MICROSCOPIC DESCRIPTION OF DECOUPLED $h_{11/2}$ BANDS. THE NEGATIVE PARITY SPECTRA OF THE Au NUCLEI ☆

K.T. HECHT
Physics Department, University of Michigan, Ann Arbor, Michigan 48104, USA

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The decoupled $h_{11/2}$ bands in Au nuclei are investigated in the framework of a shell model description based on the coupling of an $h_{11/2}$ proton hole to core proton states approximated by the leading representation $(\tilde{\lambda}\tilde{\mu}) = (06)$ of the pseudo SU_3 coupling scheme for the positive parity part of the proton configuration.

Almost all theoretical analyses of high-spin phenomena in deformed nuclei have been based on a quasiparticle description of intrinsic degrees of freedom. The pseudo SU_3 model [1, 2] may furnish an alternate, microscopic approach for the investigation of such phenomena. Although simplified shell model calculations for nuclei in the rare earth region based on leading representations of the pseudo SU_3 scheme show some promise [1], detailed calculations for nuclei in the rare earth region are probably beyond present computer capabilities. For the neutron-deficient isotopes of Ba, La, Ce, ..., where active neutrons and protons are both filling the same ($3s_{3/2}$, $2d_{3/2}$, $2d_{5/2}$, $1g_{7/2}$, and $1h_{11/2}$) orbits, such calculations may become feasible. With the assumption that the $1g_{9/2}$ orbit is filled and spectroscopically inert, it is possible to treat the $s_{1/2}d_{3/2}d_{5/2}g_{7/2}$ part of the shell model space as a pseudo p-f shell. In a deformed field the Nilsson states which grow out of these spherical shell model orbits can be assigned pseudo oscillator quantum numbers $[\tilde{N}\tilde{n}_z\tilde{\Lambda}]$ with $\tilde{N} = 3$. The very near degeneracy of pseudo spin orbit doublets with $\Omega = \tilde{\Lambda} \pm \frac{1}{2}$ (see fig. 1 of ref. [1]) and the approximate validity of the asymptotic quantum numbers $[\tilde{N}\tilde{n}_z\tilde{\Lambda}]$ for realistic nuclear deformations suggest that the pseudo SU_3 scheme may be a good approximation for the many-particle states of this configuration. The filling, in order, of the deformed single particle states $[\tilde{N}\tilde{n}_z\tilde{\Lambda}]$ leads to a many-particle state which becomes an intrinsic state of highest weight for the leading pseudo SU_3 representation $(\tilde{\lambda}\tilde{\mu})$, (maximum possible $2\tilde{\lambda}+\tilde{\mu}$ for prolate, $\tilde{\lambda} + 2\tilde{\mu}$ for oblate deformations). Low energy excitations may therefore be expected to be dominated by the leading pseudo SU_3 representation, of the ($s_{1/2}d_{3/2}d_{5/2}g_{7/2}$) part of the configuration, making possible a severe truncation of the full shell model space. Even if these positive parity parts of the configuration are well described by the leading pseudo SU_3 representation (or a few representations near the leading one), the presence of the negative parity $h_{11/2}$ intruder in the midst of the $s_{1/2}d_{3/2}d_{5/2}g_{7/2}$ shell model orbits can lead to a challenging configuration mixing problem. Interesting physical phenomena, such as the rotational alignment of $h_{11/2}$ nucleons at high spin, and the formation of decoupled bands based on the $h_{11/2}$ orbit [3], are associated with this configuration mixing problem. Because of the pseudo SU_3 truncation of the positive parity part of the shell model space it may be possible to study such phenomena in a shell model framework. Although the aim is to make a detailed study of nuclei in the region of neutron-deficient Ba-Ce isotopes, recent measurements [4–6] of high spin negative parity states in the isotopes of Au have furnished us with a very simple prototype for these more challinging systems. The remarkable similarity of the spectra of the Au isotopes 195, 193, 191, and 189 indicates that the details of the spectra must be determined by the proton configuration only. Although the neutrons paly a vital role in furnishing the field for the proton motion (which is responsible for the validity of the pseudo SU_3 truncation of the shell model space), the neutrons in the present approach serve mainly to renormalize the interaction among protons.

