THE ROTATIONAL AND VIBRATIONAL DESCRIPTIONS OF ^{193,195}Au

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I. INTRODUCTION

The relation between the rotational and vibrational descriptions of the odd mass transitional nuclei has been investigated for a long time |1-3|. However, due to the lack of accurate and extensive experimental data on their complex level spectra with medium excitation energy the search for such relationship was mainly restricted to the low-lying excited levels.

The recent extensive experimental investigations carried out on the ^{193,195}Au level schemes using both radioactive |4,5| and nuclear reaction |6| studies make these nuclei a favourable case for testing experimentally the theoretical properties, predicted by different models, of their medium excited levels ($2.5 > E > 0.5$ MeV).

For that purpose we made extensive calculations with the Alaga and the Kisslinger-Sorensen intermediate coupling vibrational models and compared their results with those of previous calculations assuming a deformed basis as well as with the available experimental data.

The present report summarizes a few results obtained in this investigation. The negative and positive parity levels of ^{193}Au and ^{195}Au found in the quoted experimental studies |4-6| are compared in figs. 1 and 2 with different theoretical spectra calculated from rotational and vibrational models.

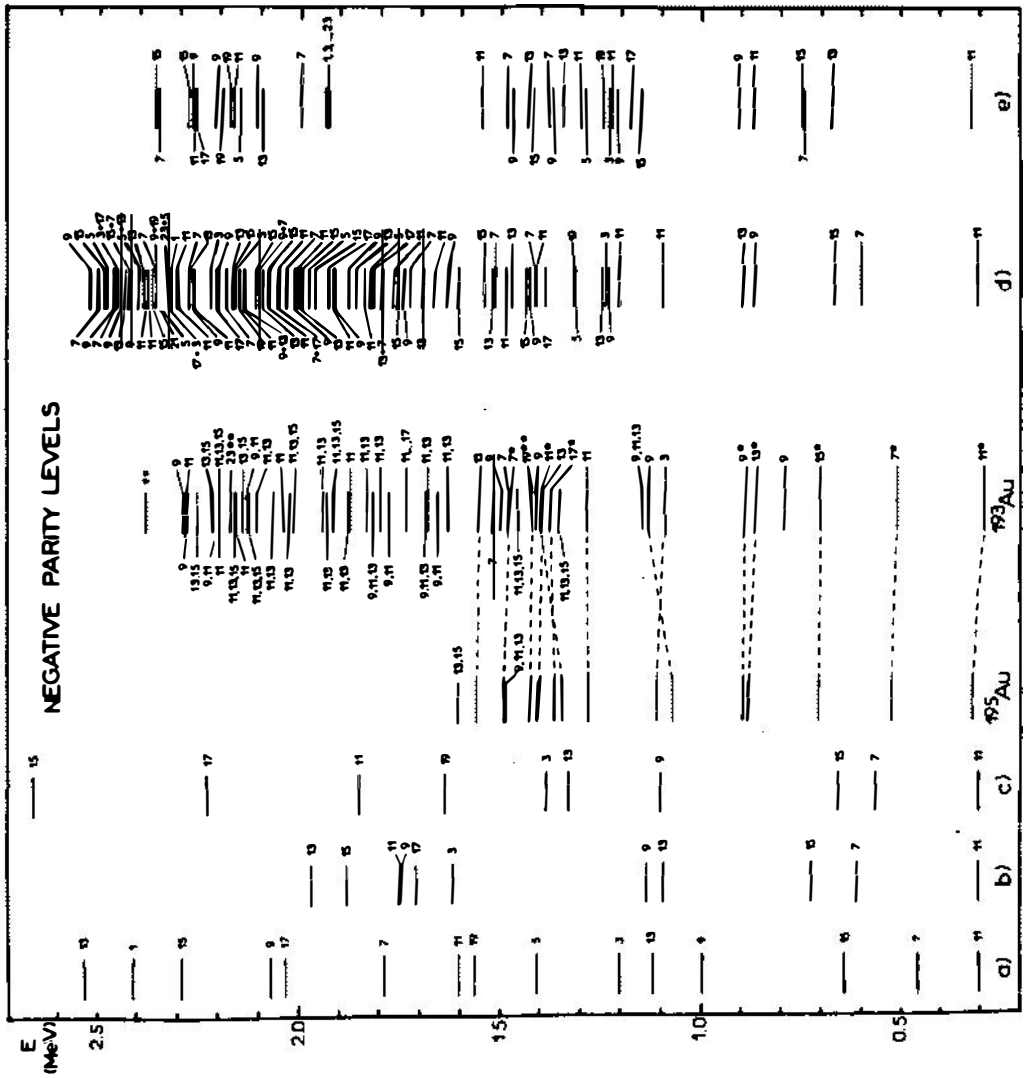

Fig. 1

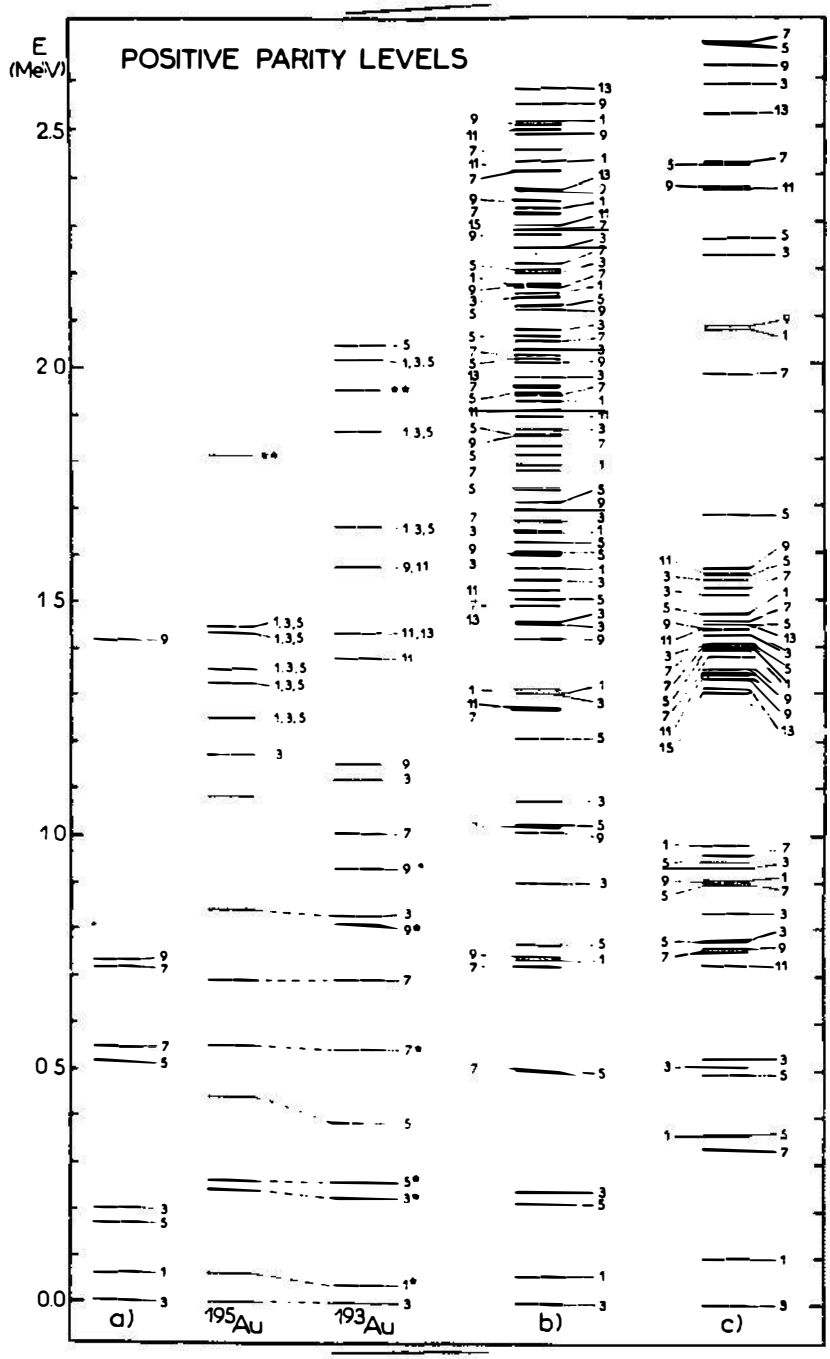

Fig. 2

