FR9002181

I.P.N. BP n°1 - 91406 ORSAY

CNRS - IN2P3 - UNIVERSITÉ PARIS - SUD

institut de physique nucléaire

IPNO-DRE 89.26

LASER-SPECTROSCOPY MEASUREMENTS OF THE SHAPE TRANSITION IN NEUTRON-DEFICIENT GOLD ISOTOPES

F. LE BLANC, J. ARIANER, P. KILCHER, J. OBERT,
J. OMS, J.C. PUTAUX, B. ROUSSIERE, J. SAUVAGE
Institut de Physique Nucléaire, Orsay, France
J.E. CRAWFORD, H. DAUTET, J.K.P. LEE, G. THEKKADATH
Foster Radiation Laboratory, Mc Gill University,
Montréal, Canada
H.T. DUONG, J. PINARD, S. LIBERMAN†
Laboratoire Aimé Cotton, CNRS II, Orsay, France
and the *ISOCELE Collaboration*

Presented: XII WORKSHOP ON NUCLEAR PHYSICS, Iguazu Fal:
Argentina, 1989

LASER-SPECTROSCOPY MEASUREMENTS OF THE SHAPE TRANSITION IN NEUTRON-DEFICIENT GOLD ISOTOPES

F. Le Blanc, J. Arianer, P. Kilcher, J. Obert, J. Oms, J.C. Putaux, B. Roussière, J. Sauvage,
Institut de Physique Nucléaire, Orsay, France
J.E. Crawford, H. Dautet, J.K.P. Lee, G. Thekkadath,
Foster Radiation Laboratory, Mc Gill University, Montréal, Canada
H.T. Duong, J. Pinard, S. Liberman†
Laboratoire Aimé Cotton, CNRS II, Orsay, France
and the ISOCELE Collaboration

ABSTRACT : Hyperfine structure HFS have been recorded for Au with A=191 and 186 using PILIS II (Post-ISOCELE Laser Isobar Separation) apparatus. The quadrupole moment values obtained yield decisive information on gold nuclear shape.

INTRODUCTION. - Recently, spectroscopic investigations of gold isotopes [1,2] were carried out and a sudden change in nuclear charge radius r_c was observed between A=187 and A=186. This corresponds to a large increase in the deformation parameter β. Since up to now no quadrupole moments have been measured, it is impossible to affirm that the sharp change in the $\delta\langle r^2\rangle$ corresponds to a sign change of β. Indeed the large difference of the r_c value observed between the nuclei ^{193,191,189}Tl [3] in their ground and isomeric states does not lead to shape coexistence in those nuclei. It is well known that for the even-even nuclei in this region, potential energy curves calculated assuming axial symmetry exhibit two minima : one corresponding to an oblate shape, the other to a prolate shape. Using HF+BCS calculations, the $\langle r_c\rangle$ values can be determined for the prolate and oblate solutions of the Hg and Pt cores. This allows us to compare in fig.1 the $\delta\langle r^2_c\rangle$ values measured for gold isotopes with the theoretical results for Hg and Pt cores. For

