THE ^{193}Au AND ^{195}Au ANALOGUE LEVELS AND THEIR INTERPRETATION

Ch. Vieu and J.S. Dionisio

C.S.N.S.M. (IN2P3) Campus 91406 Orsay, France

I - EXPERIMENTAL METHODS

The mercury 193 and 195 electron capture decays were extensively investigated |1-6| using several experimental methods and techniques (see table 1). The most striking

TABLE 1

Experimental methods

Spectrometer	Use	Measurements range (keV)	Line width (keV)	I_{min}/decay
Ge(Li)	γ or γ-γ	50-2000	2.2	10^{-5}
Si(Li)	e^-	50-2000	1.2-2.5	10^{-6}
$\pi\sqrt{2}$	e^-	10-1600	0.05-0.7	10^{-6}
Gerholm	e^+	50-4000	1.9-90	10^{-4}

All the measurements were performed with isotopically pure samples (average activity ∿3 mCi).

features of this table are the values of the lowest photon and electron intensities measured with different instruments. Particularly remarkable is the lowest electron intensity measured with the $\pi\sqrt{2}$ double focusing β spectrometer. This minimum intensity is at least one order of magnitude smaller than the usual values attained with similar instruments. Such a result was achieved using strong radioactive samples obtained with a medium current E.M. isotope separator |7,8|.

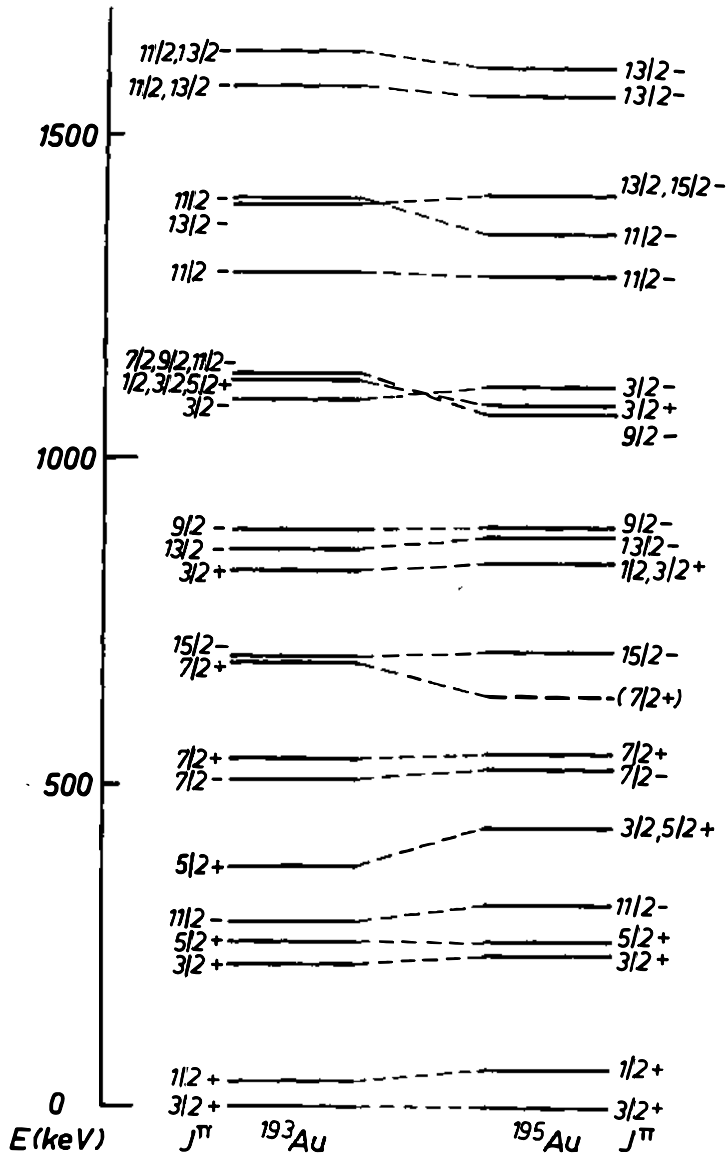

Fig.1. The ^{193}Au and ^{195}Au analogue levels.

