**CHARGE RADII AND SHAPE TRANSITIONS IN
SHORT-LIVED Hg, Au AND Pt ISOTOPES**

**Th. Hilberath¹, St. Becker¹, G. Bollen², M. Gerber¹,
H.-J. Kluge¹, U. Krönert¹, G. Passler¹ and the ISOLDE Collaboration**

¹Institut für Physik, Universität Mainz, Postfach 3980,

D-6500 Mainz, Fed. Rep. Germany

²ISOLDE Collaboration CERN, CH-1211 Geneva 23, Switzerland

(IS 150)

Contributed paper to the
"8th International Conference on Hyperfine Interactions"
Prague, Czechoslovakia, 14-19 August 1989

To be published in "Hyperfine Interactions"

CHARGE RADII AND SHAPE TRANSITIONS IN SHORT-LIVED Hg, Au AND Pt ISOTOPES

Th. Hilberath, St. Becker, G. Bollen, M. Gerber, H.-J. Kluge, U. Krönert, and G. Passler
Inst. für Physik, Uni. Mainz, Postfach 3980, D-6500 Mainz, F.R. Germany and the ISOLDE
Collaboration, CERN, CH-1211 Geneva 23, Switzerland

Abstract

The hyperfine structure and the isotope shift of very neutron-deficient Au and Pt isotopes have been determined at the on-line isotope separator ISOLDE/CERN by resonance ionization mass spectroscopy combined with pulsed-laser induced desorption of the implanted radioactive sample. The changes of the mean-square charge radii were determined for the isotopes ^{184}Au ($T_{1/2} = 53\text{ s}$) and ^{183}Au ($T_{1/2} = 42\text{ s}$) as well as for 15 isotopes of platinum in the range between ^{198}Pt (stable) and ^{183}Pt ($T_{1/2} = 6.5\text{ min}$). The strong deformation of ^{185}Au ($|\beta_2| \simeq 0.25$) persists down to ^{183}Au . In ^{183}Pt nearly the same value of $|\beta_2|$ is reached but the deformation is build up rather smoothly in contrast to the neighbouring isotopes of gold and mercury. The magnetic moment of ^{183}Pt was found to be $\mu_I = +0.51(3)\mu_N$.

1 Introduction

Nuclear spins and moments and the changes of the nuclear charge radii are key input parameters for nuclear-model calculations. These quantities can be determined by measuring the hyperfine structure (HFS) and the isotope shift (IS) in optical transitions with the help of tunable lasers [1]. At the isotope separator ISOLDE at CERN/Geneva these investigations can be performed on-line with the production of the isotopes which are available in a broad isotopic range with high purity and intensity [2]. Since 1977 investigations of more than 300 short-lived isotopes have been made resulting in an enormous increase of our knowledge about nuclear structure [1]. Especially the region near $Z = 80$ and $N = 104$ has attracted a lot of attention: In 1972 the phenomena of nuclear shape transition, and later on shape coexistence and shape staggering were discovered in the neutron-deficient Hg-isotopes [3]. Because these effects depend critically on shell and pairing energies, we have performed similar systematic studies in the neighbouring elements Au and Pt.

2 Experimental set-up and performance

Fig. 1 shows the experimental set-up which had been installed at the new on-line isotope separator ISOLDE-3 at CERN/Geneva. Since no efficient target-ion-source system was available for the direct production of gold or platinum isotopes, the nuclei were obtained as daughters in the decay of isobaric Hg isotopes. Resonance ionization mass spectroscopy (RIMS) in combination with pulsed-laser induced desorption (PLID) [4, 5] was applied in order to investigate these isotopes.

The mass-separated Hg^+ -beam from the isotope separator was focused onto a target wheel made of graphite. After the selected isotope had decayed into Au or Pt this wheel was turned by 180° and the implanted atoms were evaporated by means of PLID using 10-ns light-pulses of a Nd:Yag laser ($\lambda = 532\text{ nm}$). The atoms desorbed were photo-ionized using tunable dye lasers pumped by a second Nd:Yag laser. In the case of gold a three-colour, three-step resonant excitation to an autoionizing state ($\lambda_1 = 267\text{ nm}$, $\lambda_2 = 407\text{ nm}$, $\lambda_3 = 592\text{ nm}$) was used whereas in the case of platinum the last ionizing step was accomplished by the frequency-doubled light of the Nd:Yag pump laser ($\lambda_1 = 266\text{ nm}$, $\lambda_2 = 451\text{ nm}$, $\lambda_3 = 532\text{ nm}$). A time-of-flight (TOF) spectrometer with a two-stage acceleration region, a field-free drift tube, a 40° ion reflector and

Fig.1 Set-up for the on-line resonance ionization mass spectroscopy of short-lived Au and Pt isotopes with pulsed-laser induced desorption

a microchannel plate detector served for mass-selective detection of the photo ions and hence reduction of background.

