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K. Wallmeroth¹, G. Bollen¹, M.J.G. Borge²⁻³, J. Campos³, A. Dohn¹,
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F. Lindenlauf¹, R.B. Moore⁴, A. Rodriguez³,
A. Venugopalan²⁻⁶, J. Wood⁵

and the ISOLDE Collaboration

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¹Universität Mainz, Mainz, Fed. Rep. Germany

²CERN, Geneva, Switzerland

³Universidad Complutense and J.E.N., Madrid, Spain

⁴McGill University, Montreal, Canada

⁵Georgia Institute of Technology, Atlanta, USA

⁶Bhabha Atomic Research Center, Bombay, India

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On-line resonance ionization mass spectrometry has been applied to determine the isotope shift and hyperfine structure of $^{185-189}\text{Au}$ and the $I = 9/2$ isomer of ^{189}Au in the $6s\ ^2S_{1/2} \rightarrow 6p\ ^2P_{1/2}$ ($\lambda = 268\text{ nm}$) transition. The Au atoms were obtained as daughters of mass-separated Hg isotopes produced at the ISOLDE facility at CERN, ionized by a three-step resonant photoionization process, detected and mass-selected by time of flight. A drastic change of the nuclear charge radius was observed between ^{187}Au and ^{186}Au , which is interpreted as an onset of strong deformation of $\beta_2 \approx 0.25$ in ^{186}Au and ^{185}Au .

The nuclei near $Z = 80$ and $N = 104$ have attracted considerable attention following the discovery by Bonn et al.¹⁻², that there is a big change in the ground-state mean-square charge radius between ^{187}Hg and ^{185}Hg which was interpreted as an onset of strong deformation at $A \lesssim 185$. This observation, obtained from a measurement of the optical isotope shift (IS), was completely unexpected, since at that time the unanimous view was that nuclei near closed shells, such as the isotopes of Hg with $Z = 80$, are only weakly deformed. This view and our knowledge of the region around ^{185}Hg have since changed dramatically. It is becoming evident that coexisting shapes occur widely throughout the region below $Z = 80$.

A measurement of the isotope and/or isomer shift represents the most straightforward and model-independent signature for shape transitions or shape coexistence. In recent experiments, the IS's in the isotopic chains of Tl and Au have been determined³⁻⁴. No indication of a shape transition or coexistence was observed because the experiments were restricted to the study of heavier isotopes ($N \geq 108$) whereas the shape effects are expected to occur in nuclei with about half-filled neutron shell.

The present experiment was designed to investigate shorter-lived Au isotopes and to determine their IS's. As a byproduct the magnetic hyperfine splitting is obtained. The Au isotopes were produced at the ISOLDE mass separator at CERN. Since no target and ion-source system exists for a direct production of Au isotopes, these nuclei have at present to be obtained as daughters of Hg isotopes which can be produced with yields up to 10^{10} atoms per second and mass number by a $\text{Pb}(p,3pxn)\text{Hg}$ spallation reaction⁵.

Fig. 1. Set-up for on-line resonance ionization mass spectroscopy (RIMS) on short-lived Au isotopes. The oven collects the 60 keV mercury ion beam delivered by ISOLDE and produces a thermal atomic Au beam. The time-of-flight spectrometer consists of a two-stage acceleration region, a field-free drift tube, a 40° ion reflector, and a multichannel plate detector (MCP). With the exception of the reflector the spectrometer is of the same type as the one described in detail in Ref. 8. The ion reflector is installed to allow an efficient shielding of the MCP against nuclear β and γ radiation from the oven and acceleration region where strong radioactivity is accumulated during the on-line experiment.

The technique of resonance ionization spectroscopy (RIS)⁶⁻⁷ was used and combined with time-of-flight (TOF) mass spectroscopy. Because of the short half lives and the small production rates of the Au isotopes far off stability, the investigations had to be performed on line with the ISOLDE facility. This Contribution reports the first application of resonance ionization mass spectroscopy (RIMS) to an on-line study of short-lived isotopes.

Figure 1 shows the experimental set-up. The ISOLDE beam was focused into an atomic beam oven. After a suitable time has elapsed during which the Hg nuclei decay to the daughter isotope, a thermal atomic beam is formed by evaporating the radioactive sample. The Au atoms were excited and photoionized via a three-step resonant process by the light from two tunable dye lasers pumped by a Nd:YAG laser and the frequency-doubled output of the same Nd:YAG laser (repetition rate = 10 Hz). The optical transitions used for this experiment were (i) $6s\ ^2S_{1/2} \rightarrow 6p\ ^2P_{1/2}$, $\lambda_1 = 268\text{ nm}$, (ii) $6p\ ^2P_{1/2} \rightarrow 6d\ ^2D_{3/2}$, $\lambda_2 = 406\text{ nm}$, (iii) $6d\ ^2D_{3/2} \rightarrow \text{continuum}$, $\lambda_3 = 532\text{ nm}$.