Fig. 1. Comparison between the ^{193,195}Au experimental and theoretical negative parity states. All the levels represented without a double asterisk (**) were established by radioactive decay studies |4,5|. Those states labelled by a double asterisk were obtained exclusively from (α,xnγ) and (Li^7,xnγ) reaction studies |6|. The levels established with both methods are represented by a single asterisk (*). The theoretical spectra (a,b,c) are those calculated by Stephens and co-workers |6,8| assuming one proton hole ($1h_{11/2}$) coupled to different types of rigid rotors: symmetric with pairing correlations (a), asymmetric without pairing correlations (b) and symmetric without pairing correlations (c). The theoretical spectra for the cluster vibration (d) and the quasi particle vibration (e) models were derived from the present calculations with the parametrization given in the text. For clearness, double spin values are indicated for all levels except for the ^{195}Au states identified also in ^{193}Au (levels connected by dotted lines).

Fig. 2. Comparison between the ^{193,195}Au experimental and theoretical positive parity states. The asterisks have the same meaning as in fig. 1. The theoretical spectrum (a) was derived from the results of the calculations made by Hecht and Satchler |9| with the parameters quoted in the text. The theoretical spectra (b) and (c) are those deduced from the results of the present calculations made with the Alaga and the Kisslinger-Sorensen models, respectively. The same spin notation as in fig. 1 was adopted.

II. ROTATIONAL DESCRIPTIONS

Stephens and co-workers have recently performed several calculations |6-7| with the rotation aligned scheme for the negative parity states of the odd mass gold isotopes. The theoretical level spectra a, b, c (see fig. 1) correspond to one $1h_{11/2}$ hole coupled to a symmetric rotor (with pairing correlations included |6|), to an asymmetric rotor ($\beta = 0.131$, $\gamma = 37.4^{o}$ without pairing |8|) and to a symmetric rotor ($\beta = 0.113$, $\gamma = 60^{o}$ also without pairing |8|), respectively. From the comparison between these theoretical and those experimental spectra the following conclusions can be drawn:

