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To cite this version:

V. Berg, C. Bourgeois, R. Foucher. Some features of odd Au nuclei revealed by half-life measurements. Journal de Physique, 1975, 36 (7-8), pp.613-616. 10.1051/jphys:01975003607-8061300 . jpa-00208293

HAL Id: jpa-00208293

https://hal.science/jpa-00208293

Submitted on 4 Feb 2008

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Classification
Physics Abstracts
4.162

SOME FEATURES OF ODD Au NUCLEI REVEALED BY HALF-LIFE MEASUREMENTS

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(*Reçu le 17 mars 1975, accepté le 21 mars 1975*)

Résumé. — L'identité de structure des premiers niveaux $9/2^-$ dans les noyaux d'or de nombre de masse impair de 187 à 193 ainsi que cette structure elle-même, sont révélées par le mode de population et désexcitation de ces niveaux et leurs vies moyennes. Ceci montre l'importance de la prise en compte du paramètre d'asymétrie γ dans les noyaux impairs d'or comme cela a déjà été montré pour les noyaux de platine. Ceci montre également la nécessité de tenir compte dans ces noyaux d'états appartenant à la couche majeure suivante.

Abstract. — The half-life (1.2 ± 0.1 ns) of the 789.9 keV $9/2^-$ level in ^{193}Au is measured. The retardation of the deexciting M 1 and E 2 transitions suggests that this $9/2^-$ state, as well as those found in 187, 189, 191 gold nuclei, issues from the $h_{9/2}$ orbit. The average shape of the Au nuclei in these states and of their even Pt cores is interpreted with the particle + asymmetric rotor model.

The great interest focused on transitional nuclei in the Os to Pb region is connected with observations made precedently :

— Signs of a prolate to oblate shaped transition revealed by the study of level positions in even Pt nuclei [1, 2].

— Establishment of $9/2^-$ states issued from the $h_{9/2}$ orbital in Tl nuclei [3].

— The discovery and interpretation of negative parity states in Ir nuclei [4].

— The existence of unexpectedly large retardations of transitions in Ir and Pt nuclei [5].

— The large isotopic shift measured between ^{185}Hg and ^{187}Hg [6].

Most of the above information was obtained at ISOLDE, CERN and studies of odd Au and Pt nuclei are actually continued at ISOCELE, Orsay.

Half-life measurements of excited states [7] and heavy ion reaction experiments [8, 9] have led to the proposal of two decoupled bands in ^{189}Au. They are based on $9/2^-$ and $11/2^-$ levels, joined as in ^{187}Ir [4] by a very retarded M 1 transition (78 keV, $F_W \sim 15\,000$).

The $11/2^-$ band is supposed to result from the coupling of an $h_{11/2}$ proton hole to the « rotation » of a Hg core and has, in fact, « rotation » energies similar to those of even Hg isotopes. In these states the deformation of the nucleus should be oblate as in Hg nuclei. The band appears in all odd Au isotopes and is observed to have a very stable structure [7-14]. As seen in figure 2 the band head lowers slowly, when the neutron number decreases.

The $9/2^-$ state is proposed to arise from the coupling of a proton in the $h_{9/2}$ shell to the « rotation » of a Pt core and has, according to this interpretation, a prolate shape. States issued from the high lying $h_{9/2}$ orbital, have already been observed in Tl nuclei and their appearance at low excitation energy is explained by the gain in pairing energy [3]. In Tl, and, as shown below, in Au these states lower rapidly with decreasing mass number.