In order to increase the signal-to-background ratio, the photoions were detected and mass selected by a TOF spectrometer. Fig. 2 shows the TOF spectrum in case of the measurement of ^{186}Au . A background rate as low as 1 event per 1000 laser shots was obtained with a mass resolution of the TOF set-up of 250 and a time window of 70 ns for gating on the mass of the isotope under investigation.

The overall detection efficiency ϵ of our RIMS technique for Au was determined to $\epsilon = 10^{-6}$ (defined as the ratio of Au ions detected by the MCP to the number of atoms collected in the oven). The efficiency is mainly limited by the low repetition rate of the laser system and the small cross-section of the third excitation step, which cannot be saturated even with laser powers up to 5 MW/cm².

Fig. 2. Time-of-flight spectrum. ^{186}Au was collected in the atomic beam oven. Stable ^{197}Au was added to serve as a mass marker. The medium-mass ions are due to photo ionization of rest gas and can be suppressed by setting an appropriate time window.

Figure 3 shows the HFS structure in the first optical transition of the Au isotopes. The deduced $A(6s)$ factors are compiled in Table 1. In order to calculate the magnetic moments, the relation⁹ $\mu_I = AI/29005 \mu_N$ is used. This procedure corrects for the large Bohr-Weisskopf effect ($\epsilon = 8.21\%$) of the $d_{3/2}$ configuration of ^{197}Au which is used as reference isotope. A common error of $0.03 \mu_N$ (about 10 times larger than the experimental errors) is assigned to the final values in Table 1 in order to account for the uncertainty of the remaining HFS anomaly. The agreement with earlier measurements⁹⁻¹⁰ is good except for the case of ^{187}Au . The reason for this discrepancy is unknown. The sign of the magnetic moment of some isotopes could not be determined since the statistics were too low to measure the intensity ratios of the HFS components.

TABLE 1. Magnetic moments of short-lived Au isotopes

A	I	This work		Literature	
		$A(6s^2S_{1/2})$ (MHz)	μ_I (μ_N)	μ_I (μ_N)	Reference
189	1/2	+28632(128)	+0.49(3)	-	-
189m	11/2	±32625(42)	±6.19(3)	±6.19(12)	10
188	1	-1940(127)	-0.07(3)	±0.069(24)	9
187	1/2	+31032(168)	+0.54(3)	+0.72(7)	9
186	3	±12207(48)	±1.26(3)	±1.07(13)	10
185	5/2	±25176(56)	±2.17(3)	±2.22(14)	10

Fig. 3. Hyperfine structure in the $\lambda_1 = 268$ nm optical transition of Au. The centres of gravity are indicated by full dots and give directly the isotope shifts.

Fig. 4. Changes of the mean-square charge radii of Au (dots) and of Hg⁹ (squares) isotopes. ¹⁹⁸Hg and ¹⁹⁷Au are used as reference isotopes.

The measured IS's are converted into changes of mean-square charge radii and plotted in Fig. 4 relative to ¹⁹⁷Au. In addition, the $\delta\langle r^2 \rangle$ values¹² of Hg are shown. The slope of the mean-square charge radii is very monotone and is similar to those of Hg down to ¹⁸⁷Au. Then, between ¹⁸⁷Au and ¹⁸⁶Au, a drastic change occurs, similar to the one in the Hg isotopic chain but (i) two neutron numbers earlier and (ii) with a much less pronounced odd-even staggering than for the Hg isotopes. As in the case of Hg, the break in the IS can be related to a change in the nuclear quadrupole deformation β_2 . From the IS values and with $|\beta_2|(^{197}\text{Au}) = 0.11$ (Ref.4) one calculates a smoothly increasing $|\beta_2| = 0.14$ to 0.16 for the isotopes ¹⁹⁰Au to ¹⁸⁷Au. $|\beta_2| = 0.25$ is obtained in case of ¹⁸⁶Au, and 0.24 for ¹⁸⁵Au. These results confirm earlier suggestions^{9, 11} that the ground states of these nuclei might be strongly deformed. C. Ekström et al. interpreted the measured $I = 5/2$ ground-state spin of ¹⁸⁵Au as due to the Coriolis-decoupled $1h_{9/2}$ intruder state and the prolate ($\beta \approx 0.25$) ¹⁸⁴Pt core. A strong deformation of the ground state of the odd-odd nucleus ¹⁸⁶Au was proposed by Porquet et al.¹¹.

In conclusion, a clear evidence for a shape transition from oblate ($A \geq 188$) to prolate ($A < 187$) deformation in the neutron-deficient Au isotopes has been observed by optical spectroscopy.

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