Submitted to Physical Review Letters

LBL-3416
Preprint c.2

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September 19, 1974

Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

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LBL-3416

Rotational Band-Structures in Transitional Odd-A Nuclei*

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Abstract

The spectrum of a single-j nucleon coupled to a triaxially deformed core is investigated. A system of rotational bands characterized by low-lying quasi-γ-bands is shown to exist in the triaxial region. A comparison of energies and transition probabilities is made with the negative parity states based on the h11/2-shell in ^{187}Ir and ^{195}Au. The model reproduces all known high- and low-spin states of this group. The model applies to other transitional odd-A nuclei in the A = 190 and the A = 135 mass region.

The model of an odd nucleon coupled to a rotating core has proved to be very successful for well deformed odd-A nuclei. The aim of the present paper is to show that this model also applies to transitional, odd-A nuclei, provided one allows for triaxially deformed cores. In particular, this holds in the A = 190 and A = 135 mass region where low-lying second 2^+ states are observed for even-mass nuclei. The discussion will be restricted to unique parity states for which the odd nucleon is located in a rather pure single-j shell. The stretched-E2 yrast bands observed in a number of transitional nuclei can be well understood as particle-rotation alignment assuming the high-j nucleon coupled to an axially symmetric core[1]. In order to describe, however, other states of the unique parity system simultaneously with the yrast states, one has to consider triaxial cores, as reported previously in Ref. 2. In the present paper, this model is investigated in more detail considering the complete low-lying level scheme. The model describes the continuous transition from strongly-coupled to decoupled spectra by changing the shape-asymmetry γ between 0° and 60°. As a new result, a system of quasi-rotational bands having normal spin sequence and including very low quasi-γ-bands is shown to exist in the triaxial regime. This band-structure is dominant in the region of strong coupling ($30° < \gamma < 60°$ for particles, $0° < \gamma < 30°$ for holes), but is also present in the decoupled region, though less apparent. The calculated level schemes will be compared with the h11/2-level systems of ^{187}Ir and ^{195}Au as typical examples for a strongly-coupled and a decoupled type of spectrum, respectively. These two transitional nuclei are favored examples since rather complete level schemes are known from heavy-ion and β-decay experiments, and it is one of our objectives to show that the model accounts for all known high- and low-spin states of the h11/2-systems.

The model Hamiltonian, as given in Ref. 2, has been generalized to include the effect of partial filling of the single-j shell and the effect of pairing. This is accomplished by taking the particle's Hamiltonian as

$$H_p = \sqrt{(\epsilon_v - \lambda_F)^2 + \Delta^2} \ ,$$

where λ_F is the Fermi energy, Δ is the pairing gap, and $\epsilon_v (v = 1, 2, \cdots, (j+1/2))$ are the energy eigenvalues of the particle in the field of the triaxial core which is determined by the deformation β and the shape-asymmetry γ. All the other details of the calculation are the same as in Ref. 2.

In Fig. 1, the calculated spectrum of an h11/2-hole coupled to a triaxial prolate core is shown and compared with the measured h11/2-system in ^{187}Ir[3]. Note that only one parameter has been fitted directly to ^{187}Ir. All the calculated levels have been grouped in bands with band-heads having spins from 5/2 to 15/2. This order is based on B(E2)- and B(M1)-values which are found to be rather regular within the bands being of the order $B(E2) \approx 0.8\ e^2 b^2$ and $B(M1) \approx 2\mu_N^2$. The magnetic quantities have been calculated with $g_R = Z/A$ and $g_s = 0.6\ g_s^{free}$. The nature of these bands is best seen from the dominant components of the wavefunctions

$$\Psi_{IM,j} = \sum_{K,\Omega} C_{K,\Omega}^{(I,j)} (D_{M,K}^{(I)} X_{\Omega}^{(j)} + (-)^{I-j} D_{M,-K}^{(I)} X_{-\Omega}^{(j)})$$

($|K - \Omega| = 2n$, $n = 0, 1, 2 \cdots$; $\Omega > 0$) as given in Table 1 for some of the lowest states. Though K and Ω are not good quantum numbers due to the lack of axial symmetry, it turns out that the states can be classified by the K and Ω values of the dominant components which are the same at least for the lowest states of each band. The 11/2 - band is seen to be basically the $\Omega = 11/2$ [505] band but strongly mixed with the $\Omega = 9/2$ [514] band. The structure of the 7/2-band is

