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# NUCLEAR SPIN OF $^{185}$Au AND HYPERFINE STRUCTURE OF $^{188}$Au

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## ABSTRACT

The nuclear spin of $^{185}$Au, $I = {}^{5}/_{2}$, and the hyperfine separation of $^{188}$Au, $\Delta\nu = \pm 2992(30)$ MHz, have been measured with the atomic-beam magnetic resonance method. The spin of $^{185}$Au indicates a deformed nuclear shape in the ground state. The small magnetic moment of $^{188}$Au is close in value to those of the heavier $I = 1$ gold isotopes $^{190,192,194}$Au, being located in a typical transition region.

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## 1. INTRODUCTION

In a previous paper [1], we reported on spin-measurements in the gold isotopes in the mass range A = 186 - 189. These measurements were performed at ISOLDE using conventional off-line techniques. By introducing an intermittent experimental procedure, it has been possible to extend the measurements to include the nuclear spin of $^{185}$Au and the hyperfine structure of $^{188}$Au.

## 2. EXPERIMENT

The radioactive gold isotopes were obtained as daughter products of mercury produced in spallation reactions when irradiating a molten lead target of the isotope separator with 600 MeV protons from the CERN synchro-cyclotron. The ion-beam from the isotope separator was focused on the on-line oven of the atomic-beam apparatus [2]. The oven was in these measurements operated in an intermittent mode, i.e. collecting on a cold foil of molybdenum followed by a delay period to allow the gold activity to saturate, heating the oven foil to about 1000 $^0$C to evaporate the remaining mercury activity and finally performing the experiment, evaporating gold out of the foil at a temperature of about 1600 $^0$C. The different time intervals used for the experiments in $^{185}$Au and $^{188}$Au are indicated in Table 1. It is evident that only four and three exposures, respectively, could be made per hour. The activity transmitted through the atomic-beam apparatus was measured in well-shielded NaI(Tl) detectors, sensitive to the KX-rays following EC decay.

The experimental procedure for spin and moment measurements in elements with a $J = {}^1/_2$ electronic ground state is described in our papers on gold [1] and cesium [3]. Resonance signals corresponding to a nuclear spin $I = {}^5/_2$ in $^{185}$Au were observed at three different settings of the external magnetic field; $\mu_B B/h$ = 2.060, 2.941 and 4.455 MHz. No signals were observed for other halfinteger spin values up to $^{11}/_2$. In Fig. 1, we show the decay curve of a $I = {}^5/_2$ resonance signal. The half-life corresponds to that reported for the isotope $^{185}$Au [4], 4.3 ± 0.2 min.

The nuclear spin of the 8.8 min isotope $^{188}$Au was measured in ref. [1] to be I = 1. In order to determine the hyperfine separation between the hyperfine levels $F = {}^3/_2$ and $F = {}^1/_2$ ( c.f. Fig. 6 of ref. [3] ), resonance experiments have to be made in successively stronger external magnetic fields. The single-quantum transition ( $F = {}^3/_2$, $m_F = -{}^1/_2$ ) $\longleftrightarrow$ ( $F = {}^3/_2$, $m_F = -{}^3/_2$), identified by the low r.f. power required to induce it, was observed in the present experiment at two settings of the external magnetic field; $\mu_B B/h$ = 35.717(11) MHz and 63.566(9) MHz. The resonance curves, shown in Fig. 2, exhibit the same shape and width as the potassium calibration line at the two fields. The resonance frequencies 24.236(7) MHz and 43.668(9) MHz ( errors taken to be a quarter of the line widths ) were fitted to the Breit-Rabi formula ( eq. 4 in ref. [3] ), assuming either a positive or a negative sign of the nuclear g-factor. The resulting hyperfine separations were 2988(26) MHz and - 2996(26) MHz, respectively. Since there was no significant difference in the goodness of fit between the two alternatives, we give as a final result

$$\Delta\nu(^{188}\text{Au}) = \pm\ 2992(30)\ \text{MHz}$$

The radioactive decay of the resonance samples gave a half-life of about 9 minutes, which ascertains the connection to $^{188}$Au.

