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# DYNAMICAL SYMMETRIES FOR ODD-ODD NUCLEI*

A. B. Balantekin†
Physics Division, Oak Ridge National Laboratory
Oak Ridge, TN 37831 U.S.A.

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# DYNAMICAL SYMMETRIES FOR ODD-ODD NUCLEI*

A. B. Balantekin†
Physics Division, Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831 U.S.A.

ABSTRACT

Recent work for developing dynamical symmetries and supersymmetries is reviewed.

## 1. INTRODUCTION

The Interacting Boson-Fermion Model (IBFM) has greatly facilitated both experimental and theoretical studies of odd-mass nuclei. This model provides a simple phenomenological description to analyze and classify the experimental data[1]. In addition, the IBFM has considerable theoretical importance in two ways. First, the coupling of single particle degrees of freedom to bosons, invoked in this model, provides an excellent theoretical laboratory to investigate boson-fermion mapping. Second, when the even-even core is described by one of the symmetry chains of the Interacting Boson Model and the odd fermion is in a configuration with particular j values, the solutions of the IBFM Hamiltonian exhibit dynamical supersymmetries[2], thus providing the first experimentally observed example of a supersymmetry in nature. Consequently, the IBFM has been widely used to analyze data for odd-even nuclei.

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The situation for odd-odd nuclei is completely different. The excitation spectra are much more compressed than those of odd-even nuclei, and the information on the electromagnetic transitions is very scarce. Nevertheless, there are some recent attempts to search for dynamical symmetries describing odd-odd nuclei[3,4,5]. One major motivation is the simultaneous success of the U(6/4) dynamical supersymmetry for $^{194}$Pt and $^{195}$Au, and the U(6/12) dynamical supersymmetry for $^{194}$Pt and $^{195}$Pt. The existence of these two schemes together raises the question whether or not the odd-odd nucleus $^{196}$Au can be described by a suitable combination of them. It turns out that the simplest such scheme[4,5], incorporating the direct product supergroup U(6/4) × U(6/12), cannot account for the correct ground state spin.

Before we study algebraic approaches to the odd-odd nuclei, let me emphasize that such nuclei are systems with two fermions. Furthermore, since very little data are available for the excited states in odd-even nuclei with two unpaired nucleons, odd-odd nuclei are the only candidates for a mixed system of many bosons and two fermions that we can investigate experimentally and theoretically. In order to be able to describe odd-even nuclei properly, it is sufficient to incorporate the correct form of the boson-fermion exchange interaction in the Interacting Boson-Fermion Hamiltonian. However, an accurate description of odd-odd nuclei requires the correct form of the fermion-fermion force (the residual interaction) as well. Correspondingly, the algebraic modeling of the spectra of odd-odd nuclei is intrinsically more difficult.

One major step towards a proper account of the residual neutron-proton residual force is to algebraically distinguish between the fermion configurations which are particle-like and those which are hole-like. To illustrate how this is done, let me assume for simplicity that the unpaired proton ($\pi$) and the unpaired neutron ($\nu$) occupy single j orbitals $j_\pi$ and $j_\nu$. The dimension of unpaired proton space is $m_\pi = 2j_\pi+1$, and that of the unpaired neutron space is $m_\nu = 2j_\nu+1$. The odd-proton is placed in an $m_\pi$-dimensional representation of the group $U_F^\pi(m_\pi)$ and the odd-neutron in an $m_\nu$-dimensional representation of

$U_F^{\nu}(m_{\nu})$. The group U(N) has two N-dimensional representations: the fundamental (particle) representation (denoted by $\square$ in the Young tableau notation), and its conjugate (antiparticle) representation (denoted by $\boxdot$ ). The unpaired fermions which are mostly particle-like ($u_j > v_j$) are placed in the fundamental representation $\square$ of the appropriate fermionic group, and the unpaired fermions which are hole-like in the conjugate representation $\boxdot$ of the associated fermionic group[6]. I will denote the group realized in the conjugate representation by $\overline{U}(m)$. Consequently, if the odd-proton is hole-like and the odd-neutron is particle-like, the group structure of the Hamiltonian is $U_B(6) \times U_F^{\pi}(m_{\pi}) \times \overline{U}_F^{\nu}(m_{\nu})$. In a similar way, when they both are hole-like, the group structure is $U_B(6) \times U_F^{\pi}(m_{\pi}) \times U_F^{\nu}(m_{\nu})$.