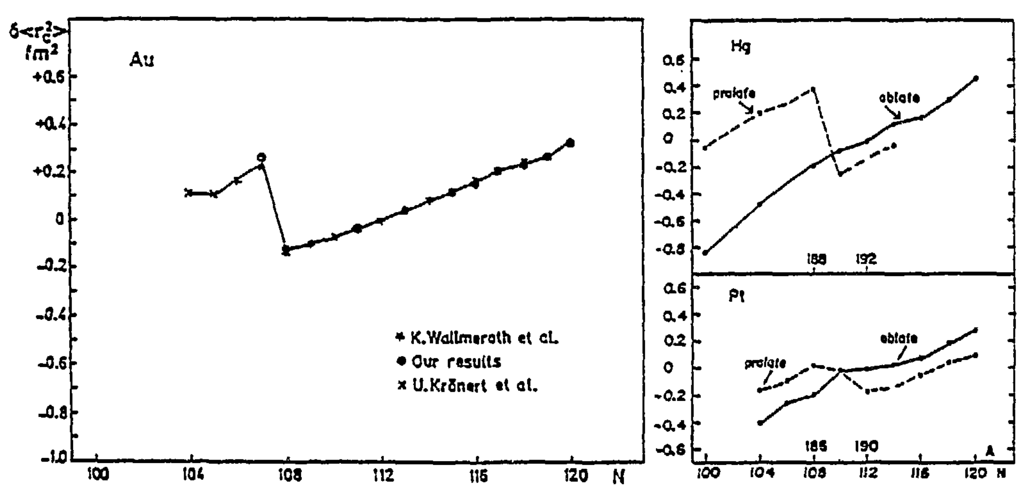

Fig. 1 : Experimental $\delta\langle r^2\rangle$ and $\delta\langle r^2\rangle$ axially HF+BCS calculations.

the mercury for example, the sudden change in the r_c value is not necessarily accompanied by a change of sign of the β value. Indeed, for the prolate solution, we can see an abrupt change of the radius between A=190 and A=188. The only way to unambigucusly identify a shape transition in the gold isotopes is to measure the quadrupole moment before and above the sudden change in the charge radius. For this reason, the quadrupole moments for ^{191}Au and ^{186}Au have been measured.

EXPERIMENTAL TECHNIQUE. - Radioactive gold isotopes are produced by (p,xn) reactions in a molten Pt-B alloy placed inside the ion source of the ISOCELE mass separator. The 30 kV gold ions obtained after extraction and separation are slowed to 500 V and collected in a graphite foil. The decelerating voltage is turned off and the atoms are desorbed by Nd:YAG laser pulses at the implantation region. Then, they are ionized via the resonant ionization spectroscopic process by a group of three synchronized laser pulses with a ν_1 frequency for the first excitation step. Ions created are reaccelerated by a potential of 1.5 kV

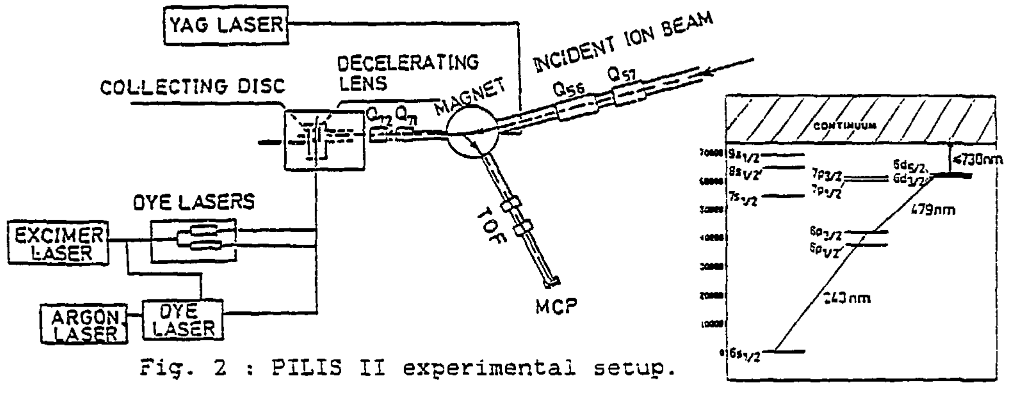

Fig. 2 : PILIS II experimental setup.

and detected by a microchannel plate following time-of-flight identification (fig.2). The laser spectroscopy is performed on the first resonant laser excitation step at 243nm. The decelerating high voltage is turned on during the collection and turned off for the measurements. After each collection, the frequency of the first laser excitation step is changed in order to obtain the complete hyperfine spectrum HFS.

