Eur. Phys. J. A **10**, 139–143 (2001)

**THE EUROPEAN PHYSICAL JOURNAL A**



# Low-spin states of doubly odd $^{182}$Au

F. Ibrahim[1,a], J. Genevey[1], E. Cottereau[2], A. Gizon[1], A. Knipper[3], F. Le Blanc[2], G. Marguier[4], J. Obert[2], J. Oms[2], J.C. Putaux[2], B. Roussière[2], J. Sauvage[2], A. Wojtasiewicz[5], and the ISOLDE Collaboration

[1] Institut des Sciences Nucléaires, 38026 Grenoble Cedex, France
[2] Institut de Physique Nucléaire, 91406 Orsay Cedex, France
[3] Institut de Recherches Subatomiques, 67037 Strasbourg, France
[4] Institut de Physique Nucléaire, 69621 Villeurbanne Cedex, France
[5] University of Warsaw, Warsaw, Poland

Received: 19 December 2000 / Revised version: 22 February 2001
Communicated by W.F. Henning

**Abstract.** Low-lying states in the odd-odd light gold isotope $^{182}$Au have been populated by the $\beta^+/EC$ decay of the $^{182}$Hg nuclei. Level energies, spin and parity values were determined using on-line $\gamma$-ray and $e^-$ spectroscopy measurements. No isomeric state with a long half-life was found in the $^{182}$Au nucleus. Spin and parity $I^\pi = 2^+$ can be very likely assigned to the $^{182}$Au ground state.

**PACS.** 21.10.Hw Spin, parity and isobaric spin – 23.20.Nx Internal conversion and extranuclear effects – 23.20.Lv Gamma transitions and levels energies – 27.70.+q $150 \leq A \leq 189$

## 1 Introduction

Even-$A$ or odd-$A$ nuclei around $A = 186$ have already been extensively studied providing exciting results [1–7]. For ground states along isotopic series, shape transitions were pointed out by laser spectroscopy experiments and, using nuclear spectroscopy methods, it has been shown that nuclear states corresponding to different shapes coexist at around the same excitation energy in neutron-deficient isotopes [8]. In this region the $^{184}$Au ($Z = 79$) nucleus has been the subject of radioactive decay [9], in-beam $\gamma$-ray spectroscopy [10] and atomic hyperfine spectroscopy studies [11]. In this nucleus two isomers are known and in particular, a low-spin isomeric state is linked to the higher-spin ground state by an $M3$ transition. In order to check if such a long-lived isomer is also present in $^{182}$Au, low-lying states have been populated using the $\beta^+/EC$ decay of $^{182}$Hg. Prior to this investigation, nothing was reported about the excited levels of $^{182}$Au [12]. A nuclear orientation experiment performed at ISOLDE [13] led to possible spin values ($I = 2, 3, 4$) for the ground state with a half-life $T_{1/2} = 15.6(4)$ s.

[a] *Permanent address:* Institut de Physique Nucléaire, 91406 Orsay Cedex, France.
e-mail: `ibrahim@ipno.in2p3.fr`

## 2 Experimental procedure

The decay of $^{182}$Hg ($T_{1/2} = 10.8$ s) was investigated by $\gamma$-$\gamma$ and $e^-$-$\gamma$ coincidence measurements. Mercury isotopes were produced by bombarding a molten lead target with the 1 GeV proton beam delivered by the CERN PS Booster. The target was connected to a plasma ion source and the extracted ion beam was mass-separated by ISOLDE . The beam was finally implanted onto an aluminized mylar tape. The radioactive source was counted immediatly at the collection point ($\gamma$-$\gamma$ measurement) or moved to reach the second detection station ($e^-$-$\gamma$ measurement). Mass-separated radioactive ions were collected during 400 ms and measurements were performed for 5 s. The collection tape was moved after each implantation-counting cycle to reduce the background coming from unwanted long-lived activity for the $\gamma$-$\gamma$ measurement . The detection system for the $e^-$-$\gamma$ experiment consisted of a cooled 3 mm thick Si(Li) detector for electron detection and a coaxial Ge(HP) detector (efficiency 18%, resolution 2.1 keV at 1.3 MeV) covering an energy range up to 1.5 MeV. The detection system for the $\gamma$-$\gamma$ experiment consisted of two detectors: a planar Ge (HP) X-ray detector having a 300 $\mu$m beryllium window for detecting low-energy X- and $\gamma$-rays (resolution 0.75 keV at 122 keV) covering an energy range up to 1 MeV, and a large 60% efficiency germanium detector covering an energy range up to 1.6 MeV (resolution 2.6 keV at 1.3 MeV). $4.8 \cdot 10^6$ $e^-$-$\gamma$-t and $1.7 \cdot 10^7$ $\gamma$-$\gamma$-t coincidence events were recorded in an event-by-event mode.