predominantly that of a ($K-\Omega=-2$) γ-band related to the 11/2-band, the structure of the 15/2 - band that of the corresponding ($K-\Omega=+2$) γ- band, but less pronounced. Note that the 15/2 - band represents the yrast band. The 5/2- and 13/2 - band can be interpreted in the same way as quasi-γ-bands related to the 9/2- band which contains large components of the $\Omega = 9/2$ [514] band. The agreement of the calculated bands and their transition rates with experiment is obvious from Fig. 1. The staggering of the experimental yrast band could be better reproduced with a slightly larger γ; this indicates variations of γ in different bands. The theory suggests spin-values for all levels where experimental assignments are lacking. Since the calculation predicts a strong mixing of the 13/2- band with the yrast band, the measured 1127 keV state is a clear candidate for the 15/2 state in the 13/2-band both because of its energy and its decay. The measured[4] $B(E2, 7/2(305) \rightarrow 11/2\,(0)) = 0.3\ e^2b^2$ is in excellent agreement with the calculated value $0.32\ e^2b^2$.

In Fig. 2, theory and experiment[5,6] are compared for ^{195}Au. Note that none of the model parameters has been fitted to ^{195}Au. The calculation reproduces the level order as well as the characteristics of the transition branchings. The rotational band-structure, seen in ^{187}Ir, is now less obvious. This is because γ has changed to the oblate side where nucleon-holes tend to decouple from the core and because β has decreased. Nevertheless, the 11/2-band (connecting the basic 11/2 with the first 13/2 and second 15/2 state) and the onset of the 15/2-band (with the first 15/2 and 17/2 state) can still be identified in both the calculated and the measured spectrum. Three more negative parity states than shown in Fig. 2 have been found for ^{195}Au in a recent β-decay study[7], a 9/2 state at 1068 keV and two (9/2, 11/2, 13/2) states at 1406 and 1487 keV. The calculation yields a second 9/2 state, but no more 9/2, 11/2, or 13/2 states in this region. Considering the decay of the additional states to their $9/2^-$ member and then most strongly to a $7/2^+$-state

one is tempted to attribute them to an h 9/2- system with a basic $9/2^-$ state and, depending thereon, an $11/2^-$ and a $13/2^-$ state, in analogy to the first $13/2^-$ and $15/2^-$ levels of the h 11/2- system. Provided this interpretation is right, the calculation accounts for all measured negative parity states in ^{195}Au. Note that the h 9/2- system has recently been detected together with the h 11/2- system in ^{189}Au[8] and is now well established in ^{187,189}Ir[3].

We conclude that the assumption of a rigid, triaxial shape appears to be a simple means to account for the complicated correlations in the wave-functions of transitional nuclei[9], at least in so far as they are relevant for low-lying states in odd-A nuclei. The model describes various intermediate coupling situations as exemplified here for ^{187}Ir and ^{195}Au and seems to provide a rather complete understanding of energy spacings and transition rates in these nuclei. Similar spectra are observed in the neighboring odd-A Ir-, Au-, and Tl-isotopes and in the A = 135 mass region where β-decay spectra e.g. for ^{133}La[10], ^{135}Pr[11], and ^{137}Nd[12] have been measured recently in addition to the yrast states. This shows that the model applies to transitional nuclei in different mass regions.

The author thanks Dr. J. Jastrzebski for the communication of new data on ^{187}Ir prior to publication and also Drs. R. M. Diamond and F. S. Stephens for enlightening discussions.

Footnotes and References

*Work performed under the auspices of the U. S. Atomic Energy Commission, and supported in part by the Deutsche Forschungsgemeinschaft.

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Table 1. Dominant components $\left| C^{(I,j)}_{K,\Omega} \right|^2$ of calculated wave-functions for ^{187}Ir.

I	E (keV)	K = 11/2, Ω = 11/2	K = 9/2, Ω = 9/2
11/2	0	0.86	0.11
13/2	314	0.73	0.19
15/2	721	0.44	0.18
		K = 7/2, Ω = 11/2	K = 5/2, Ω = 9/2
7/2	385	0.86	0.10
9/2	608	0.71	0.20
11/2	864	0.52	0.29
		K = 15/2, Ω = 11/2	K = 11/2, Ω = 11/2
15/2	438	0.69	0.15
17/2	777	0.45	0.22
19/2	1098	0.31	0.19

Figure Captions

Fig. 1. Comparison of the calculated and the experimental h11/2-spectrum for ^{187}Ir including spins, energies (keV) and transition intensities. Parameters used in the calculation: $\beta = 0.21$ determined from the averaged energy of the first 2^+ states in ^{186}Os and ^{188}Pt, $\gamma = 24°$ from the energy ratio of the second 2^+ and the first 4^+ state in ^{188}Pt (see Ref. 2), $\Delta = 0.7$ MeV from odd-even mass differences, $\lambda_F = \epsilon_5 + 0.58 \cdot (\epsilon_6 - \epsilon_5)$ from an estimate of 10 protons in the h11/2-shell for ^{187}Ir, based on a Nilsson-level-scheme, and by adjusting the first 9/2 state approximately to the corresponding state in ^{187}Ir. Solid lines indicate transitions with 80 to 100%, broken lines transitions with 20 to 80% of the strongest decay intensity of each level. Calculated intensities are based on calculated B(E2)- and B(M1)-values, but experimental transition energies when known. Q and μ are quadrupole and magnetic moment of the basic 11/2 state.