## 3. DISCUSSION

An extensive discussion on the nuclear structure in the gold region was made in our contribution to the Cargèse Conference on Nuclei far from Stability [5]. The nuclear spin $I = {}^5/_2$ of $^{185}$Au was shown to give strong arguments for a deformed nuclear shape. The ground state may be classified by the Nilsson model configuration $^5/_2[541\ {}^1/_2]$, a configuration which appears systematically in the lighter odd-proton elements iridium, rhenium and tantalum ( c.f. ref. [6] ). It is interesting to note that the isotope-shift measurements performed by the optical-pumping group [7] at ISOLDE have revealed a strong nuclear deformation in the isobar $^{185}$Hg, characterized by the neutron orbital [521 $^{1}/_{2}$].

The gold isotopes $^{188,190,192,194}$Au all have a nuclear ground state spin I = 1. The hyperfine structure separations measured [8 - 10] in these isotopes are given in Fig. 3. In all cases only absolute values have been determined. It may be noted that the separations in $^{188}$Au and $^{190}$Au agree within the error limits, indicating similar nuclear structure of these isotopes.

In order to calculate the magnetic moments of the doubly-odd gold isotopes from the measured hyperfine constants, a direct comparison with known values [11] in the stable isotope $^{197}$Au may be used. Since the influence of the hyperfine anomaly might be considerable and is difficult to estimate, the magnetic moments shown in Table 2 are given without error bars. The magnetic moments are in these cases too small to allow a direct measurement, from which the hyperfine anomaly could be determined. Likewise, the uncertainty as to configuration assignments is too large to allow a theoretical calculation of the hyperfine anomaly. The nuclear ground states of these typical transition nuclei probably arise from a combination of several configurations with contributions from the low-lying $s_{1/2}$ and $d_{3/2}$ proton states and the $p_{1/2}$ and $p_{3/2}$ neutron states in the neighbouring nuclei.

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Table 1. Time sequence followed in the experiments on $^{185}Au$ and $^{188}Au$.

| Isotope | Collection on cold foil | Delay | Evaporation of mercury | Evaporation of gold |
|---|---|---|---|---|
| $^{185}Au$ | 10 min | 1.5 min | 1 min | 3 min |
| $^{188}Au$ | 12 min | 2 min | 2 min | 4 min |

Table 2. Hyperfine separations and nuclear magnetic moments of some I = 1 gold isotopes.

| Isotope | Hfs separation $\lvert\Delta\nu\rvert$ MHz | Magnetic moment $\lvert\mu_I\rvert$ n.m. a) | Ref. |
|---|---|---|---|
| $^{188}$Au | 2992(30) | 0.064 | b) |
| $^{190}$Au | 3004(7) | 0.064 | 8 |
| $^{192}$Au | 374.30(10) | 0.008 | 9 |
| $^{194}$Au | 3489.865(32) | 0.074 | 10 |

a) Because of the uncertainty as to the hyperfine anomaly, the moments are given without error bars.

b) Present work.

## FIGURE CAPTIONS

Fig.1 : Decay of a resonance signal corresponding to the nuclear spin $I = {}^{5}/_{2}$ in $^{185}$Au. The signal was recorded in an external magnetic field of $\mu_B B/h = 2.941$ MHz.

Fig.2 : Results from frequency scans in external magnetic fields of $\mu_B B/h = 35.717(11)$ MHz and 63.566(9) MHz. The resonance curves observed correspond to the single-quantum transition $( {}^{3}/_{2}, -{}^{1}/_{2} ) \longleftrightarrow ( {}^{3}/_{2}, -{}^{3}/_{2} )$ in the isotope $^{188}$Au.

Fig.3 : Hyperfine structure separations, measured in the doubly-odd gold isotopes $^{188,190,192,194}$Au, all having a nuclear ground state spin I = 1. The present measurement in $^{188}$Au is indicated by crosses, while previous results [8 - 10] are given by circles. Since the signs of the separations could not be concluded from the experiments, both possibilities are shown.