**Table 1.** $\gamma$-ray and conversion-electron data for the decay of $^{182}$Hg→$^{182}$Au. The total intensities are determined using the multipolarities indicated in column 4.

| $E_\gamma$(keV) | $I_\gamma$ | $I_{tot}$ | Multipolarity | $ICC_{exp}$ or ratio | Location |
|---|---|---|---|---|---|
| 25.6(1) | 0.5(2) | 38(15) | ($M1$) | - | 25.6→0.0 |
| 30.5(1) | 3.7(7) | 11.5(21) | ($E1$) | - | 129.5→98.9 |
| 37.8(1) | 0.4(2) | 11(5) | ($M1$) | - | 100.7→62.9 |
| 51.9(1) | 3.5(2) | 36(3) | $M1$ | $\alpha(L1) = 5$ | 325.4→273.5 |
| 61.0(1) | 1.4(7) | 9.4(47) | ($M1$) | - | 543.0→482.1 |
| 62.9(1) | 6.0(30) | 37(18) | ($M1$) | - | 62.9→0.0 |
| 64.1(2) | 3.2(16) | 19(9) | ($M1$) | - | 127.0→62.9 |
| 98.9(2) | 4.2(2) | 37(2) | ($M1$) | - | 98.9→0.0 |
| 103.9(2) | 23(2) | 32(3) | $E1$ | $\alpha(L3) < 1.9 \cdot 10^{-2}$, $\alpha(L1+L2) < 8 \cdot 10^{-2}$ | 129.5→25.6 |
| 127.0(3) | 1.2(6) | 6(3) | ($M1$) | - | 127.0→0.0 |
| 129.5(1) | 100 | 122 | $E1$ | $\alpha(M) = 7.7 \cdot 10^{-3}$, $K/L = 5.1$ | 129.5→0.0 |
| 144.0(2) | 6.7(10) | 24(4) | $M1$ | $\alpha(K) = 2.1$ | 273.5→129.5 |
| 173.1(2) | 6.6(4) | 7.3(5) | $E1$ | $\alpha(K) < 0.15, K/L > 5.3$ | 482.1→309.0 |
| 179.5(2) | 3.1(2) | 7.4(5) | $M1+E2$ | $\alpha(K) = 0.75$ | 309.0→129.5 |
| 180.3(3) | 0.7(2) | 1.6(4) | ($M1$) | - | 543.0→362.7 |
| 182.0(2) | 6.7(5) | 7.3(6) | $E1$ | $\alpha(K) \sim 0.1, K/L > 6.4$ | 309.0→127.0 |
| 195.9(2) | 4.5(5) | ∼30 | $E0+M1$ or abn $M1$ | $\alpha(K) = 4.5, K/L = 4.8$ | 325.4→129.5 |
| 203.7(1) | 1.0(2) | 2.0(4) | ($M1$) | $\alpha(K) = 1.6$, $\alpha(L1) = 0.3, K/L = 4.5$ | 543.0→339.3 |
| 212.3(2) | 5.7(5) | 10.8(10) | $M1$ | $\alpha(K) = 0.8, \alpha(L1) = 0.16$ | 339.3→127.0 |
| 217.6(1) | 62(5) | 66(6) | $E1$ | $\alpha(K) = 3 \cdot 10^{-2}$ | 543.0→325.4 |
| 233.2(3) | 7.9(3) | 8.3(3) | ($E1$) | $\alpha(K) = 0.1$ | 362.7→129.5 |
| 235.7(1) | 11.8(5) | 19.7(10) | $M1$ | $\alpha(K) = 0.58$ | 362.7→127.0 |
| 240.4(3) | 1.3(2) | 2.0(3) | ($M1$) | - | 339.3→98.9 |
| 248.0(2) | 6.1(2) | 6.4(2) | ($E1$) | $\alpha(M1) = 5.8 \cdot 10^{-3}, K/L > 2.2$ | 273.5→25.6 |
| 269.5(1) | 8.2(3) | 8.5(3) | $E1$ | $\alpha(L1) < 1.7 \cdot 10^{-2}, K/L \sim 6.6$ | 543.0→273.5 |
| 273.5(1) | 15.7(3) | 16.2(3) | $E1$ | $\alpha(L1) < 1.6 \cdot 10^{-2}, K/L \geq 6$ | 273.5→0.0 |
| 339.3(2) | 8.6(2) | 10.7(3) | $M1$ | $\alpha(K) = 0.12, K/L = 6.1$ | 339.3→0.0 |
| 362.7(3) | 8.5(2) | 10.2(2) | $M1$ | $\alpha(K) = 0.17$ | 362.7→0.0 |
| 413.5(1) | 52(5) | 53(5) | $E1$ | $\alpha(K) = 1.6 \cdot 10^{-2}$ | 543.0→129.5 |
| 442.3(2) | 7.1(2) | 8.0(3) | $M1$ | $\alpha(K) = 0.11$ | 543.0→100.7 |
| 480.0(3) | 9.9(5) | 10.9(6) | $M1$ | $\alpha(K) = 9.5 \cdot 10^{-2}$ | 543.0→62.9 |
| 543.0(2) | 6.4(4) | 10.9(7) | $M1$ | $\alpha(K) = 5.5 \cdot 10^{-2}$ | 543.0→0.0 |

