, R; Hippe, D; Schuh, HW; von Brenato, P; Scholten, O

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A TEST OF THE INTERACTING BOSON FERMION MODEL AND ITS MICROSCOPIC BASIS IN TRANSITIONAL Tc AND Ag NUCLEI[☆]

U. KAUP, R. VORWERK, D. HIPPE, H.-W. SCHUH and P. von BRENTANO

Institut für Kernphysik der Universität zu Köln, D-5000 Köln 41, West Germany

and

O. SCHOLTEN

Michigan State University, Cyclotron Laboratory, East Lansing, MI 48824, USA

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Parameters of the interacting boson fermion model obtained by fitting the model to the spectra of four nuclei in the $1g_{9/2}$ shell have been compared with the values given by microscopic formulas taking into account the two-particle structure of the bosons.

Recently an extension of the Interacting Boson Model [1,2] (IBM) of the collective excitations in even-even nuclei to odd nuclei has been proposed [3], called the Interacting Boson Fermion Model (IBFM). In this model the odd system is described as a core consisting of s- and d-bosons, coupled to one extra particle which interacts with the bosons. In principle, the interaction may be quite complicated; nevertheless, in general one gets on well with a simple force containing a quadrupole and a monopole part; the Pauli principle comes in via an exchange term in the force, which is found to play a fundamental role in the phenomenological description of odd- A spectra [3].

The hamiltonian can be written as [4]:

$$H = \sum_j \sqrt{5} A_j [(d^+ \tilde{d})^{(0)} (a_j^+ \tilde{a}_j)^{(0)}]^{(0)} \\ + \sum_{jj'} \sqrt{5} \Gamma_{jj'} \{ [(d^+ s + s^+ \tilde{d}) + \chi (d^+ \tilde{d})^{(2)}] (a_j^+ \tilde{a}_{j'})^{(2)} \}^{(0)} \\ + \sum_{jj'j''} (2j''+1)^{-1/2} \Lambda_{jj''}^{j''} : [(\tilde{d} a_j^+)^{(j'')} (d^+ \tilde{a}_{j'})^{(j'')}]^{(0)} : \quad (1)$$

The parameters of this model are $\Gamma_{jj'}$ and χ for the quadrupole force, A_j for the monopole force, and $\Lambda_{jj''}^{j''}$ for the Pauli term.

The subject of this letter is a test of the model in some particular cases, where an odd proton is predominantly in the $g_{9/2}$ particle state. Thus we can apply a single j -shell approximation which leaves only four adjustable parameters, viz. A_j , Γ_{jj} , χ , and Λ_{jj}^{jj} . Special attention is paid to the dependence of the parameters Γ_{jj} and Λ_{jj}^{jj} on particle number, which can be directly compared with predictions given by microscopic formulae [4]. This is in fact the main purpose of this discussion.

A large number of levels in the nuclei ^{97}Tc and $^{105,107}\text{Ag}$ has been obtained recently by means of in-beam γ -ray spectroscopy [5–9], thus allowing to test the model in a more or less vibrational region. The calculations have been performed with the code ODDA [10]. A special programme ORACLE [11] has been used for fitting the four parameters of the model to experimental energies. The agreement with experiment obtained in this way may be called excellent (figs. 1–3). For instance, in the case of ^{97}Tc 20 levels are described with one set of four parameters.

The isotopes $^{105,107}_{47}\text{Ag}$ are described by an odd pro-

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Fig. 1. Comparison of the experimental spectrum of ^{97}Tc with the IBM calculation. The parameters are given in table 1.

Fig. 2. Same as fig. 1, for ^{105}Ag .

Fig. 3. Same as fig. 1, for ^{107}Ag .

ton coupled to $^{104,106}\text{Pd}$ [6,12]. Although we believe that it would be more consistent to couple a proton hole to ^{48}Cd , only very few levels are available in Cd isotopes, and the structure seems to be complicated by low-lying single-particle states. We do not see the influence of such single-particle configurations in $^{105,107}\text{Ag}$ and hence prefer to give the description with the Pd cores, which should not change the strength of the particle-boson interaction drastically.

The fourth case for our model test is the nucleus ^{101}Rh . The result of the calculation for this nucleus is taken from ref. [4]. It is interesting in the context of our discussion because its spectrum can be described by a pure exchange (Λ_{jj}^i).

In the calculations, the nucleus $^{100}_{50}\text{Sn}_{50}$ has been taken as an inert core, i.e. $N_\pi = N_\nu = 0$. As an exception, for ^{97}Tc it seems to be justified to consider $Z = 40$ as a shell closure; hence we assume $^{90}_{40}\text{Zr}_{50}$ to be the inert core for ^{97}Tc .

The parameters obtained by fitting the model hamiltonian to the experimental energy spectra and the boson numbers N_π, N_ν associated with each nucleus are shown in table 1. While the parameters A_j and χ have a minor influence on the structure of the spectra, i.e. a large variation produces only a small improvement of the fit, the parameters Γ_{jj} and Λ_{jj}^i represent the essential part of the nuclear particle boson

Table 1

Values of parameters obtained by fitting to experimental energies.

Z	N	N_π	N_ν	Γ_{jj}	Λ_{jj}^j	A_j	χ
43	54	1	2	-0.85	-11.7	1.18	0.2
45	56	2	3	0	-10.2	0	0
47	58	2	4	0.30	-10.3	-0.01	-1.0
47	60	2	5	0.34	-10.3	0.05	-0.9

force. As a matter of fact, they both carry information about the microscopic structure of the boson core.