In ^{187}Au the $9/2^-$ state is placed below the $11/2^-$ isomer (Fig. 2) and the decoupled character of the band is well developed [13]. The half-life of the $11/2^-$ state has been measured, but the retardation factors for the $11/2^-$ to $9/2^-$ transition cannot be given, as the M 1 to E 2 mixing ratio has not yet been determined. (The experimental results on ^{185}Au are now being analysed.) In ^{195}Au the $9/2^-$ level is proposed as lying at 1 068 keV [15]. More information is available in ^{191}Au : Höglund *et al.* [14] have found the $9/2^-$ band at about 200 keV higher excitation energy than in ^{189}Au (Fig. 2), and measured a similar hindrance as in the latter nucleus for the $9/2^-$ to $11/2^-$ M 1 transition (Table I). For the identification of the $9/2^-$ state in ^{193}Au, the extensive studies by Vieu and Dionisio [11] give aid. Their table of analogue states in ^{193}Au and ^{195}Au, i.e. states with the same spin and parity, nearly same excitation energy and identical depopulation mode, shows that the 789.9 keV $9/2^-$ level in ^{193}Au has no equivalence in the 195 iso-

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Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/jphys:01975003607-8061300

TABLE I

Half-lives of $9/2^-$ *levels, and absolute transition probabilities of* $9/2^-$ *to* $11/2^-$ $(7/2^-)$ *transitions in* 189, 191, 193 Au *isotopes*

Nucleus	Level keV	$T_{1/2}$ level ns	Transition keV	Initial state	Final state	Multipole	F_W	B (M 1) $(e\hbar/2\,Mc)^2$	B (E 2) $e^2\,b^2$
—	—	—	—	—	—	—	—	—	—
^{193}Au	789.9	1.2 ± 0.1	499.65	$9/2^-$	$11/2^-$	M 1 ([a])	17 000	$(1.0 \pm 0.3) \times 10^{-4}$	
						E 2	11		$(6.0 \pm 2.0) \times 10^{-4}$
			281.76	$9/2^-$	$7/2^-$	M 1	14 000	$(1.3 \pm 0.3) \times 10^{-4}$	
						E 2	6.3		$(11 \pm 3) \times 10^{-4}$
^{191}Au	541.3	12 ± 1 ([b])	274.1	$9/2^-$	$11/2^-$	M 1 ([b])	16 000	$(1.1 \pm 0.2) \times 10^{-4}$	
^{189}Au	325.1	190 ± 15 ([c])	78.0	$9/2^-$	$11/2^-$	M 1 ([d])	15 000	$(1.2 \pm 0.1) \times 10^{-4}$	
						E 2	> 20		$< 3.2 \times 10^{-4}$

([a]) Référence [11].
([b]) Référence [14].
([c]) Référence [7].
([d]) Référence [25].