## 3 Experimental results

The energies and intensities of $\gamma$-rays belonging to the $^{182}$Hg→$^{182}$Au decay are listed in table 1. The identification of the transitions has been obtained by analysing the spectrum in coincidence with the 68.8 keV $K_{\alpha_1}$ X-ray of gold. When the intensities of the electron lines are determined unambiguously we can deduce the multipolarity of the observed transitions. The experimental conversion coefficients obtained for these transitions are therefore listed in column 5 of table 1. The electron intensities have been normalized using the $E2$ 154.9 keV transition present in the $^{182}$Au→$^{182}$Pt decay. The deduced multipolarity obtained from the comparison of the experimental conversion coefficients to those given by Rösel *et al.* [14] are indicated in column 4. For some transitions, the corresponding electron lines are too mixed with other strong transitions to determine the conversion coefficients. For these transitions, only the most probable multipolarities is indicated in column 4.

The level scheme of $^{182}$Au shown in fig. 1 has been built using the e$^-$-$\gamma$ and $\gamma$-$\gamma$ coincidences. All the transitions belonging to the $^{182}$Hg→$^{182}$Au have been placed in the level scheme. The location of the transitions in the level scheme is indicated in column 6 of table 1. In the gamma spectrum three main lines are observed at 129.5, 217.6 and 413.5 keV. Figure 2 displays the $\gamma$-spectrum in coincidence with the 129.5 keV $\gamma$-line. The 413.5 keV $\gamma$-ray is placed directly on the 129.5 keV level. The strong 217.6 keV transition decays on the 129.5 keV level via a weak-intensity 195.9 keV $\gamma$-transition (see fig. 2) while the electron spectrum in coincidence with the same 129.5 keV $\gamma$-line, shown in fig. 3, exhibits strong electron lines corresponding to the 195.9 keV transition. As reported in table 1, the conversion coefficient for the $K$ line of the 195.9 keV transition is 4.5. This excludes the $E1$, $M1$ or $E2$ multipolarities for this transition. Neither is an M2 multipolarity possible: this line is in prompt coincidence with the 217.6 keV and moreover, due to the clear $E1$ multipolarities of the 217.6 and 413.5 keV transitions, no parity change is possible between the levels at 325.4 and 129.5 keV. Therefore, the most probable multipolarities for the 195.9 keV are $E0+M1$ or abnormal $M1$. Such abnormal $M1$ transitions have been observed in the odd-$A$