The overall detection efficiency ϵ_{exp} of the RIMS apparatus, which is defined as the ratio of the number of ions detected in resonance to the number of atoms implanted into the target, was determined to be $\epsilon_{exp} = 10^{-5}$ for the case of Au in satisfactory agreement with the calculated value [5]. This is an increase of the efficiency by three orders of magnitude in comparison to a continuous evaporation of the Au-atoms as used in an earlier experiment on heavier Au isotopes [6].

During the run at ISOLDE an efficiency was observed which was two orders of magnitude lower than stated above. For the case of Au this reduction is due to the limited spatial overlap of the beamspot of the desorption laser with the area of the implanted ion beam (20%), the losses due to radioactive decay in the case of short-lived isotopes (50%), and the bad performance of the dye laser used for the third excitation step during the beam time. For platinum, a similar efficiency was found. Here, the desorption efficiency might have been lower and/or the third ionization step into the continuum far from saturation.

A background counting rate of typically one event per 1000 laser pulses was observed in test as well as during the on-line experiments.

3 Results

Spins, magnetic moments, quadrupole moments, and changes of the mean-square charge radii $\delta \langle r^2 \rangle$ can be deduced from the HFS splitting and the IS in the first excitation step which is in both cases a $6s \rightarrow 6p$ transition (Pt: $5d^9 6s^3 D_3 \rightarrow 5d^9 6p^7 F_4$, Au: $5d^9 6s^2 S_{1/2} \rightarrow 5d^9 6p^2 P_{1/2}$). Fig. 2 shows the resonances in the ion signal of ^{183}Pt , the most neutron-deficient Pt isotope investigated by us. Since only two resonances are observed, the nuclear spin is determined to be $I = 1/2$. The data points of Fig. 2 are corrected for the time constant of the desorption, which is of the order of 30 s (300 laser shots). The measured intensity ratio of the two HFS components of $R_{exp} = 1.4(5)$ favours the choice of a positive sign of the magnetic moment ($R_{theo} = 1.3$ for $\mu_I > 0$, $R_{theo} = 0.77$ for $\mu_I < 0$). Hence the splitting of the two HFS components yields a magnetic moment of $\mu_I = +0.51(3) \mu_N$ which is typical for a $\nu 1/2^-$ [521] orbital at large prolate deformation.

The most striking data obtained are the changes of the mean-square charge radii of the Hg, Au and Pt nuclei in the mid-shell region around $N=104$ compiled in Fig. 3. In the case of Hg the well-known nuclear shape transition from slightly oblate ($A \geq 186$) to strongly prolate deformation ($A = 185, 183, 181$) is shown as well as the shape coexistence in ^{185}Hg and the huge odd-even staggering in the region $181 \leq A \leq 186$ [3].

A similar shape transition from slightly oblate to a strong prolate shape was also observed in the gold nuclei. The deformation changes from $|\beta_2| \simeq 0.16$ in ^{187}Au to $|\beta_2| \simeq 0.25$ in ^{186}Au

Fig. 2 Resonance signal of laser-desorbed ^{183}Pt atoms ($I = 1/2$, $T_{1/2} = 6.5$ min) versus the laser frequency in the first excitation step as obtained by resonance ionization mass spectroscopy. The solid line represents a fit to the data points. For this signal $3 \cdot 10^9$ ions of ^{183}Hg were implanted into the target.

Fig. 3 Changes of the mean-square charge radii of Hg, Au and Pt isotopes as a function of the mass number. The ground state data points are connected by eye-guiding lines. The isomeric states are indicated by asterisks. The values for Hg and Au are taken from Refs. [3] and [7]. The dashed line indicates the change of the radius of a spherical nucleus according to the droplet model [8].

and ^{185}Au [6]. By using the RIMS/PLID method we were able to investigate two even more neutron-deficient isotopes ^{184}Au and ^{183}Au . From an analysis of the IS a similar strong deformation of $|\beta_2| \simeq 0.25$ is obtained for these isotopes [7]. This behavior is due to the $\pi h_{9/2}$ intruder orbital which stabilizes the strong prolate deformation of the isotopes below $A = 186$.

In the case of platinum the influence of the proton shell closure at $Z = 82$ is diminished drastically. As can be seen from Fig. 3 by comparison with the slope of the spherical droplet prediction [8] the nuclear deformation starts to build up already in the heavy isotopes. For ^{183}Pt a similar deformation value ($|\beta_2| \simeq 0.24$) is observed as in the corresponding light Hg and Au isotopes.