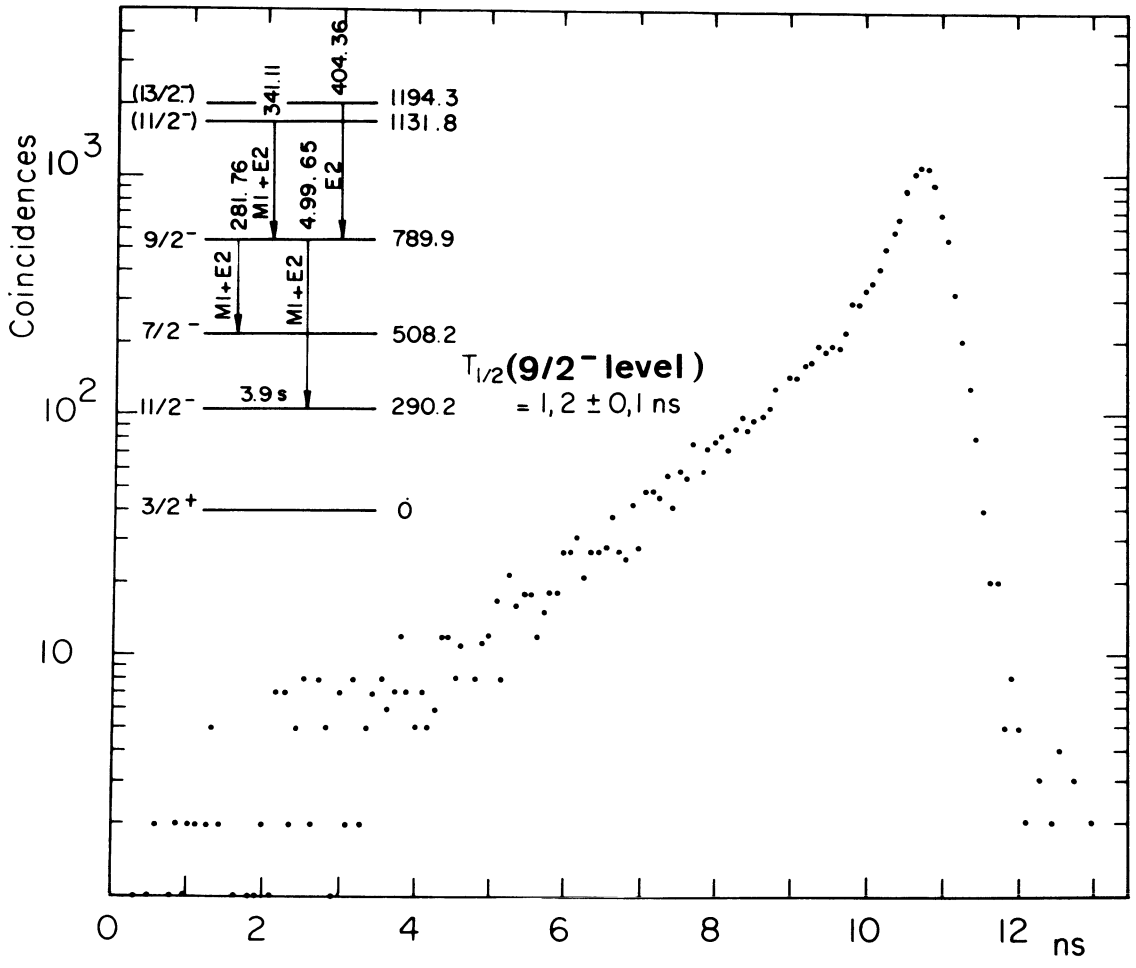

FIG. 1. — Time distribution obtained by measuring 499.65 K − γ coincidences in ^{193}Au.

tope. The level lies about 200 keV higher than the $9/2^-$ state in ^{191}Au. It decays to the $11/2^-$ isomer and is fed as the $9/2^-$ states in ^{189}Au and ^{191}Au by a pure E 2 and a mixed M 1 + E 2 transition (Fig. 1). However, calculations of transition rates performed within the frame of the Alaga Paar 3-hole cluster model [16] (using parameters fitting best the positive parity states and without octupole coupling), do not give the large retardation factors expected for the deexciting transitions [11]. A state with the required properties was placed at 500 keV higher energy. It therefore seemed necessary to make a half-life measurement in order to check the character of the state. The experiment was performed according to the delayed coincidence method, with an isotopically pure ^{193}Hg source, using a Gerholm