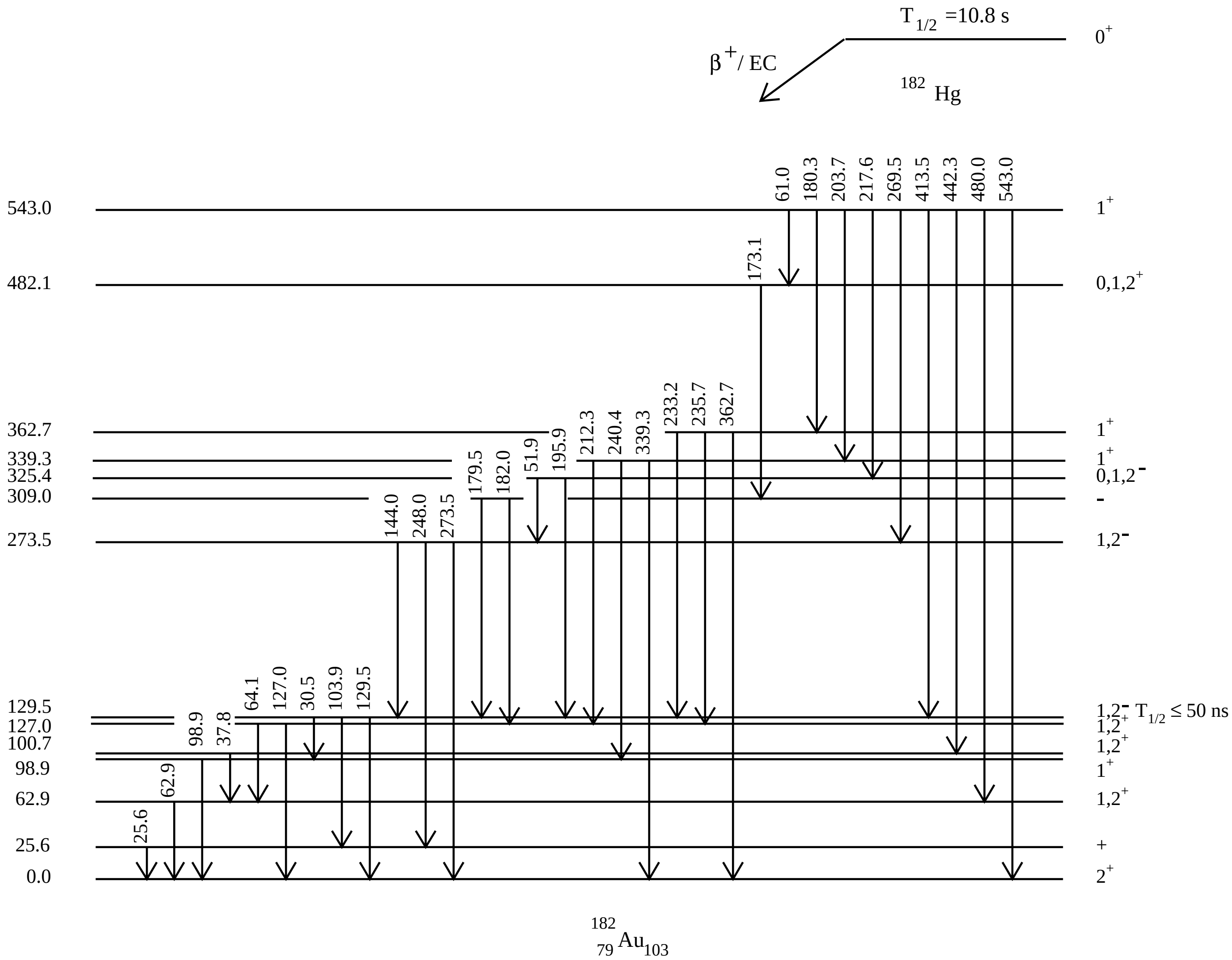


**Fig. 1.** Low-spin level scheme of $^{182}$Au.

nuclei of this region [15]. The total intensity measured for this line ($I_{\text{tot}} \sim 30$) would lead in the first case to about 70% $E0 + 30\%$ $M1$ mixing.