## 2. REALIZATION OF THE PARABOLIC RULE

Some time ago it was shown that[7] the energies of the lowest-lying states of the proton-neutron multiplet in odd-odd nuclei are quadratic functions of L(L+1), where L is the angular momentum of such states. Furthermore, if neutron and proton are both particle-like or both hole-like, the parabola is open down, and if one of them is hole-like, but the other one is particle-like, the parabola is open up[7]. Let me now demonstrate that an approximate parabolic dependence readily follows from the scheme described in the previous paragraph. To do so, I will assume that $j_{\pi} = j_{\nu} = 3/2$. For the two cases, when both unpaired nucleons are particle-like (or hole-like), or when one of them is particle-like and the other one is hole-like, the energy spectrum is described by the same energy formula. However, since the groups are realized in different representations, the quantum numbers, hence the level schemes are different for these two cases. Typical spectra for these two possibilities are shown in Fig. 1, where the same parameters are used to calculate both spectra. The energies of four low-lying states as a function of L(L+1) are plotted in Fig. 2. We observe that these states approximately lie on a parabola, which is inverted appropriately when particle or hole character of the configuration changes[6].

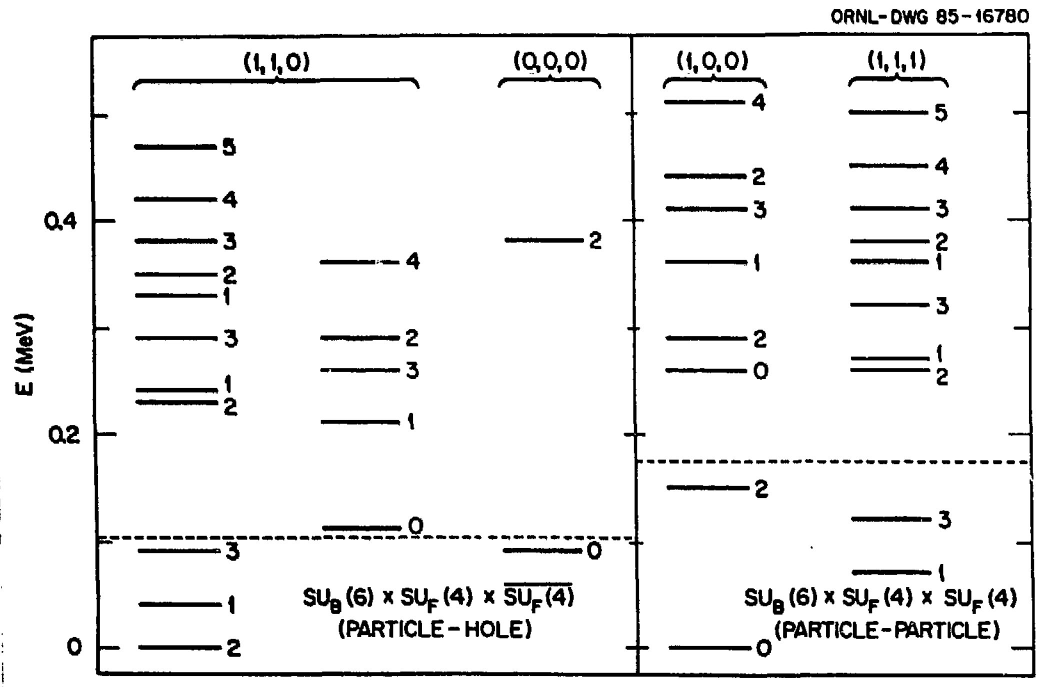


Fig. 1. Typical spectra for odd-odd nuclei when $j_\pi = j_\nu = 3/2$. The $Spin_F^{\pi,\nu}(6)$ representations are shown at the top of the figure.

## 3. EMBEDDING IN A SUPERGROUP

So far I have only talked about the Bose-Fermi symmetries for odd-odd nuclei. Now let me briefly explain how to embed a group structure like $U_B(6) \times U_F(m_\pi) \times \overline{U}_F(m_\nu)$ into a supergroup. First if $m_\pi = m_\nu \equiv m$, we observe that the embedding[8]

$$Sp_F(2m) \supset SU_F(m) \tag{1}$$

places the odd-odd nucleus, and the two quasi-particle states of the even-even nuclei in the same representation of $Sp_F(2m)$ since the $\langle 1^2 \rangle$ representation of Sp(2m) decomposes into SU(m) representations as

$$\langle 1^2 \rangle = \begin{array}{|c|}\hline \phantom{\bullet} \\ \hline \phantom{\bullet} \\ \hline \end{array} \oplus \begin{array}{|c|}\hline \bullet \\ \hline \bullet \\ \hline \end{array} \oplus \begin{array}{|c|c|}\hline \bullet & \phantom{\bullet} \\ \hline \end{array} \tag{2}$$