(i) Only fifteen theoretical states are predicted with an excitation energy lower than 2.5 MeV but fifty two experimental levels were established in ^{193}Au.

(ii) The mean deviation between the theoretical and the experimental energies of each level is nearly the same (= 300 keV) in each calculation. However, there is a better agreement for the levels interpreted by Stephens as members of favoured ($11/2^{-}_{1}$, $15/2^{-}_{1}$, $19/2^{-}_{1}$) and unfavoured ($9/2^{-}_{1}$, $13/2^{-}_{1}$, $17/2^{-}_{1}$) bands with the asymmetric rotor model ($\langle\Delta E\rangle$ = 260 keV) spectrum (b) than with the symmetric ones (a,c). Nevertheless, the former model still has several serious limitations, mainly concerning the positive parity state description. Indeed, the only calculation available for these states was made by Hecht and Satchler |9| by coupling a $2d_{3/2}$ proton to an asymmetric rotor. Adjusting the $3/2^{+}_{1}$ and $7/2^{+}_{1}$ theoretical and experimental excitation energies (which correspond to $\gamma = 15^{o}$ for $\beta = 0.20$) there is a satisfactory agreement for the other six lowest levels ($\langle\Delta E\rangle$ = 70 keV, see fig. 2a). However, it is known |10-15| that the influence of the $3s_{1/2}$ neighbouring shell cannot be neglected for the description of these states. Finally, it should be noticed that there are not yet available theoretical predictions on the

reduced electromagnetic transition probabilities of these models with deformed basis applied to the odd mass gold isotopes.