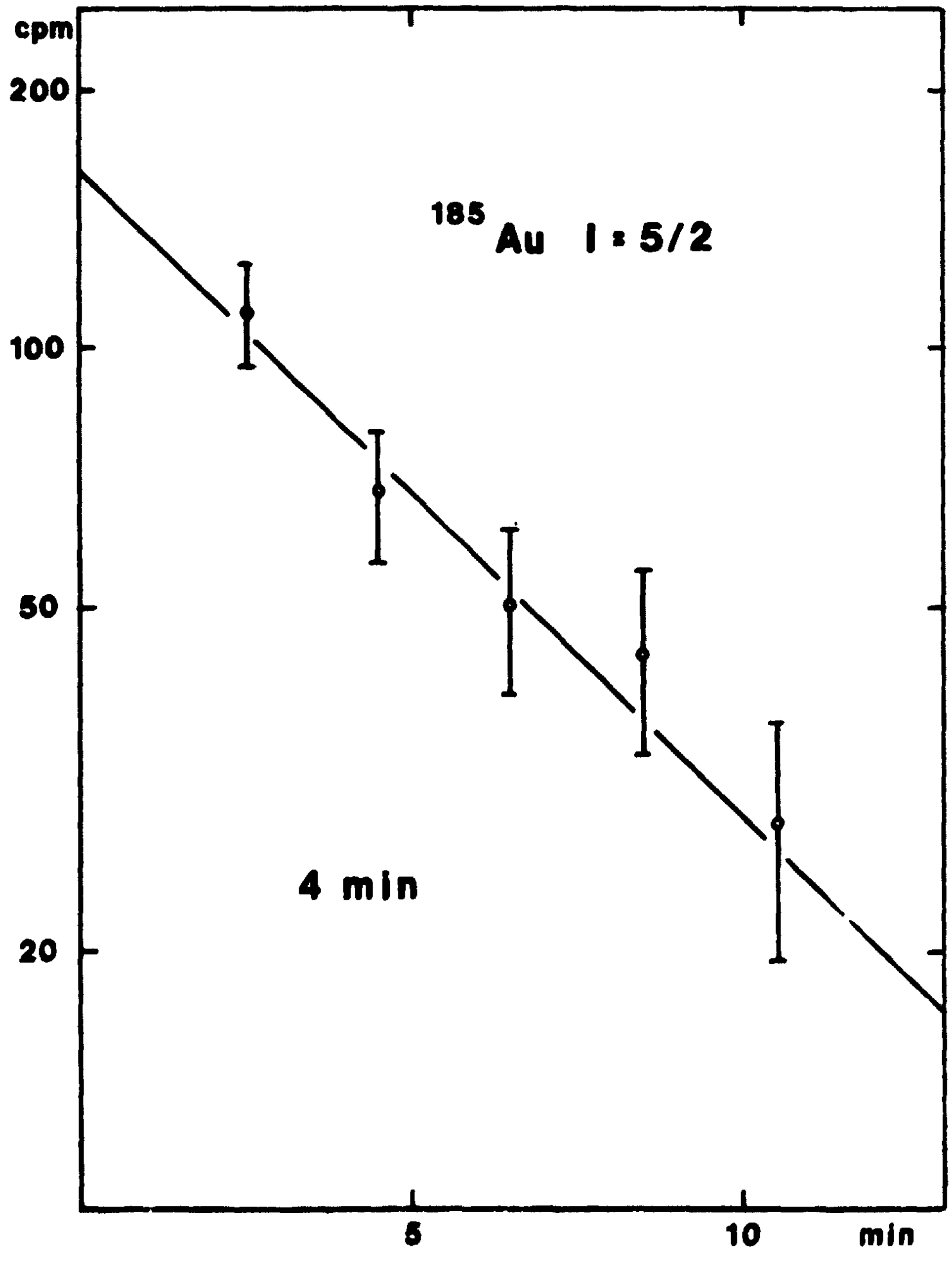