The decomposition $U_F^\pi(m) \times U_F^\nu(m) \supset U_F^{\pi,\nu}(m)$ yields the adjoint ( $\begin{array}{|c|c|}\hline \bullet & \phantom{\bullet} \\ \hline \end{array}$ ) and the singlet representations of $U_F(m)$. The adjoint representation is already included in Eq. (IV.2). The singlet comes from the

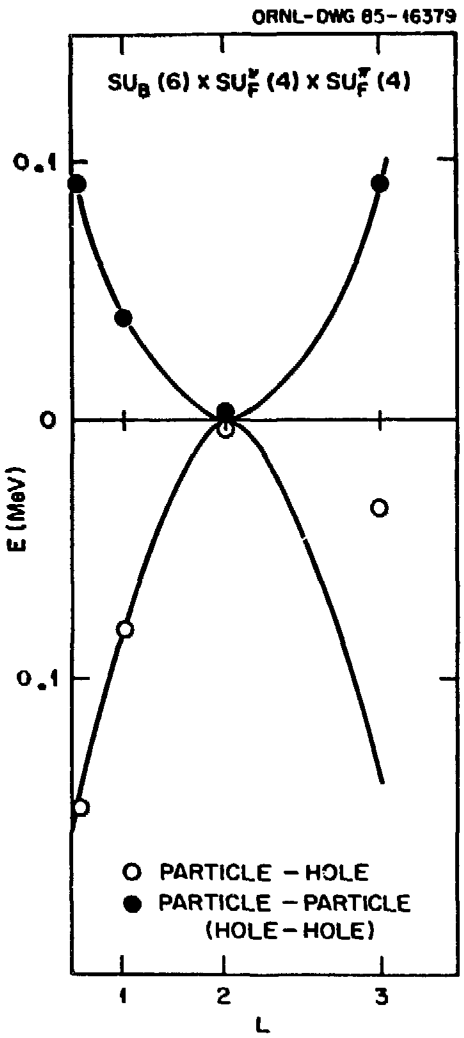


Fig. 2. Realization of the parabolic rule in the Bose-Fermi symmetry for odd-odd nuclei.

decomposition $U_F(2m) \supset Sp_F(2m)$, since the two-fermion representation $\{1^2\}$ of $U_F(2m)$[2] contains $\langle 1^2 \rangle$ and $\langle 0 \rangle$ of $Sp_F(2m)$. Hence the dynamical supersymmetry starts with the chain

$$U(6/2m) \supset U_B(6) \times U_F(2m) \supset U_B(6) \times Sp_F(2m) \supset U_B(6) \times U_F(m) \qquad (3)$$

and can be continued in the standard fashion[2].

## 4. APPLICATION TO ODD-ODD GOLD ISOTOPES

In the Pt-Au region, the odd-neutron occupies mostly the levels

$j^{\nu} = 1/2^-$, $3/2^-$, $5/2^-$ ($p_{1/2}$, $p_{3/2}$, $f_{5/2}$), and the odd-proton occupies the levels $j = 1/2^+$, $3/2^+$, $5/2^+$ ($s_{1/2}$, $d_{3/2}$, $d_{5/2}$). For this region $m_{\pi} = m_{\nu} = 12$. We assume that for $^{196}$Au and $^{198}$Au nuclei, the neutron orbitals enumerated above can be considered as particle-like[9]. Since the protons are hole-like, unpaired protons and neutrons can be placed in conjugate representations and the scheme described in the previous sections may be applicable. A typical spectrum predicted by the Sp(24) scheme is shown in Fig. 3, where the boson number is taken to be n = 5