II - EVIDENCE FOR ANALOGUE LEVELS

A new very complex ^{193}Au level scheme (74 levels de-exciting through 212 transitions) was established from our extensive spectrometric data. In the same way, a simpler level scheme was built for gold 195 (31 levels and 88 transitions). The lower number of ^{195}Au levels relatively to ^{193}Au is due to the large difference between the total E.C. decay energies of the 195 and 193 mercury isobars.

The detailed comparison between the 193 and 195 gold level schemes gives evidence for the existence of "analogue levels" in these isotopes (see fig. 1). By analogue levels we mean those levels which have the same spin and parity as well as nearly the same excitation energy and deexcitation modes. These remarkable analogies suggest the application of the intermediate coupling vibrational models to the description of these transitional nuclei. Moreover, due to the recent interest in the interpretation of high spin states, our experimental data are also compared with the predictions of the asymmetric rotor model.

III - THEORETICAL INTERPRETATION

The ^{193}Au and ^{195}Au level excitation energies ($E \lesssim 1.6$ MeV) are compared, in table 2, with the energy values calculated in the Kisslinger-Sorensen |9| and the Alaga |10-13| intermediate coupling models. To illustrate the parameter influence on the calculated spectra, the energy eigenvalues for each model are given for two different parameter sets. In the same table are also included the excitation energies obtained by Meyer, Stephens and Diamond in the asymmetric rotor model. The experimental ground state static moments and a few electromagnetic reduced transition probabilities are compared in table 3, to the theoretical values calculated with the Kisslinger-Sorensen and the Alaga models. Finally, the main components of the wave functions used in these calculations are given in table 4. The same analysis cannot be extended here to the rotational model considered because there are no

TABLE 2

The ^{193}Au and ^{195}Au experimental and theoretical excitation energies

I^{π}	^{193}Au	^{195}Au	K-S (1)	A-P (2)	M-S-D (3)
$3/2^+$	0	0	0^*-0^{**}	$0^{\dagger}-0^{\dagger\dagger}$	
$1/2^+$	38.24	61.46	24-155	57-26	
$3/2^+$	224.81	241.53	569-432	212-211	
$5/2^+$	258.00	261.77	353-330	196-241	
$11/2^-$	290.21	318.60	290-356	573-264	[304]
$5/2^+$	381.60	439.51	535-426	461-555	
$7/2^-$	508.22	525.70	731-781	744-451	608
$7/2^+$	538.99	549.34	301-343	441-544	
$7/2^+$	687.51	(687.80)	744-758	583-735	
$15/2^-$	697.84	706.47	734-784	788-520	722
$9/2^-$	789.90	-	880-980	953-786	1137
$9/2^+$	808.63	-	756-706	494-564	
$3/2^+$	827.64	841.24	589-479	721-1057	
$13/2^-$	863.41	878.82	635-709	939-777	1096
$9/2^-$	890.79	894.18	1243-1248	1286-1346	1744
$9/2^+$	929.11	-	960-839	975-1250	
$9/2^+$	1004.10	-	1384-1227	1271-1632	
$3/2^-$	1089.25	1110.70	1230	1176-1033	1619
$3/2^+$	1118.97	1082.92	798-787	831-1195	

TABLE 2 (continued)

I^{π}	^{193}Au	^{195}Au	K-S (1)	A-P (2)	M-S-D (3)
$11/2^-$	1284.79	1280.45	922-907	1193-1205	1748
$15/2^-$	1355.46	1404.60	1153-1188	1355-1387	1878
$17/2^-$	1373.00	-	1191-1214	1255	1711
$11/2^+$	1380.00	-	699-739	950-1277	
$13/2^-$	1398.63	(1406.2)	1413-1386	1303-1362	1971
$11\ 2^-$	1400.35	1346.17	1258-1266	1276-1315	
$13/2^-$	1575.50	1559.6	1557-1473	1385-1456	

1 - Kisslinger-Sorensen parameter sets:

* $\varepsilon_{1/2} = 0.00$ $\varepsilon_{3/2} = 0.33$ $\varepsilon_{5/2} = 2.22$ $\varepsilon_{7/2} = 3.00$ $\varepsilon_{11/2} = 0.89$
$\hbar\omega = 0.416$ $G = 0.12$ $a = 0.4$ MeV.