EXPERIMENTAL RESULTS. - The atomic transition studied in gold is the 6s $^2S_{1/2}$→6p $^2P_{3/2}$. Since J=3/2 in the excited state, the electric quadrupole effect can be observed in the HFS. We report here the HFS of ^{186,191}Au obtained from the 243nm resonant transition. The energy of the hyperfine levels characterized by the quantum number F (F=I+J is the angular momentum of the atom) may be written as a linear combination of the HFS constants for the magnetic (A) and electrostatic (B, for the excited state only) interactions. $A=\mu\langle H_e(0)\rangle/I.J$ where μ is the magnetic dipole moment and $\langle H_e(0)\rangle$ the magnetic field produced at the nucleus by the electrons of the J level. $B = e\,Q_s\langle\phi_{JJ}(0)\rangle$ where Q_s is the spectroscopic quadrupole moment and $\langle\phi_{JJ}(0)\rangle$ the electric field gradient at the nucleus.

Since the μ values have previously been measured [1,2,4] and the $\langle H_e(0)\rangle$ values known for both the ground and the excited states [2,5], the B value can be extracted from only two frequencies of the HFS. $\langle \phi_{JJ}(0)\rangle$ has been calculated by semi-empirical methods [6] from the fine structure of the ^2P configuration. In the extraction of Q_s, the relative values are very reliable but the absolute values are limited by the accuracy in the calculation of $\langle \phi_{JJ}(0)\rangle$. The values of μ and Q_s corrected for the Sternheimer effect [7] (15%), are listed in Table 1.

A	186	191
$\mu(\mu_N)^*$	−1.284(33)	+0.138(7)
Qs(b)	+2.69(8)	−1.1(1)
	I=K=3	I=K=3/2
$Q_o(fm^2)$	+649	−549

Table 1 : Nuclear moments of ^{191}Au and ^{186}Au.

* [2,4]

DISCUSSION. - The most remarkable feature of table 1 is the sign change of the spectroscopic quadrupole moment between ^{186}Au and ^{191}Au. Since the ^{186}Au ground state is believed to be $\nu 9/2^+$ [624]⊗π5/2 $3/2^-$ [532], the sign of its intrinsic quadrupole moment Q_o is positive which confirms the prolate shape attributed to this nucleus from nuclear structure measurements. For the nucleus ^{191}Au, its spin I=3/2 could correspond to two values of K (projection of I on the symmetry axis) : K=1/2 or K=3/2. If K=1/2, its Q_o value is positive which corresponds to a prolate shape. However, no K=1/2 orbital near the Fermi level has a negative decoupling parameter for such a prolate nucleus. Consequently I=K=3/2 and in that case, Q_o must be negative (see Table 1). Thus a prolate shape for ^{191}Au can be definitely ruled out.

We have calculated the magnetic moment for ^{186}Au following the formalism of S.G. Nilsson [8]. Assuming a $\nu 9/2^+$[624]⊗π5/2 $3/2^-$ [532] ground state, the μ value is quite well reproduced (see Table 2) indicating the validity of the prolate shape for this nucleus. For ^{191}Au, we have attempted to calculate the magnetic moment using both the Nilsson model [8] and the rotor+one quasiparticle coupling model

TABLE 2 : MAGNETIC MOMENTS OF ^{186}Au AND ^{191}Au

MODEL				NILSSON [8]	ROTOR+1 QUASIPARTICLE [9] (HARTREE FOCK+BCS)			
DEFORMATION CORE				η=4	A−1 Pt		A+1 Hg	
A	STATE	μ_{exp}	k \ g_R	Z/A				
186	$\nu 9/2^+$[624]⊗ π5/2 $3/2^-$[532]	−1.28(3)	1	−1.28				
			0.6	−1.15				
				η=−4	β=−0.22		β=−0.15	
			k* \ g_R	Z/A	Z/A	0.36	Z/A	0.36
191	3/2 $3/2^+$[431]	+0.138(7)	1	1.75	0.72	0.51	2.69	2.55
			0.6	1.46	0.87	0.67	1.97	1.83