Transitions of 103.9 and 129.5 keV exhibit a $T_{1/2} \leq$ 50 ns delay and allow us to attribute such a lifetime to the 129.5 keV level. Many transitions populate the 129.5 keV level and establish levels at 273.5, 309.0, 325.4, 362.7 and 543.0 keV. Couples of transitions with a difference in energy of 2.5 keV decay the 309.0 and 362.7 keV levels. This leads to establish a level at 127.0 keV close to the 129.5 keV level. The existence of this level is confirmed by coincidence relationships: the $\gamma$-spectrum gated by the 173 keV $\gamma$-line shows both the 179.5 and 182.0 keV transitions and the electron lines corresponding to the 64.1, 62.9 and 127.0 keV transitions are clearly observed in the spectrum in coincidence with the 235.7 keV $\gamma$-line (fig. 4).

The NICOLE experiment at ISOLDE [13] leads to a spin $I = 2,\ 3$ or 4 for the ground state. We can therefore consider that the $\beta$-feeding to the ground state is negligible for the level scheme shown in fig. 1. $\log ft$ values have been calculated using $Q_{EC} = 4.78$ MeV [16]. Results are

**Table 2.** ($EC + \beta^+$) feedings and $\log ft$ values in the $^{182}$Hg decay

| Level (keV) | $I(EC + \beta^+)$% | $\log ft$ |
|---|---|---|
| 543.0 | 55(9) | 4.2±0.1 |
| 482.1 | - | - |
| 362.7 | 12.1(16) | 4.9±0.1 |
| 339.3 | 7.2(16) | 5.1±0.1 |
| 325.4 | - | - |
| 309.0 | 2.5(16) | 5.6±0.4 |
| 273.5 | - | - |
| 129.5 | 14(13) | - |
| 127.0 | - | - |
| 100.7 | - | - |
| 98.9 | 7(2) | 5.2±0.1 |
| 62.9 | - | - |
| 25.6 | - | - |