The present investigation examines the high spin negative parity spectra of the Au nuclei in terms of

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Table 1
2-proton-hole components of the leading representation $(\tilde{\lambda}\tilde{\mu}) = (06)$

j_1	j_2	$J = 0$	$J = 2$	$J = 4$	$J = 6$
1/2	1/2	−0.529			
3/2	3/2	−0.748	0.410		
3/2	1/2		0.580		
5/2	1/2		−0.379		
5/2	3/2		0.203	−0.614	
7/2	1/2			0.542	
7/2	3/2		−0.497	0.458	
5/2	5/2	−0.262	0.153	−0.164	
7/2	7/2	−0.302	0.181	−0.210	0.378
7/2	5/2		0.089	−0.221	0.926

the simple microscopic model in which a single $h_{11/2}$ proton hole is coupled to the positive parity proton hole configuration approximated by the leading pseudo SU_3 representation $(\tilde{\lambda}\tilde{\mu}) = (06)$. Two proton holes in the $s_{1/2}d_{3/2}d_{5/2}g_{7/2}$ shell can couple to pseudo SU_3 representations $(\tilde{\lambda}\tilde{\mu}) = (06), (22)$, (pseudo spin $\tilde{S} = 0$); and $(\tilde{\lambda}\tilde{\mu}) = (14), (30)$, $(\tilde{S} = 1)$; with the leading representation, (06), corresponding closely to an oblate axially symmetric core. The 2-hole components for the $J = 0, 2, 4, 6$ states of the (06) representation are shown in conventional *j-j* coupling shell model language in table 1. The effective interaction among the proton holes is chosen to be the simple surface delta interaction. However, the diagonal matrix elements for the $J = 0, 2, 4, 6$ states of the (06) representation are fitted to the observed excitations in the neighboring Hg isotopes. The results of the calculation are shown in fig. 1 where the predicted negative parity spectrum is compared with the experimentally observed [4, 5] states in ^{195}Au. For comparison, fig. 1 also shows the results of the Coriolis coupling calculation of Tjφm et al. [4] for the conventional particle plus axially symmetric rotor model which is most closely related to the present microscopic description. (More recent calculations by Meyer ter Vehn [7] based on a triaxially deformed core would in the present microscopic description correspond to admixtures of $(\tilde{\lambda}\tilde{\mu}) = (22)$ into the dominant (06) representation of the pseudo SU_3 model. Since the 2^+, 3^+, 4^+ and 0^+, 2^+ states needed for this model are not well established in the 2-proton-hole Hg isotopes, such a refine-

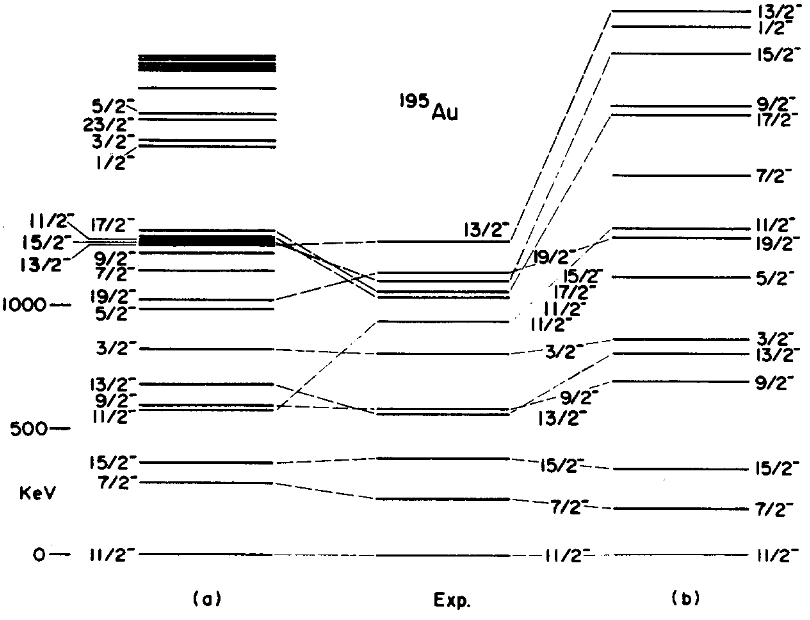

Fig. 1. Comparison of the calculated and experimental $h_{11/2}$ spectrum of ^{195}Au. (a) Results of the shell model calculation based on a single $h_{11/2}$ proton-hole coupled to the leading pseudo SU_3 representation $(\tilde{\lambda}\tilde{\mu}) = (06)$ of the $s_{1/2}d_{3/2}d_{5/2}g_{7/2}$ configuration by a surface delta interaction. (b) Results of a Coriolis coupling calculation based on a particle-plus-axially symmetric rotor model (taken from Tjφm et al. [4]).