III. VIBRATIONAL DESCRIPTIONS

There are several vibrational descriptions of the odd mass gold isotopes: three valence-shell proton holes cluster coupled to quadrupole vibrations (Alaga model) |10-11|, one quasiparticle coupled to quadrupole vibrations (Kisslinger-Sorensen model) |12| and core-excited (A. de Shalit) model |13,14|. The properties of ^{193,195}Au were calculated, in the present work, according to the cluster-vibration model, which describes ^{197,199}Au completely and accurately |10,15|. The following parametrization was adopted for these calculations:

(a) The single hole energies ($\varepsilon_{1/2}$ = 0.00; $\varepsilon_{3/2}$ = = 0.20; $\varepsilon_{5/2}$ = 1.00; $\varepsilon_{7/2}$ = 3.50 and $\varepsilon_{11/2}$ = 1.34 MeV) are nearly those of ^{207}Tl |16| but the $2d_{3/2}$ and $2d_{5/2}$ levels were approached to the $3s_{1/2}$ level.

(b) The strength of the residual pairing force is G = 23/A = 0.12 |12|, the phonon energy and the particle-vibration coupling strength are $\hbar\omega$ = 0.5 and a = 0.4 MeV, respectively.

The negative and positive parity level spectra calculated with this model and parametrization, are drawn in figs. 1d and 2b, respectively. In the same figure are also included the spectra calculated with the Kisslinger-Sorensen model adopting a parameter set similar to the one used in the Alaga model calculations (see figs. 1e and 2c). From their comparison with the experimental level spectra the following conclusions can be drawn:

(i) The one quasiparticle model gives a more complete and accurate description of ^{193,195}Au levels than the rotational models considered previously. For example, the lowest twenty eight ^{193}Au levels and nineteen ^{195}Au levels are

fairly described (<ΔE> = 195 keV) but the density of high energy levels is lower than observed.

(ii) The cluster-vibration model gives the best description |17| of these isotopes. Indeed, it well reproduces not only the excitation energies of all the quoted above lowest levels (<ΔE> = 87 keV) but also their experimental level densities at higher energies.

These results show that the contributions of three holes (or three quasiparticles) configurations are essential to describe the high excited states where they play a preponderant role. However, the influence of the neglected correlations (higher multipolarities of the residual force, velocity dependent interactions, phonon anharmonicities) as well as the possibility of a better parametrization should be kept in mind when interpreting quantitative results obtained with these vibrational models.

Now some electromagnetic properties (static moments Q and μ, reduced transition probabilities B(M1) and B(E2), sign of the mixing ratios $\delta = \langle E2\rangle/\langle M1\rangle$) predicted by the cluster vibration model will be discussed (see table 1). In these calculations the effective charges $e^p = 2.0$, $e^{vib} = 3.0$ and the gyromagnetic ratios $g_R = Z/A$, $g_\ell = 1$ and $g_s = 0.8\, g_s^{free}$ were adopted.

The theoretical Q values corresponding to the negative parity yrast states with low and medium excitation energies are positive suggesting effective oblate deformations. However, there are no experimental values to check these predictions of the Alaga model. According to the zero order approximation, the negative parity yrast states are based on several clusters coupled to no phonons $[(s_{1/2}^{-2})0, h_{11/2}^{-1}]11/2$, $[(s_{1/2}^{-1}\, d_{3/2}^{-1})2, h_{11/2}^{-1}]7/2...$ ...15/2, or one phonon $\{[(s_{1/2}^{-1}\, d_{3/2}^{-1})2, h_{11/2}^{-1}]I|12\rangle\}3/2...$ ...19/2. Consequently, the ΔI = 1,2 theoretical transitions between these states are rather strong as experi-

mentally observed.