** $\varepsilon_{1/2} = 0.00$ $\varepsilon_{3/2} = 0.20$ $\varepsilon_{5/2} = 1.67$ $\varepsilon_{7/2} = 3.00$ $\varepsilon_{11/2} = 0.89$
$\hbar\omega = 0.416$ $G = 0.12$ $a = 0.5$ MeV.

2 - Alaga-Paar parameter sets:

† $\varepsilon_{1/2} = 0.00$ $\varepsilon_{3/2} = 0.20$ $\varepsilon_{5/2} = 1.67$ $\varepsilon_{7/2} = 3.50$ $\varepsilon_{11/2} = 1.10$
$\hbar\omega = 0.400$ $G = 0.12$ $a = 0.3$ MeV.

†† the same set except $a = 0.5$

3 - Meyer-Stephens-Diamond theoretical values deduced from ref. |14|.

available theoretical results. Now, the predictions of each model will be discussed briefly.

The Kisslinger-Sorensen model describes the odd mass gold isotopes as one quasi-proton states (in the $3s_{1/2}$, $2d_{3/2}$, $2d_{5/2}$, $1g_{7/2}$ or $1h_{11/2}$ subshells) coupled to the quadrupole vibrations of the even-even core. This model predicts all the $^{193,195}Au$ analogue levels but the average deviation between the experimental and calculated energy values cannot be smaller than 180 keV. Furthermore, the one quasi-particle model gives a satisfactory account for the enhancements (or retardations) of the M1, E2, E3 and M4 reduced transition probabilities between the lowest levels (see table 3). However, strong discrepancies exist between the experimental and the theoretical values of the ground-state static moments. These discrepancies as well as the deviations observed for the energies of the $3/2^+_2$ or the $7/2^+_1$ levels can be attributed to the influence of the three quasi-particles neglected in these calculations.

The Alaga model overcomes these failures of the one quasi-particle model introducing explicitly three proton holes cluster configurations coupled to quadrupole vibrations. Indeed, the agreement between the experimental and theoretical excitation energies is improved, the mean average deviation being reduced to 120 keV. Furthermore, the Alaga model accounts satisfactorily for the available static moments and reduced electromagnetic transition probabilities (see for instance the examples given in table 3). Finally, the analysis of the Alaga and the Kisslinger-Sorensen wave functions describing the $^{193-195}Au$ first excited states, clearly shows the higher configuration mixing in the three holes cluster model (see table 4).

The asymmetric rotor model describes the negative parity levels of the odd mass gold isotopes as a single

TABLE 3

Static moments and electromagnetic properties of the lowest ^{193}Au and ^{195}Au excited levels

	Experiment		Theory		
	^{193}Au	^{195}Au	K-S	A-P	S-P
$\mu(3/2_1^+)$	0.139	0.147	0.65	0.055-0.242	0.124
$Q(3/2_1^+)$	$(0.58\pm0.01)^a$	-	1.00	0.70-0.52	0.130
$B(M1\ 1/2_1^+\to3/2_1^+)$	2.1 ± 0.4	3.1 ± 0.7	0.59	4.51-0.16	3350
$B(M1\ 5/2_1^+\to3/2_1^+)$	24 ± 13	22 ± 6	82	51-59	2007
$B(E2\ 1/2_1^+\to3/2_1^+)$	32 ± 8	26 ± 7	11	20-11	1.36
$B(E2\ 5/2_1^+\to1/2_1^+)$	3.4 ± 2.2	5.4 ± 1.8	8	26-14	0.66
$B(E2\ 5/2_1^+\to3/2_1^+)$	8.8 ± 6.4	11.2 ± 5.6	56	54-23	0.19
$B(E3\ 11/2_1^-\to5/2_1^+)$	98 ± 11	5.6 ± 1.0	30	-	3420
$B(M4\ 11/2_1^-\to3/2_1^+)$	-	0.28 ± 0.09	0.67	-	2.10

TABLE 3 (continued)

All μ and Q values are expressed in μ_N and eb units, respectively.