ment has not been attempted.) The only parameter in the present calculation is the strength of the surface delta interaction, (for fig. 1, $G = 0.2$ MeV in the notation of ref. [2]); but the qualitative nature of the predicted spectrum is relatively insensitive to changes in this parameter (by factors as great as 2, provided the (06) diagonal matrix elements are fitted to the observed Hg excitations). The predicted excitation energies for the favored $11/2^-$, $15/2^-$, $19/2^-$, $23/2^-$ branch of the band differ very little from the excitation energies of the 0^+, 2^+, 4^+, 6^+ states in the Hg isotopes. The order and approximate positions of the unfavored spin states are in qualitative agreement with the experimental spectrum with one important exception. The scecond $11/2^-$ level is predicted to lie below the $13/2^-$, $9/2^-$ doublet (about 370 keV below the observed second $11/2^-$ level in ^{195}Au). The predicted E2 and M1 transition probabilities are shown in fig. 2. The transition probabilities are given in relative units on a scale for which the $2^+ \to 0^+$ transition probability in ^{196}Hg is normalized to unity. To fit the experimentally observed BE2 value for this transition an effective proton charge of 3.6 units is needed in the present model, not an unreasonable value in view of the extreme truncation of the shell model space. (With this effective charge the predicted quadrupole

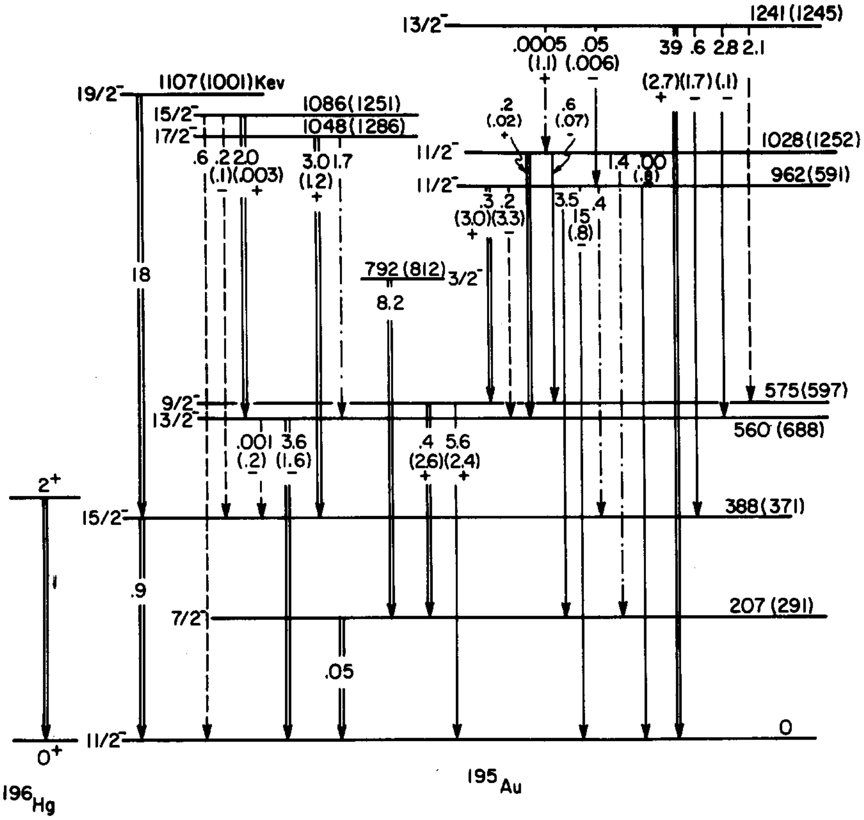

Fig. 2. Predicted E2 and M1 transition probabilities. Double solid arrows indicate transitions with more than 50% of the experimentally observed decay intensity from each level, single solid lines 10–50%, dashed lines < 10%. Transitions corresponding to dot-dashed arrows have not been observed. The numbers on the arrows give the predicted E2 transition probabilities, (upper numbers); and M1 transition probabilities, (lower numbers in parentheses); the ± signs indicate the predicted relative sign of E2/M1 reduced matrix elements. Predicted transition probabilities are based on calculated BE2 and BM1-values but experimentally observed transition energies. Transition probabilities are given in *relative* units on a scale for which the $2^+ \to 0^+$ transition probability in ^{196}Hg is normalized to 1.0. Numbers on the energy levels are the observed excitation energies in keV relative to the lowest $11/2^-$ level (at 318.49 keV); numbers in parentheses are the predicted energies of the model calculation.