All the available electromagnetic experimental data concerning the positive parity states are well reproduced by the cluster vibration model predictions. For example, the theoretical magnetic dipole moment of the $3/2^+$ ground state is close to the experimental values ($\mu_{3/2}$ = 0.139 and 0.147 μ_N of gold 193 and 195, respectively). The ^{193,195}Au electric quadrupole moments $Q(3/2_1^+)$ have not yet been measured but the corresponding ^{197}Au experimental value, $Q(3/2_1^+) = 0.58 \pm 0.01$ eb is close to the theoretical one. Furthermore, according to this model, the main components of the $3/2_1^+$ and $1/2_1^+$ states come from the $[(s_{1/2}^{-2})0, d_{3/2}^{-1}]3/2$ and $[(d_{3/2}^{-2})0, s_{1/2}^{-1}]1/2$ clusters, respectively. These interpretations account satisfactorily for the large hindrance factor (1/1600) of the $1/2_1 \rightarrow 3/2_1$ M1 transition. In the same way, the identification of the $5/2_1^+$ level with the one phonon vibrational state $[(s_{1/2}^{-2})0, d_{3/2}^{-1}|3/2]12>$ explains the strong $5/2_1 \rightarrow 3/2_1$ E2 transition $[(B(E2)_{exp} = 0.20 \pm 0.12\ (eb)^2]$. Finally, the theoretical spectroscopic factors of $3/2_1^+$, $1/2_1^+$ and $11/2_1^-$ states populated by pick-up reactions are sizeable and have the same order of magnitude. This very pronounced feature provides an important experiment test of the Alaga model. It should be stressed that $S(1/2_1^+) = 0$ according to the asymmetric rotor model calculation of Hecht and Satchler [9].

The systematic coherence (or incoherence) of terms with different orders in perturbation theory explains some features of the cluster vibration model which are characteristic of "weak (or strong) coupling" patterns. For example, the vibration-aligned coupling scheme is established in the yrast region as a geometrical effect creating a "quasirotational band" pattern. More generally, the simple criteria for qualitative predictions of the electromagnetic properties according to the cluster-vibra-

TABLE 1

Electromagnetic properties of ^{193,195}Au calculated in the cluster-vibration model. All the calculated values correspond to the parametrization given in the text. The available experimental data for ^{193}Au and ^{195}Au, taken from refs. |4| and |5|, are:
$B(E2; 1/2^+_1 \to 3/2^+_1) = 0.32 \pm 0.08$ and 0.26 ± 0.07 $(eb)^2$;
$B(M1; 1/2^+_1 \to 3/2^+_1) = 0.0021 \pm 0.0004$ and 0.0035 ± 0.0007 $(nm)^2$;
$B(E2; 5/2^+_1 \to 3/2^+_1) = 0.20 \pm 0.12$ and 0.11 ± 0.06 $(eb)^2$;
$B(M1; 5/2^+_1 \to 3/2^+_1) = 0.024 \pm 0.013$ and 0.022 ± 0.006 $(nm)^2$;
$B(E2; 5/2^+_1 \to 1/2^+_1) = 0.088 \pm 0.064$ and 0.054 ± 0.018 $(eb)^2$;
$B(E2; 7/2^-_1 \to 11/2^-_1) = 0.31 \pm 0.04$ $(eb)^2$;
$\mu(3/2^+_1) = 0.139$ and 0.147 (nm), respectively.