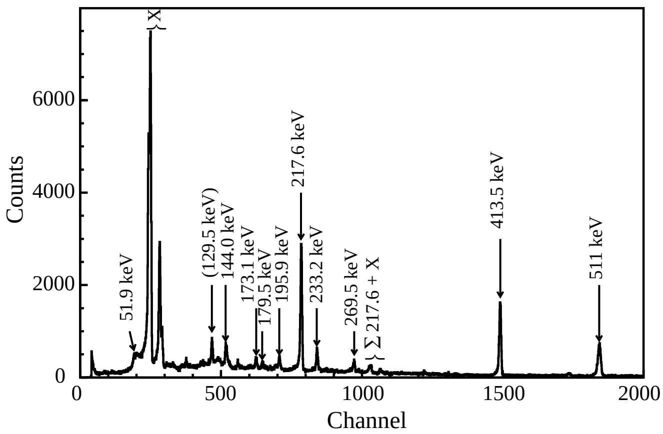


**Fig. 2.** $\gamma$-ray spectrum observed in coincidence with the $\gamma$-ray 129.5 keV.

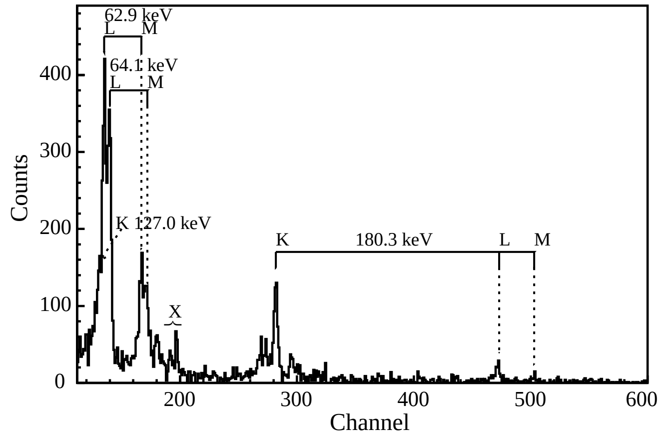


**Fig. 4.** Electron spectrum observed in coincidence with the $\gamma$-ray 235.7 keV.

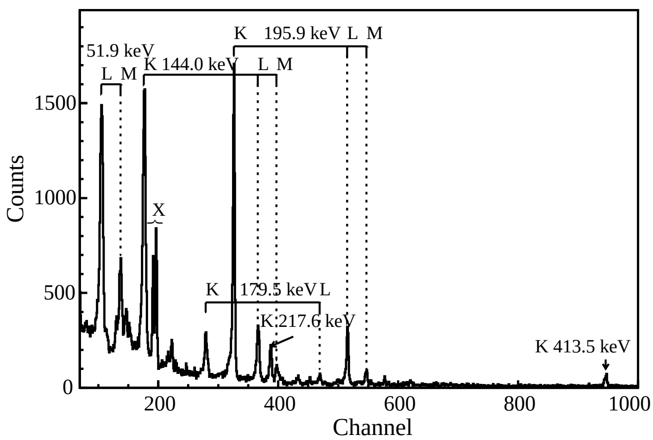


**Fig. 3.** Electron spectrum observed in coincidence with the $\gamma$-ray 129.5 keV.

reported in table 2. Levels with $\log ft$ values lower than 5.9 correspond to allowed transitions $\Delta J = 0, 1$ with $\Delta\pi = +$, except $0^+ \rightarrow 0^+$ [17].

Since the $^{182}$Hg ground state has $0^+$ as spin and parity, levels in $^{182}$Au having unambiguously a $\log ft$ value smaller than 5.9, namely levels located at 543.0, 362.7, 339.3, and 98.9, have spin and parity $I^\pi = 1^+$. In the present stage of the level scheme, the evaluated $I(EC + \beta)$ feeding reaches 14 (13)% for the 129.5 keV level. This value cannot be used to extract a significant $\log ft$. However, $I^\pi = 1, 2^-$ characteristics for this level can be deduced from the strong 413.5 keV ($E1$)-129.5 keV ($E1$) cascade starting from the $1^+$ excited at 543.0 keV. Based on transition multipolarities, four negative-parity states have been found. Multipolarities of the 543.0 and 362.7 keV transitions are clearly $M1$. This supports spin and parity $I^\pi = 2^+$ for the ground state of $^{182}$Au. No long-lived isomeric state similar to the one observed in $^{184}$Au has been observed in this $\beta$-decay.

## 4 Discussion

The study of the neighboring odd-A nuclei of $^{182}$Au may allow the identification of the single-particle states present at low energy and suggests the neutron-proton configurations in $^{182}$Au.

Both $^{181}$Au and $^{183}$Au nuclei have a ground state interpreted as the $5/2^-$state built mainly on the $1/2^-[541]$ configuration arising from the subshell $\pi h9/2$ [18,19]. Moreover, in $^{183}$Au a positive-parity state $I^\pi = 1/2^+$ has been proposed at very low-excitation energy. In $^{181}$Pt, the states present at low-excitation energy are $\nu 1/2^-[521]$, $\nu 7/2^-[514]$, $\nu 5/2^-$ [512], $\nu 9/2^+[624]$ and $\nu 7/2^+[633]$ [18]. In $^{183}$Hg the ground state is known to be $\nu 1/2^-[521]$ [20]. A zero-order approximation of the spectrum of $^{182}$Au is obtained by coupling the proton states present in $^{181}$Au and $^{183}$Au to the neutron states observed in $^{181}$Pt and $^{183}$Hg.