moments in the lowest $11/2^-$, $7/2^-$, $15/2^-$, $13/2^-$, and $9/2^-$ states are $Q = +1.9, +1.6, +2.3, +1.0$, and $+0.4$ eb, respectively). No renormalizations have been made of proton g_l and g_s factors for the 3-proton-hole M1 predictions. Large BE2 values are predicted for the favored branch of the decoupled band. The predicted BE2 values for the $15/2^- \to 11/2^-$, $19/2^- \to 15/2^-$, $23/2^- \to 19/2^-$ transitions are 1.4, 1.3, and 0.8, respectively, on a scale where the $2^+ \to 0^+$ BE2 value in the neighboring Hg isotope is fixed at 1.0. Other BE2 values > 1 on this scale involve transitions from unfavored states to the lowest $11/2^-$ state; e.g. $7/2^- \to 11/2^-$ (1.8), $9/2^- \to 11/2^-$ (1.3), or transitions such as $3/2^- \to 7/2^-$ (1.7). With the exception of the $11/2^-$ excitations the predicted transition probabilities are in qualaitative agreement with the characteristics of the observed transition branchings. E.g., the first $13/2^-$ level decays mainly to the $11/2^-$ state with a very weak (predominant M1) branch to the first $15/2^-$ level). The second $15/2^-$ level decays mainly to the $13/2^-$ level, although the predicted M1 component may be too weak. Weak branches to the first $15/2^-$ and lowest $11/2^-$ levels are observed. The observed deexcitation of the $9/2^-$ level favors the $7/2^-$ branch relative to the direct transition to the $11/2^-$ level (by a factor of ~ 2). The predictions, however, favor the $7/2^-$ branch by a similar factor, a feature which is shared by the Coriolis coupling calculations [7]. The predicted decay characteristics of the second and third $11/2^-$ levels are quite different from those of the corresponding observed levels in the Au isotopes, another indication that the present model fails to account for higher $11/2^-$ excitations. This is perhaps not too surprising since the present model has excluded states based on an $h_{11/2}$ proton hole coupled to a second 2^+ excitation of the positive parity proton core. Such 2^+ excitations are observed in the neighboring Hg isotopes around 1 MeV. The model has of course also neglected excitations into the $h_{9/2}$ orbit. Although levels based on such excitations have recently been observed, [8, and refs. quoted in 7], it is not unreasonable to assume that these excitations coexist with the $h_{11/2}$ decoupled bands without greatly perturbing the latter, since the observed $h_{9/2}$ excitation energies decrease from 1068 to 315 keV in going from ^{195}Au to ^{189}Au, whereas both the favored and unfavored branches of the $h_{11/2}$-decoupled bands are remarkably similar in all isotopes of Au from 195 to 189.

Although the present calculation is based on a shell model description of the three proton holes in the Au nuclei, it should be remarked that the results show some features of the weak coupling model used by De-Shalit [9] in an attempt to understand the positive parity spectrum of the Au nuclei. In terms of the abbreviated notation, $|J\rangle \equiv |[(\widetilde{\lambda}\widetilde{\mu}) = (06)J \times 11/2]IM_I\rangle$ for the state vectors of the 3-proton-hole states of the present model, the eigenvector for the lowest $I = 11/2^-$ state, e.g., is given by

$$0.912|0\rangle - 0.382|2\rangle + 0.141|4\rangle - 0.037|6\rangle,$$

predominantly an $h_{11/2}$ proton hole coupled to the 0^+ state of the "core". The eigenvector for the lowest $15/2^-$ state is

$$0.976|2\rangle - 0.229|4\rangle + 0.061|6\rangle,$$

with eigenvectors of very similar structure for the lowest $7/2^-$, $9/2^-$, and $13/2^-$ states.

The qualitative success of the present oversimplified model for the Au nuclei indicates that it may be possible to investigate high spin phenomena involving the $h_{11/2}$ orbit in a shell model framework based on a pseudo SU_3 truncation, particularly in nuclei in the Ba–Ce region where the interaction among active neutrons and protons can be treated explicitly.

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