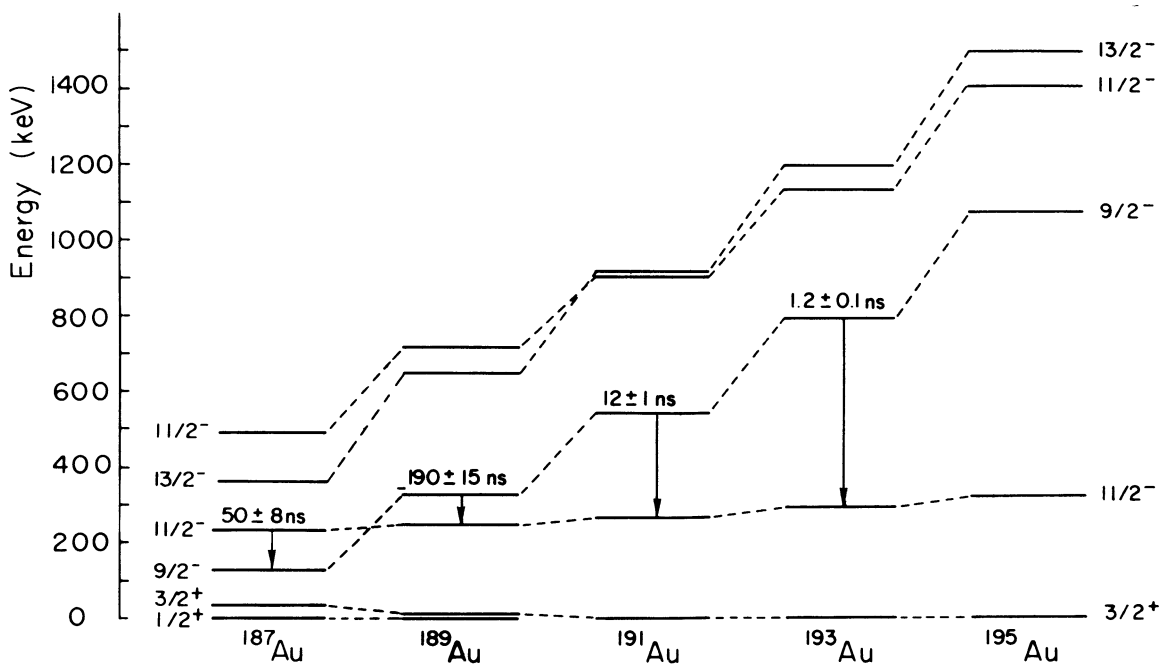

FIG. 2. — Ground state, $11/2^-$, and $9/2^-$ levels in odd Au isotopes. The two highest levels are the first two excited states of the $9/2^-$ band. Their relative positions indicate that, in this band, rotation aligned coupling and prolate shape dominate in ^{187}Au and ^{189}Au, strong coupling and oblate shape in the heavier gold nuclei.

coincidence spectrometer [17]. The K-line of the 499.7 keV transition, which depopulates the 789.9 keV level, was then selected by one lens and the feeding γ-rays were detected with a plastic scintillator.

Figure 1 shows the time distribution of the e-γ coincidences and the relevant part of the decay scheme. The slope of the curve gives

$$T_{1/2}\,(789.9\text{ keV level}) = 1.2 \pm 0.1\text{ ns}\,.$$

The retardation factors of the depopulating M 1 transitions (Table I) resemble those obtained for the correspondent transitions in ^{189}Au and ^{191}Au. Even the E 2 transitions are hindered compared to the Weisskopf estimate. The measurement provides good support to the assumption that the 789.9 keV $9/2^-$ state in ^{193}Au has the same structure as the $9/2^-$ levels in ^{189}Au and ^{191}Au.

The study of even Pt [1, 2] and Hg [18] nuclei has shown the necessity of taking into account, not only the variation of the deformation parameter β from one state to another and the fluctuations of it within each state, but also the variations and the fluctuations of the shape asymmetry parameter γ. In a recent interpretation of the $11/2^-$ band of ^{195}Au, Meyer *et al.* [19] assume a triaxial nuclear shape and investigate, as a first step, the band structure of a single j-nucleon coupled to a rigid asymmetric rotor. For $\gamma = 0°$, they find a pure rotation aligned level order with strongly populated I, $I + 2$, $I + 4$. ... states; for $\gamma = 60°$ the band structure becomes typically strong coupled with an I, $I + 1$, $I + 2$, ... spin sequence. A continuous transition from decoupled to strong coupled structure takes place by changing γ from 0° to 60°. The strong coupling level order dominates in the interval $30° < \gamma < 60°$.

The model allows a comparison between even Pt nuclei and the $9/2^-$ states in Au, interpreted as formed by the coupling of an $h_{9/2}$ proton to the rotation of the neighbouring Pt core. The measurement of the static quadrupole moment in ^{194}Pt has proved that this nucleus has an oblate shape [20], but a change to the prolate form is expected in lighter Pt nuclei [1, 21] (around mass 188).