The configuration $\pi h9/2 \otimes \nu 1/2^-[521]$ is expected to be located at the lowest energy. Such a configuration is known to have a bandhead with spin and parity values $I^\pi = 2^+$ in both the $^{184}$Au and $^{186}$Au nuclei. Therefore the $2^+$ ground state of $^{182}$Au has very likely this $\pi h9/2 \otimes \nu 1/2^-[521]$ configuration. The interpretation of the negative-parity states is less obvious. They could correspond to the coupling of the $1/2^+$ proton state with the $\nu 1/2^-[521]$ state or to the $\pi h9/2 \otimes \nu i13/2$ configuration. In the first case, the resulting band would be very perturbed explaining why no $I^\pi = 0^-$ state is observed at very low energy. In the second case, the two states with an $\nu i13/2$ parentage located at low energy are $\nu 9/2^+[624]$ and $\nu 7/2^+[633]$ as in $^{181}$Pt [18]. These two states are observed in some isotones $N = 107$, 105 and 103. In platinum isotopes the energy distance between the $\nu 9/2^+[624]$ and $\nu 7/2^+[633]$ states is 706 keV for $N = 107$, 180 keV for $N = 105$ and only 10 keV for $N = 103$. In both $^{186}$Au and $^{184}$Au odd-odd nuclei, a $3^-$ state corresponding to the $\pi h9/2 \otimes \nu 9/2^+[624]$ configuration has been observed. No evidence for such a $3^-$ state was found in $^{182}$Au. However, in the neighbouring odd-odd $^{176,178}$Re and $^{180}$Ir nuclei [21–23], negative-parity bands have been observed in in-beam experiments. They have been proposed to correspond to the $\pi h9/2 \otimes \nu i13/2$ configuration, where the $\nu 7/2^+[633]$ orbital should be the largest configuration in the $\nu i13/2$ multiplet. Thus, negative-parity states observed in $^{182}$Au could correspond to a preponderant $\pi h9/2 \otimes \nu 7/2^+[633]$ configuration which would lead to a band head $I^\pi = 2^-$. More experimental data, in particular the structure of the band involving these negative-parity states, are needed to firmly conclude on the $\pi\nu$ configuration describing the low-spin negative-parity states observed in the present work in $^{182}$Au.

## References


1. W.F. Mueller et al., Phys. Rev. C **59**, 2009 (1999).
2. M.G. Desthuilliers et al., Nucl. Phys. A **313**, 221 (1979).
3. A.J. Larabee et al., Phys. Lett. B **169**, 21 (1986).
4. B. Roussière et al., Nucl. Phys. A **504**, 511 (1989).
5. J. Nyberg et al., Nucl. Phys. A **511**, 92 (1990).
6. P. Dabkiewicz et al., Phys. Lett. B **82**, 199 (1979).
7. F. Hannachi et al., Z. Phys. A **330**, 15 (1988).
8. K. Heyde et al., Phys. Rep. **102**, 291 (1983).
9. F. Ibrahim et al., Z. Phys. A **350**, 9 (1994).
10. F. Ibrahim et al., Phys. Rev. C **53**, 1547 (1996).
11. F. Le Blanc et al., Phys. Rev. Lett. **79**, 2213 (1997).
12. R. B. Firestone, NDS 54, (1988) 307 and *Table of Isotopes*, 8th ed., edited by R.B. Firestone, V.S. Shirley (Wiley, New York, 1996).
13. M. De Jesus, *Thesis* (Université Claude Bernard Lyon-1, 1992).
14. F. Rösel et al., At. Data Nucl. Data Tables **21**, 291 (1978).
15. B. Roussière et al., Nucl. Phys. A **548**, 227 (1992).
16. G. Audi et al., Nucl. Phys. A **624**, 1 (1997).
17. S. Raman, N.B. Gove, Phys. Rev. C **7**, 1995 (1973).
18. J. Sauvage et al., Nucl. Phys. A **540**, 83 (1992).
19. M.I. Macias-Marques et al., Nucl. Phys. A **427**, 205 (1984).
20. P. Misaelides et al., Z. Phys. A **301**, 199 (1981).
21. A.J. Kreiner et al., Phys. Rev. C **40**, R487 (1989).
22. M.A. Cardona et al., Phys. Rev. C **59**, 1298 (1999).
23. Y.H. Zhang et al., Eur. Phys. J. A **5**, 345 (1999).