Fig. 2. Comparison of the calculated and the experimental h11/2-spectrum for ^{195}Au. Parameters used in the calculation: $\beta = 0.14$ determined from ^{194}Pt and ^{196}Hg, $\gamma = 37°$ from ^{196}Hg, $\Delta = 0.7$ MeV, $\lambda_F = \epsilon_6 + 0.5 \cdot (\epsilon_6 - \epsilon_5)$ from a Nilsson-level-scheme. For further details see caption of Fig. 1.

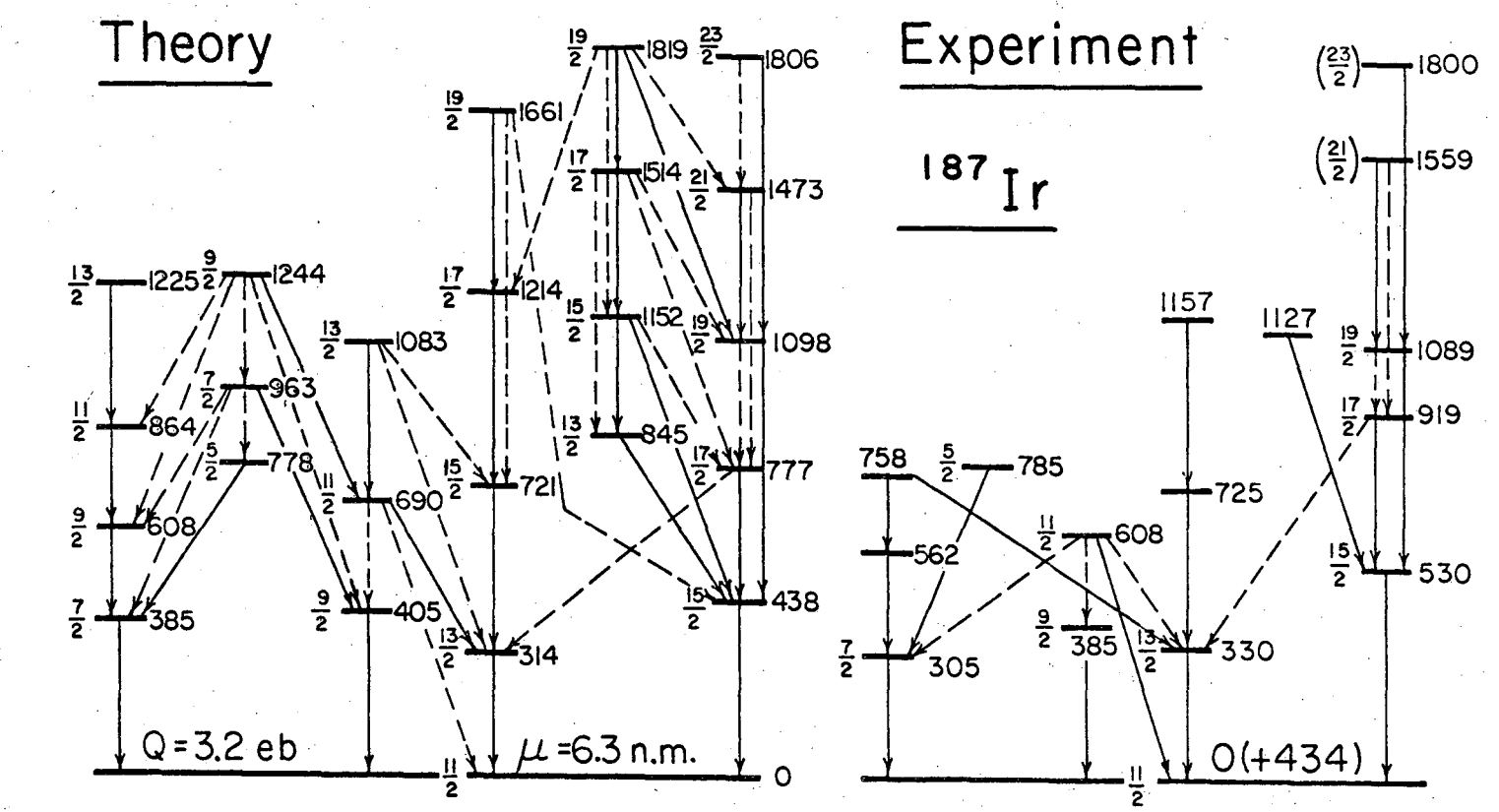
Theory
Experiment
187 Ir
Q = 3.2 eb
μ = 6.3 n.m.
0(+434)
β = 0.21 γ = 24° λ = 0.42 Δ = 0.7 MeV h 11/2 - system
XBL749-4249