All B(M1), B(E2), B(E3) and B(M4) values are expressed in $10^{-3}\mu_N^2$, 10^{-2} e^2b^2, $10^{-6}e^2b^3$ and $10^{-11}\mu_N^5$ units, respectively.

- The Kisslinger-Sorensen (K-S) theoretical values were calculated with: $\varepsilon_{1/2}$ = 0.00, $\varepsilon_{3/2}$ = 0.33, $\varepsilon_{5/2}$ = 2.22, $\varepsilon_{7/2}$ = 3.00, $\varepsilon_{11/2}$ = 0.89, $\hbar\omega$ = 0.42, G = 0.12, a = 0.40 MeV and e^P_{eff}= 2.0, e^V_{eff}= 2.55, g_R = 0.41, g_ℓ = 1, g_s = 3.91.
- The Alaga-Paar (A-P) theoretical values were calculated with: $\varepsilon_{1/2}$ = 0.00, $\varepsilon_{3/2}$ = 0.20, $\varepsilon_{5/2}$ = 1.67, $\varepsilon_{7/2}$ = = 3.50, $\varepsilon_{11/2}$ = 1.10, $\hbar\omega$ = 0.40, G = 0.12, a = 0.40 MeV and e^P_{eff} = 2.0 (or 2.5), e^V_{eff} = 2.5 (or 3.5), g_R = 0 (or 0.40), g_ℓ = 1, g_s = 4.47.
- The single particle (S-P) theoretical values correspond to the ^{195}Au static moments and electromagnetic reduced transition probabilities.

a Experimental Q value measured in ^{197}Au.

proton hole $1h_{11/2}$ coupled to an asymmetric rigid rotor |14|. The relative theoretical excitation energies, given in table 2, correspond to the parameter set which reproduces the experimental data best (β = 0.13 and γ = = 37.4 degrees). Apart from the three lowest levels, considerable discrepancies exist between our experimental excitation energies and the theoretical ones. Furthermore, the ^{193}Au experimental level scheme reveals a much higher complexity than that predicted by this model (52 negative parity states lying between 0.290 and 2.290 MeV). On the other hand, no conclusion can be drawn from

TABLE 4

The main components of the wave functions describing the first ^{193}Au and ^{195}Au excited states

Kisslinger-Sorensen

$$3/2^+_1 = 0.870|d_{3/2},00\rangle + 0.394|d_{3/2},12\rangle$$

$$1/2^+_1 = 0.938|s_{1/2},00\rangle + 0.250|d_{3/2},12\rangle$$

$$3/2^+_2 = 0.805|s_{1/2},12\rangle - 0.331|d_{3/2},12\rangle$$

Alaga-Paar

$$3/2^+_1 = -0.416|(d_{3/2})^{-2}2,s^{-1}_{1/2}|5/2,12\rangle - 0.536|(s_{1/2})^{-2}0,d^{-1}_{3/2}|3/2,00\rangle - 0.300|(s_{1/2})^{-2}0,d^{-1}_{3/2}|3/2,20\rangle$$

$$1/2^+_1 = -0.535|(d_{3/2})^{-2}0,s^{-1}_{1/2}|1/2,00\rangle - 0.363|(d_{3/2})^{-2}2,s^{-1}_{1/2}|5/2,12\rangle - 0.320|(d_{3/2})^{-2}0,s^{-1}_{1/2}|1/2,20\rangle + 0.296|(s_{1/2})^{-2}0,d^{-1}_{3/2}|3/2,22\rangle$$

$$3/2^+_2 = 0.284|(d_{3/2})^{-2}2,s^{-1}_{1/2}|5/2,12\rangle - 0.296|(d_{3/2})^{-2}0,d^{-1}_{3/2}|3/2,12\rangle - 0.442|(d_{3/2})^{-2}0,s^{-1}_{1/2}|1/2,12\rangle - 0.334|(d_{3/2})^{-2}2,s^{-1}_{1/2}|5/2,24\rangle$$