A smooth change in the ground-state deformation from predominantly oblate shape for $A > 188$ to predominantly prolate shape for $A < 188$ is expected from nuclear decay spectroscopy [9]. No evidence for such a shape transition in Pt can be found from Fig. 3. The explanation is that IS measurements are only sensitive to a change in the size but not to a change in the sign of β_2 , since $\delta \langle r^2 \rangle$ is depending on $\langle \beta_2^2 \rangle$. The spectroscopic quadrupole moments are much more decisive for a shape transition as long as the coupling of the valence neutron to the nuclear core is known [10]. Such measurements have recently been performed by nuclear orientation [11] and RIMS/PLID experiments [12] very similar to ours. These experiments yield a change in the ground state deformation between ^{187}Pt and ^{185}Pt from oblate to prolate shape. Since the IS values show no evidence for any discontinuity in this region, it can be concluded that the Pt nuclei near $A = 186$ have minima in the energy-deformation curve on the prolate and oblate side at nearly identical absolute deformation values or that they are γ -soft with $|\beta_2| \simeq 0.20$.

Supported by the BMFT under contract number MZ-458-I.

References

- [1] E.W. Otten, *Treatise on Heavy-Ion Physics*, Vol. 8: *Nuclei far from Stability*, D.A. Bromley, ed.; Plenum Press, New York (1989), page 515
- [2] ISOLDE Users Guide, H.-J. Kluge, ed.; CERN Yellow Report 86-05, CERN, Geneva (1986)
- [3] G. Ulm, S. K. Bhattacharjee, P. Dabkiewicz, G. Huber, H.-J. Kluge, T. Khl, H. Lochmann, E. W. Otten, K. Wendt, S. A. Ahmad, W. Klempt and R. Neugart, *Z. Phys.* **A325**, 247 (1986) and references therein.
- [4] H.-J. Kluge, *Hyperfine Interact.* **24** , 69 (1985) and *Hyperfine Interact.* **37** , 347 (1987)
- [5] U. Krnert, St. Becker, Th. Hilberath, H.-J. Kluge, C. Schulz and the ISOLDE Collaboration, *Appl. Phys.* **A44**, 339 (1987)
- [6] K. Wallmeroth, G. Bollen, A. Dohn, P. Egelhof, J. Grner, F. Lindenlauf, U. Krnert, J. Campos, A. Rodriguez Yunta, M. J. G. Borge, A. Venugopalan, J. L. Wood, R. B. Moore, H.-J. Kluge, and the ISOLDE Collaboration, *Phys. Rev. Lett.* **58**, 1516 (1987) and
K. Wallmeroth, G. Bollen, A. Dohn, P. Egelhof, U. Krnert, M.J.G. Borge , J. Campos, A. Rodriguez Yunta, K. Heyde , C. De Coster, J. L. Wood, H.-J. Kluge and the ISOLDE Collaboration, *Nucl. Phys.* **A493**, 224 (1989)
- [7] U. Krnert, St. Becker, G. Bollen, M. Gerber, Th. Hilberath, H.-J. Kluge, G. Passler and the ISOLDE Collaboration, *Z. Phys.* **A331**, 521 (1988)
- [8] W.D. Myers, K.-H. Schmidt, *Nucl. Phys.* **A410**, 61 (1983)
- [9] M. Finger, R. Foucher, J.P. Husson, J. Jastrzebski, A. Johnson, G. Astner, B.R. Erdal, A. Kjelberg, P. Patzelt, . Hoglund, S.G. Malmskog and R. Henck, *Nucl. Phys.* **A188**, 369 (1972)
- [10] I. Ragnarsson, *Proc. of the Int. Symp. on Future directions in studies of nuclei far from stability* , Nashville 1979, J. H. Hamilton, E. H. Spejewski, C. R. Bingham, E. F. Zganjar, eds.; North-Holland Publ. Comp., Amsterdam (1980), page 367
- [11] R. Eder, C.J. Ashworth, I. Berkes, D.E. Brown, U. Dmmrich, I.S. Grant, A.G. Griffiths, E. Hagn, R. Hassani, P. Herzog, S. Ohya, M. Massaq, C. Richard-Serre, J. Rikowska, K. Schlsser, N. Severijns, N.J. Stone, W. Vanderpoortren, J. Vanhaverbeke, L. Vanneste, T. Woelfle, E. Zech and the ISOLDE Collaboration, *Hyp. Int.* **43**, 469 (1988)
- [12] J.K.P. Lee, G. Savard, J.E. Crawford, G. Thekkadath, H. T. Duong, J. Pinard, S. Liberman, F. Le Blanc, P. Kilcher, J. Obert, J. Oms, J.C. Putaux, B. Roussire and J. Sauvage, *Phys. Rev.* **C38**, 2985 (1988)