* Factor applied to gyromagnetic ratio $g_{s,free}$

[9,10]. Assuming a $3/2^+$ [431] oblate configuration for the ground state of this nucleus, the calculated μ's for both $g_s = g_{s,free}$ and $g_s = 0.6 g_{s,free}$ using the Nilsson model give theoretical values ten times larger than the experimental ones μ_{exp} (see Table 2). In the second approach, we have used the quasiparticle wave function obtained in HF+BCS calculations using the Skyrme III interaction for the ^{190}Pt and ^{192}Hg oblate solutions i.e. an oblate core for ^{191}Au. Proton gyromagnetic ratios of $k g_{s,free}$ are used for comparison purposes. The calculations for a Pt core give a deformation parameter $\beta = -0.22$ which leads to $\mu_{th} \sim 6 \mu_{exp}$. For a Hg core it leads to $\mu_{th} \sim 20 \mu_{exp}$ (Table 2). Therefore, if axial symmetry is assumed, both theoretical models give values which are far from those observed. This is particularly puzzling since many experimental studies suggested an oblate shape, and one would expect that such calculations should reproduce the magnetic moments reasonably well. This failure suggests either that the model may not adequately describe an oblate nucleus, or that some asymmetric deformation might be required. In the fig.3 the theoretical $\delta\langle r^2 \rangle$ values of even-A platinum nuclei obtained from lattice Hartree-Fock+BCS calculations for asymmetric solutions are shown [11,12]. They predict a prolate shape for A=186 and A=188, a triaxial shape for A=190, 192 and 194 and an oblate shape for the others. The general trend of the experimental $\delta\langle r^2 \rangle$ values is quite well reproduced (fig.3). Thus the shape transition appears to pass through asymmetric shapes.

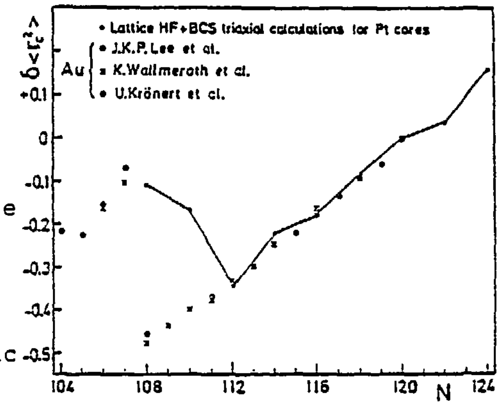

Fig. 3 : Experimental gold $\delta\langle r^2 \rangle$ compared with theory.

From the values of the moments of ^{191}Au we can conclude that this nucleus is likely asymmetric in its ground state while for ^{186}Au a prolate shape is clearly demonstrated.

References

[1] K. Wallmeroth et al., Phys. Rev. Lett. 58 (1987) 1516.
[2] J.K.P. Lee et al., 5th Int. Conf. on Nuclei far from Stability, Rosseau Lake, AIP Conf. Proc. 164 (1988) 205.
[3] J.A. Bounds et al., Phys. Rev. C36 (1987) 2560.
[4] C.M. Lederer et al., "Table of Isotopes 7^{th} ed.", Wiley, New-York (1978).
[5] G. Goldman et al., Z. Phys. 225 (1969) 1.
[6] H. Kopfermann, "Nuclear Moments", Academic Press, New-York (1958).
[7] R.M. Sternheimer et al., Phys. Rev. A3 (1971) 837.
[8] S.G. Nilsson, Dan. Mat. Phys. Medd. 29 n°14 (1955). B.R. Mottelson and S.G. Nilsson, Mat.Fys. Skr. Dan. Vid. Selsk. 1 (1959) n°8. I.L. Lamm, Nucl. Phys. A125 (1969) 504.
[9] J. Libert et al., Phys. Rev. C25 (1982) 586.
[10] M. Meyer et al., Nucl. Phys. A316 (1979) 93.
[11] H. Flocard P. Bonche, P.H. Heenen, M. Weiss, S. Krieger, N. Redon, M. Meyer, J. Meyer and P. Quentin, to be published.
[12] N. Redon et al., Phys. Lett. 181B (1986) 223.