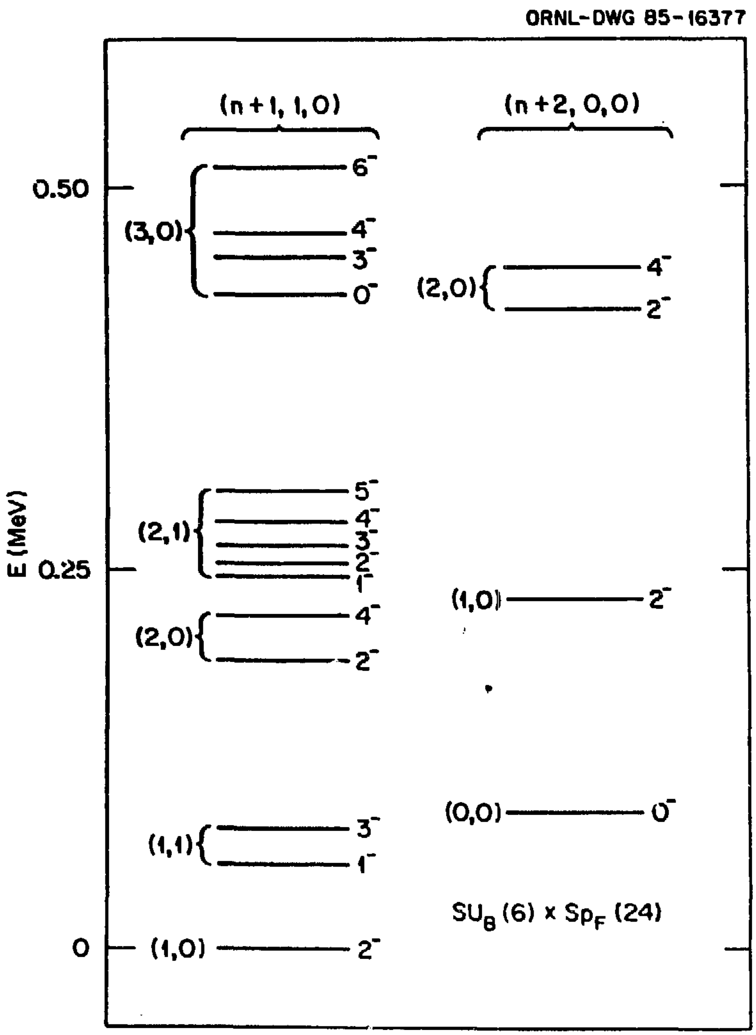


Fig. 3. A typical spectrum with $U_B(6) \times Sp_F(24)$ symmetry.

(same as the $^{196}$Au core). Unfortunately, there is very little data available on the level scheme of $^{196}$Au. If one assumes that the structure of the low-lying levels would not considerably change from $^{198}$Au, one might expect to get a rough idea about the applicability of this scheme by examining the level scheme of $^{198}$Au. A comparison of Fig. 3 with the experimental level scheme for $^{198}$Au is encouraging. In this figure a third band is not shown. The two lowest levels of this band has L = 1 and 3, and the bandhead (L=1) state can be placed at ~200 keV by choosing the parameters appropriately. Except for a low-lying $3^-$ state, there is a reasonable correspondence between the experimental spectra and the levels predicted for $E < 300$ keV. In particular, the ground state spin is correct, the experimentally observed three $1^-$ states and the $4^-$ state are accounted for. On the contrary, the scheme presented in Refs. 4 and 5 predicts the wrong ground state spin, and an additional low-lying $0^-$ state which is not experimentally seen. Furthermore, it cannot account for the experimentally observed $4^-$ state. These states cannot originate from the coupling of the positive-parity $i_{13/2}$ neutron orbit and the negative-parity $h_{11/2}$ proton orbit either as was also pointed out in Ref. 5. Further experimental exploration of a low-lying $3^-$ state in $^{198}$Au and a study of the low-lying negative parity states in $^{196}$Au is requisite to establish the validity of our scheme in this region. Obviously, a study of the energy spectrum alone is not sufficient in assessing the significance of a new symmetry, especially since the energy differences are very small (~75 keV). It is also essential to study experimentally the electromagnetic transition rates, since such a study provides the best test of the wavefunctions of the model. I should indicate, however, a potential difficulty if one wants to extend the present scheme to a dynamical supersymmetry describing the neighboring even-even, odd-even, and even-odd nuclei in this region. Namely, the odd-proton isotopes $^{195}$Au and $^{197}$Au would not be satisfactorily described in such an extended scheme. In particular, the appropriate Spin(6) limit, which was shown to be successful in describing these isotopes, cannot be obtained when the odd proton occupies three orbitals with $j = 1/2, 3/2, 5/2$. Hence, no attempt has been made to extend this dynamical Bose-Fermi symmetry for odd-odd nuclei to a supersymmetry.

The Sp(24) scheme outlined above motivated further work on the dynamical symmetries for odd-odd nuclei[11]. These authors found that although there is considerable difference between particle-hole and hole-hole representations of the dynamical symmetry $U_B(6) \times U_F^{\pi}(12) \times U^{\nu}(12)$, there is negligible difference between the hole-hole and particle-hole representations of the dynamical symmetry $U_B(6) \times U_F^{\nu}(12) \times U_F^{\pi}(4)$. Much further work is needed before we achieve a successful algebraic description of odd-odd nuclei. However, I believe that the algebraic distinction between the fermions with particle and hole character, and the following realization of the parabolic rule are the right steps in this direction.

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