TABLE 4 (continued)

Kisslinger-Sorensen		Alaga-Paar	
$5/2^+_1 =$	$0.829\|d_{3/2},12\rangle$	$5/2^+_1 =$	$-0.316\|(d_{3/2})^{-2}0,d^{-1}_{3/2}\|3/2,12\rangle$
	$+0.334\|d_{3/2},24\rangle$		$+0.416\|(d_{3/2})^{-2}2,s^{-1}_{1/2}\|5/2,00\rangle$
			$+0.366\|(d_{3/2})^{-2}0,s^{-1}_{1/2}\|1/2,12\rangle$
			$-0.444\|(s_{1/2})^{-2}0,d^{-1}_{3/2}\|3/2,12\rangle$
$5/2^+_2 =$	$0.888\|s_{1/2},12\rangle$	$5/2^+_2 =$	$0.519\|(d_{3/2})^{-2}0,s^{-1}_{1/2}\|1/2,12\rangle$
			$+0.396\|(d_{3/2})^{-2}2,s^{-1}_{1/2}\|5/2,24\rangle$
			$+0.287\|(s_{1/2})^{-2}0,d^{-1}_{3/2}\|3/2,12\rangle$
$11/2^-_1 =$	$0.716\|h_{11/2},00\rangle$	$11/2^-_1 =$	$0.255\|(d_{3/2})^{-2}0,h^{-1}_{11/2}\|11/2,00\rangle$
	$+0.602\|h_{11/2},12\rangle$		$+0.280\|(d_{3/2})^{-2}0,h^{-1}_{11/2}\|11/2,12\rangle$
			$+0.314\|(s_{1/2})^{-2}0,h^{-1}_{11/2}\|11/2,00\rangle$
			$+0.304\|(s_{1/2})^{-2}0,h^{-1}_{11/2}\|11/2,12\rangle$
$7/2^-_1 =$	$0.748\|h_{11/2},12\rangle$	$7/2^-_1 =$	$-0.287\|(d_{3/2})^{-2}0,h^{-1}_{11/2}\|11/2,12\rangle$
	$+0.542\|h_{11/2},22\rangle$		$-0.258\|(d_{3/2})^{-2}0,h^{-1}_{11/2}\|11/2,22\rangle$
	$+0.265\|h_{11/2},24\rangle$		$+0.261\|(s^{-1}_{1/2},d^{-1}_{3/2})2,h^{-1}_{11/2}\|7/2,12\rangle$
			$-0.289\|\ s^{-2}_{1/2}0,h^{-1}_{11/2}\ \|11/2,12\rangle$
			$-0.259\|\ d^{-2}_{3/2}0,h^{-1}_{11/2}\ \|11/2,22\rangle$

Wave functions calculated with the parameter sets given in table 3.

the available data on the ^{193,195}Au electromagnetic properties because the corresponding theoretical calculations are missing. Finally, this model cannot describe, in its present state, the positive parity levels where configuration mixing is important.

IV - CONCLUSIONS

The Alaga model gives the best present theoretical description of the $^{193-195}$Au "analogue levels". Indeed, the Kisslinger-Sorensen model predictions do not fit so well the experimental data available on these isotopes. Nevertheless, this one quasi-particle model gives a more complete and accurate interpretation than the asymmetric rotor model. Finally, other nuclear reaction studies are required to make still finer tests of these models from the spectroscopic factors.

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