The quadrupole force parameter Γ_{jj} , on inspection of table 1 as a function of proton number, changes sign when passing $Z = 45$, being negative for $Z < 45$, zero for $Z = 45$, and positive for $Z > 45$, while the exchange force parameter Λ_{jj}^j is essentially constant. In the following we will show that this is a direct consequence of the microscopic theory of the IBFM.

A microscopic theory for the IBM has been derived on the basis of Generalized Seniority [13]. This theory has been extended to the IBFM [4]. Here the procedure given in ref. [4] is sketched briefly, just in order to define the quantities which will be used. The particle-core interaction is written, in the case of an odd proton,

$$V_Q = \bar{\kappa} Q_\nu^{(2)} \cdot q_\pi^{(2)}, \quad (2)$$

$Q_\nu^{(2)}$ is the boson image of the quadrupole operator of the neutrons. The protons are divided into a number of pairs, treated as proton bosons, and a single outer proton, the quadrupole operator of which is $q_\pi^{(2)}$. However, while fermion creation and annihilation operators do not commute with each other, they do commute with the boson creation and annihilation operators. Hence a single fermion acts like a probe in differentiating between bosons and fermion pairs. In order to retain the more complex commutation relations of the original many-fermion system when substituting fermion pairs by bosons, one has to correct all single-fermion operators by higher-order terms which involve both the fermionic and bosonic degrees of freedom. Such corrections to the odd-particle quadrupole operator $q_\pi^{(2)}$ are the origin of the Pauli term.

A considerable simplification is obtained if one neglects any difference between protons and neutrons and treats them as identical particles. When doing that one has to renormalize the quadrupole force (2) getting

a new, particle number dependent coupling constant

$$\Gamma_0 = \bar{\kappa} N_\nu / (N_\nu + N_\pi). \quad (3)$$

Now the quadrupole and the exchange force in the IBFM hamiltonian (1) can be derived from the particle-boson interaction (2). Taking into account the intrinsic structure of the proton boson, one gets, for the case of a single j -shell [4]:

$$\Gamma_{jj} = \Gamma_0 (u_j^2 - v_j^2) \langle j || Y_2 || j \rangle, \quad (4a)$$

$$\Lambda_{jj}^j = -4 \sqrt{10} \Gamma_0 \sqrt{N_\pi} u_j v_j \langle j || Y_2 || j \rangle, \quad (4b)$$

where the v_j^2, u_j^2 are occupation probabilities similar to those of the BCS-theory. The unknowns of these equations are $\bar{\kappa}$ and v_j^2 . If we assume, for simplicity, that the proton bosons are occupying the $g_{9/2}$ state only, we can put $v_j^2 = n/10$, where n is the number of valence protons in the $g_{9/2}$ shell and 10 is the shell degeneracy. Although this is a rather crude approximation, we prefer it rather than introducing any new parameters when determining v_j^2 microscopically, for instance by BCS theory. $\bar{\kappa}$ is assumed to be constant for all nuclei under consideration. It is the only unknown left, determining the structure of four nuclei.

The overall agreement is reasonable, if we fix $\bar{\kappa}$ such that Λ_{jj}^j is normalized at ^{105}Ag . The resulting values of parameters are shown in table 2. Evidently the change of sign of Γ_{jj} is understood clearly in this way. Beyond that the microscopic formulae give correctly the relative order of magnitude for Γ_{jj} and Λ_{jj}^j , Γ_{jj} is about a factor of 20 smaller than Λ_{jj}^j . It turns out even that Λ_{jj}^j follows very closely the trend predicted by eq. (4b). However, there is still a deviation of about a factor of two in the absolute size of Γ_{jj} . This may be due to several reasons.

Table 2

Values of parameters Γ_{jj} and Λ_{jj}^j obtained from fitting eq. (1) to experiment (entries under "fit") and with eqs. (4a, b) (entries under "micr"); the latter values are normalized such that $\Lambda_{jj}^j(\text{micr}) = \Lambda_{jj}^j(\text{fit})$ for ^{105}Ag .

Z	N	N_π	N_ν	v_j^2	Γ_{jj}		Λ_{jj}^j	
					micr	fit	micr	fit
43	54	1	2	0.3	-0.50	-0.85	-7.3	-11.7
45	56	3	3	0.5	0	0	-10.1	-10.2
47	58	2	4	0.7	0.51	0.30	-10.3	-10.3
47	60	2	5	0.7	0.55	0.34	-11.0	-10.3

Most likely, there could be an admixture of the $d_{5/2}$ particle states, leading to a renormalization of parameters when restricting the model space to the $g_{9/2}$ particle state only. This has been discussed in detail elsewhere [14].

In conclusion we can say that the microscopic formulas relating the IBFM parameters to the intrinsic structure of the boson core can be applied to single j -shell IBFM calculations. Essentially they describe correctly the change of parameters as a function of particle number as well as the relative size of the quadrupole and the exchange force in a given nucleus.

In order to allow for more detailed predictions of the formulas, more sophisticated, multi-shell calculations have to be performed. However, the single j -shell approach has the great advantage of its relative simplicity. Furthermore, we should emphasize that the fits which can be obtained already with this simplified version of the model are excellent.

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