In accordance with the negative deformation of ^{194}Pt and its γ parameter $> 30°$, the $9/2^-$ band in ^{195}Au shows the strong coupling level sequence (Fig. 2). This is also the case for the bands in ^{193}Au and ^{191}Au, thus suggesting an oblate shape for ^{192}Pt and ^{190}Pt. In ^{189}Au, the $13/2^-$ member of the $9/2^-$ band is found at a lower energy than the $11/2^-$ one, and the band is decoupled, which corresponds to $\gamma < 30°$ and a *prolate* shape for the ^{188}Pt core. The assumption of positive deformation of ^{188}Pt, is supported by the fact that the $11/2^-$ isomeric state in ^{187}Ir, interpreted as a hole in the ^{188}Pt core, has been shown to be prolate [15]. The decoupled character of the $9/2^-$ band becomes more pronounced in ^{187}Au, in agreement with the prolate shape proposed for ^{186}Pt [21].

According to this simple comparison, the oblate-prolate shape transition in even Pt nuclei, i.e. the transfer of the total energy minimum from the oblate to prolate side, should occur in the step between the isotopes 190 and 188. The change of the potential

minimum takes place between ^{188}Pt and ^{186}Pt [21], which seems to demonstrate the influence of the β and γ dependent mass parameters on the location of the shape transition [1, 21]. In the above comparison, no attention was given to the influence of the particle-core interaction, which may be strong enough to shift the shape transition [7, 9, 24]. Admixtures in the $9/2^-$ state were not considered either. The most important contribution is expected to come from the 9/2 (514) state. It should give rise to a tendancy for a strong coupling level pattern in the lighter, more deformed isotopes. This effect is not observed.

It is interesting to notice that the shape transition, which arises as a function of neutron number N in Pt and Au nuclei, also takes place as a function of Z. In 191 to 199 Tl isotopes the $9/2^-$ band is found to be oblate [3], in ^{187}Ir and ^{189}Ir it is prolate [22]. These observations support the suggestion that the shape transition of the even cores occurs near a line joining ^{182}Hg, ^{188}Pt, and ^{194}Os [21].

It remains now to discuss the cause of the large retardations of the interband transitions. Several reasons can be suggested. In the lighter nuclei, a certain hindrance may be due to the change from prolate to oblate shape. According to the simple rotation aligned and strong coupling models, the $9/2^-$ and the $11/2^-$ states are respectively a pure particle state coupled to a Pt core and a pure hole state coupled to a Hg core. A transition between them is a two step process. In ^{187}Ir [5] the $11/2^-$ to $9/2^-$ transition is about 30 times more retarded than in the Au isotopes. In this case, the $11/2^-$ state is essentially strong coupled, while the $9/2^-$ one is rotation aligned and their wave functions have a very small overlap. In Au nuclei, the overlap is expected to be larger, as the difference in structure between the initial and final states are less pronounced. The retardation in ^{187}Ir can also be explained by K-forbiddeness; the states involved being $11/2^-$ (505) and a strongly perturbed $1/2^-$ (541).

The study of the $9/2^-$ states in odd Au nuclei has shown that, to a first approximation, the approach of Meyer *et al.* [19] can explain their characteristics. This indicates that a new type of coupling between particle and a collective state can appear in soft nuclei, and that γ asymmetry has to be taken into account in odd as well as in even nuclei. It must be noticed that this successful model for high angular momentum states has, necessarily, the limitations of the Davydov model [23], which identifies β with β_{rms} and γ with γ_{rms}, and thus neglects the shape and pairing fluctuations shown to be large in the even nuclei of this region [21]. Our result seems also to show the limitations of models which take into account the shape fluctuations, but neglect states belonging to the next higher shell.

We are indebted to M. Jacques Obert for the preparation of the ^{193}Hg source and to the ISOCELE collaboration for on line measured sources.

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