Fig. 1

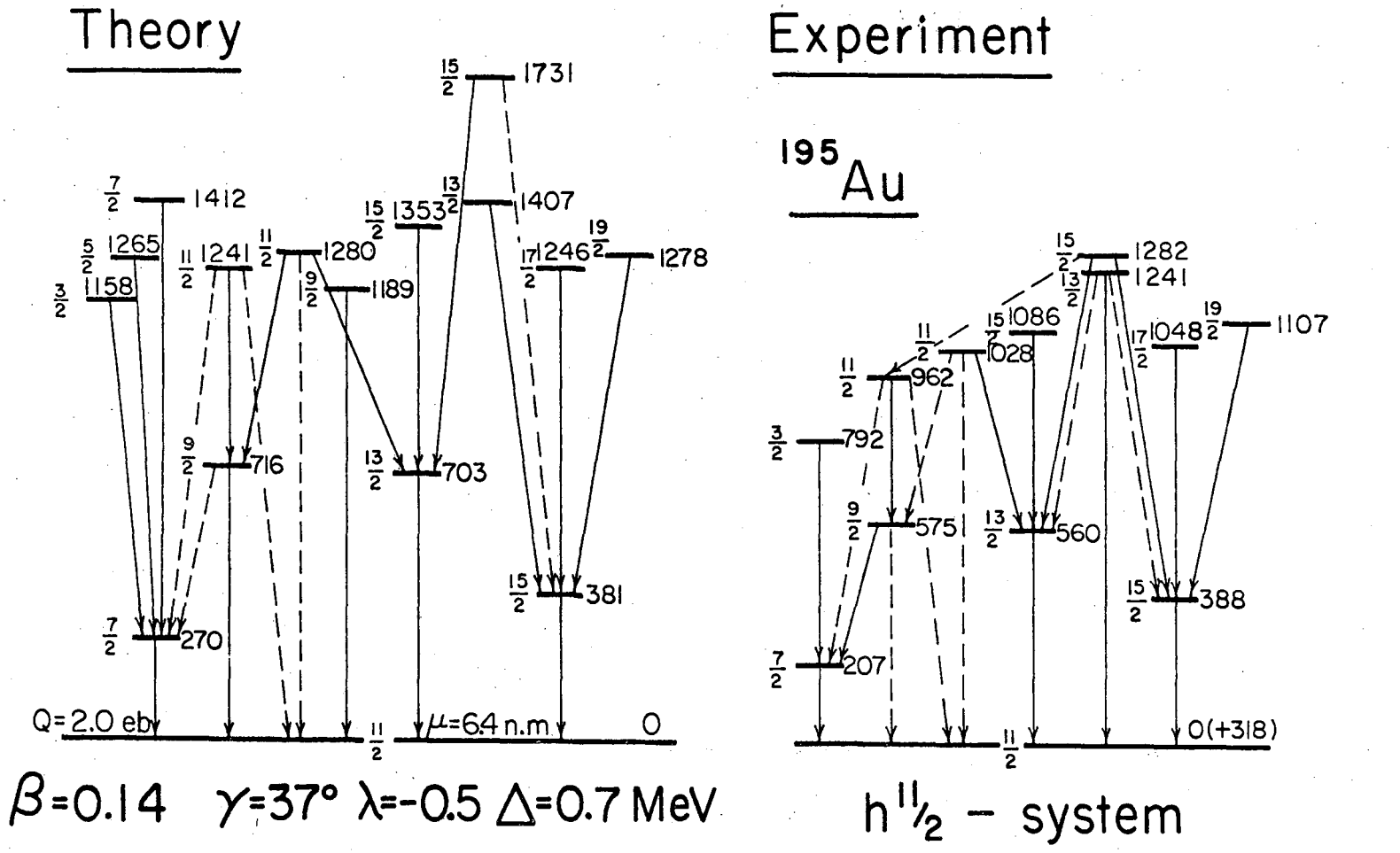
Theory
Experiment
195Au
Q=2.0 eb
μ=6.4 n.m
β=0.14 γ=37° λ=-0.5 Δ=0.7 MeV
h11/2 - system
XBL749-4250

Fig. 2

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