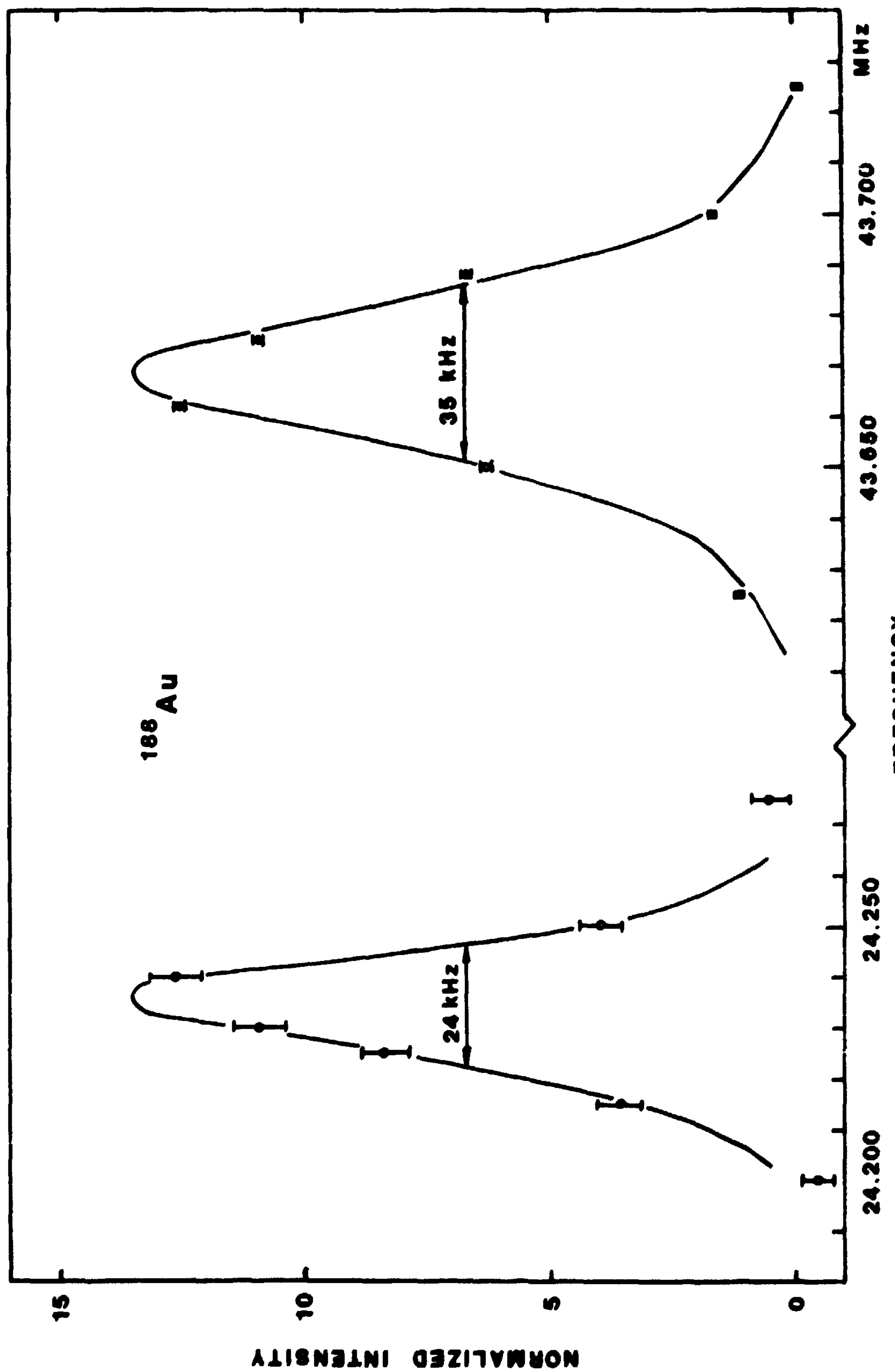