	$B(E2)$ $(eb)^2$	$B(M1)$ $(nm)^2$	sign (δ)			Q (eb)	μ (nm)
$7/2^-_1 \to 11/2^-_1$	0.128	-		$11/2^-_1$		0.342	7.08
$15/2^-_1 \to 11/2^-_1$	0.114	-		$7/2^-_1$		0.22	5.53
$9/2^-_1 \to 11/2^-_1$	0.098	0.148	(-)	$15/2^-_1$		0.70	8.40
$13/2^-_1 \to 11/2^-_1$	0.073	0.148	(+)	$9/2^-_1$		0.06	5.96
$13/2^-_1 \to 15/2^-_1$	0.023	0.229	(-)	$13/2^-_1$		0.23	7.33
$13/2^-_1 \to 9/2^-_1$	0.041	-		$3/2^-_1$	(-)	0.07	3.67
$3/2^-_1 \to 7/2^-_1$	0.155	-		$5/2^-_1$	(-)	0.14	3.96
$17/2^-_1 \to 15/2^-_1$	0.073	0.132	(-)	$17/2^-_1$		0.46	8.78
$17/2^-_1 \to 13/2^-_1$	0.082	-		$19/2^-_1$		0.46	9.62
$19/2^-_1 \to 17/2^-_1$	0.001	0.330	(+)	$21/2^-_1$	(-)	0.09	9.57
$19/2^-_1 \to 15/2^-_1$	0.167	-		$23/2^-_1$	(-)	0.18	10.48
$21/2^-_1 \to 19/2^-_1$	0.032	0.062	(+)				
$21/2^-_1 \to 17/2^-_1$	0.132	-					
$23/2^-_1 \to 21/2^-_1$	0.003	0.465	(-)				
$23/2^-_1 \to 19/2^-_1$	0.181	-					

TABLE 1 (continued)

	B(E2) $(eb)^2$	B(M1) $(nm)^2$	sign (δ)			Q (eb)	μ (nm)
$11/2_2^- \to 11/2_1^-$	0.013	0.007	(-)				
$11/2_2^- \to 7/2_1^-$	0.010	-					
$11/2_2^- \to 9/2_1^-$	0.010	0.212	(+)				
$1/2_+^+ \to 3/2_1^+$	0.192	0.001	(+)	$3/2_1^+$		0.45	0.21
$3/2_2^+ \to 1/2_1^+$	0.113	0.164	(+)	$1/2_1^+$		-	0.94
$3/2_2^+ \to 3/2_1^+$	0.039	0.000	(-)	$5/2_1^+$		0.14	1.30
$5/2_1^+ \to 1/2_1^+$	0.073	-		$3/2_2^+$	(-)	0.38	1.25
$5/2_1^+ \to 3/2_1^+$	0.157	0.066	(-)	$5/2_2^+$		0.45	3.09
$5/2_2^+ \to 1/2_1^+$	0.153	-		$7/2_1^+$		0.29	1.67
$5/2_2^+ \to 3/2_1^+$	0.002	0.215	(-)	$7/2_2^+$		0.27	2.19
$5/2_2^+ \to 5/2_1^+$	0.013	0.000	(-)	$9/2_1^+$		0.14	2.65
$7/2_1^+ \to 5/2_1^+$	0.000	0.103	(+)	$11/2_1^+$		0.03	3.10
$7/2_1^+ \to 3/2_2^+$	0.032	-		$13/2_1^+$		0.17	7.40
$7/2_1^+ \to 3/2_1^+$	0.200	-		$15/2_1^+$	(-)	0.62	8.52

tion model are expressed by the generalized vibration selection and intensity rules (GVISR) |10,18-20|.

IV. CONCLUSIONS

The cluster-vibration and particle-rotation models represent two possible choices of the quantum-mechanical representations for nuclei. The effectivity of these approaches for a particular nucleus depends on what basis (spherical or deformed) is more suitable for its description.

Among the transitional nuclei several cases can be considered:

(i) There are nuclei like ^{57}Fe and $^{51,53,55}Mn$ where the calculations performed with both representations lead to similar results |21|.

(ii) For gold 193 and 195, the spherical basis is more suitable than the deformed representations.

(iii) For the lighter gold isotopes, a detailed comparison between the experimental and theoretical data cannot be performed at present because there are still large gaps and uncertainties on the properties of their levels. For example, in spite of the large amount of experimental work carried out on ^{191}Au |22|, ^{189}Au |23| and, more recently, on ^{187}Au |24| many spin and parity assignments are unknown or uncertain. However, the total nuclear level densities observed for these isotopes are closer to the predictions of the intermediate coupling models than those of the rotational models considered. More extensive and detailed experimental investigations are planned at Orsay and ISOLDE on these isotopes in order to increase our knowledge of their structure.

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