Fig. 1



188Au
35 kHz
24 kHz
NORMALIZED INTENSITY
0
5
10
15
FREQUENCY
24.200
24.250
43.650
43.700
MHz


Fig. 2

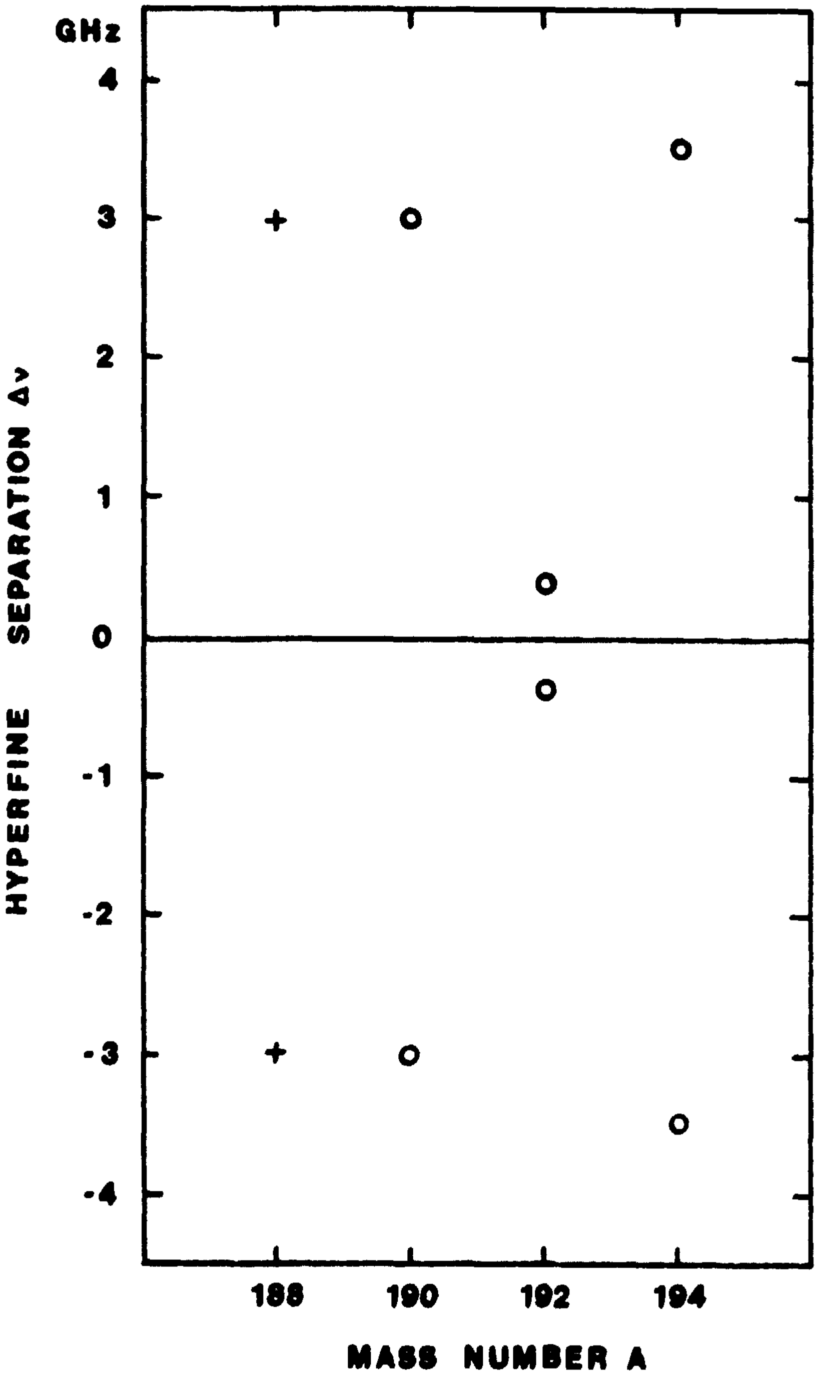

GHz
4
3
2
1
0
-1
-2
-3
-4
HYPERFINE SEPARATION Δν
188
190
192
194
MASS NUMBER A

Fig. 3