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ABSTRACT

The nuclear spin of 9.5-hr Au^{196m} has been measured by the atomic-beam magnetic-resonance method. Measurements in the $^2S_{\frac{1}{2}}$ electronic ground state have yielded the result I = 12, which is consistent with predictions of the simple shell model.

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I. INTRODUCTION

The existence of the 9.5-hr isomeric state of Au^{196} was first reported by McMillan and co-workers[1] (1937) and later by Wilkinson[2] (1949). More recently, the decay scheme of this isomer has been studied by Van Leishout et. al.[3] (1959), and independently by Kavanagh[4] (1960). A nuclear spin of I = 11 was predicted in both the latter studies, based on electron conversion ratios for the isomeric transition. The direct measurement of the spin of this isomer now has been made successfully, by the method of atomic beams. The measured nuclear spin is I = 12.[5]

II. THEORY and EXPERIMENT

An atomic-beam magnetic-resonance apparatus of the flop-in type was used to measure the nuclear spin of Au^{196m} by observing the $\Delta F = 0$ transitions in the $^2S_{\frac{1}{2}}$ electronic ground state at low magnetic fields. The apparatus used and the theory and technique involved have been described elsewhere.[6] Therefore, only a brief discussion of the method is given here.

The energy of a free atom of gold in the $^2S_{\frac{1}{2}}$ electronic ground state may be represented in a magnetic field by the Breit-Rabi formula.[7] At low magnetic field, in the "linear" Zeeman region, the frequencies of all possible transitions (including the multiple quantum transitions)[8] for $\Delta F = 0$ are the same and can be written by

$$\nu \approx \frac{(-g_J + 2Ig_I)\,\mu_0}{(2I+1)\,h}\,H \approx \frac{-g_J\mu_0}{(2I+1)\,h}\,H\ , \qquad (1)$$

where

I is the nuclear spin, g_J and g_I are electronic and nuclear g factors,

μ_0 is the absolute value of the Bohr magneton,

h is Planck's constant,

and H is the external magnetic field.

Therefore, in the Zeeman region, for a given spin the relation between the frequency ν and the magnetic field H can be represented by a straight line as shown in Fig. 1 for I = 11, 12, and 13.

The radioactive isotope used in this experiment was produced from natural platinum foil by bombardment with 48-Mev α particles from the Crocker 60-inch cyclotron on the Berkeley campus. The Au^{196m} was formed by the reaction $Pt^{194}(\alpha, pn)Au^{196m}$ along with the much more favorable reactions $Pt(\alpha, kn)Hg$, for k = 1, 2, 3, 4. The induced mercury activity was much higher than that of gold. In order to separate the gold from this mercury and the platinum target, about 20 mg of gold carrier and about 500 mg mercury carrier were dissolved along with the platinum target in hot concentrated aqua regia. Ice was added in order to make the resultant solution cold and dilute. A standard chemical method was employed to extract the gold chloride from the rest of the solution into ethyl acetate. After evaporating the gold bearing ethyl acetate, by pouring it slowly into boiling dilute HCl solution, metallic gold was precipitated by adding water freshly saturated with SO_2.

A standard tantalum oven body with carbon liner and carbon cap was heated by electron bombardment to provide the source of beam atoms. The usual slits were replaced by a carbon snout to ensure good collimation of the beam.

Sulfur-coated buttons were used to collect radioactive atoms for the resonance detection. After exposure each button was counted in continuous-flow methane counters.

III. RESULTS

The spin-search experiments indicated a strong signal at a frequency corresponding to I = 12, as shown in Fig. 2. The decay of these samples showed an enrichment of activity with the half-life of Au^{196m} (9.5-hr) over the normal composition of the beam. Figure 3 shows the decay curves of the beam, of the activity on spin I = 12, and a theoretical curve calculated for 9.5-hr Au^{196m} decaying to the ground-state 6.1-day[9] Au^{196}.

Seven resonances at different magnetic fields are shown in Fig. 1. A plot of the magnetic field intensity against the corresponding resonance frequency is also shown in the same figure. Note that all the points lie very close to the line given by Eq. (1) for I = 12. The decrease of resonance height with increasing magnetic field shows evidence of multiple-quantum transitions.[10] Consequently the hyperfine-structure separation of Au^{196m} is probably very large. This evidence is supported by the fact that there is no deviation of the observed points from the Zeeman line in Fig. 1.

Although the harmonic output of the Tektronix Type 190 oscillator is small, there was the possibility that the resonances might be produced by some harmonic of the fundamental frequency of the oscillation. Such an occurrence would imply a different value for the nuclear spin. A simple experiment was performed to eliminate this source of possible error. After a resonance had been observed on I = 12, other exposures were made at frequencies corresponding to 2, 3, 5, and 7 times the resonance frequency. No significant signal was observed. The resonance therefore could not be induced by any output harmonic between the second and tenth. Since the seven resonances of Fig. 1 lie on a straignt line of proper slope for I = 12, the possibility of the resonances being associated with other spins is remote. Only spins I = 0 and I = 2 occur with a slope which is an integral multiple of the slope for I = 12. Repeated exposures at the frequencies corresponding to I = 0 and 2 have indicated no resonance of 9.5-hr activity. On the basis of this evidence the spin assignment is unambiguous.

IV. DISCUSSION

In this region of the periodic table the spherical shell model is expected to apply. There is only one possible coupling of levels that will explain the experimental result, I = 12. Nordheim's weak rule predicts that a proton in the $h_{11/2}$ level and a neutron in the $i_{13/2}$ level should couple to a value near the possible maximum. In our case that maximum is I = 12. From pure shell-model orbitals the parity is expected to be odd. Even with considerable quenching, the nuclear moment should be very large compared to the other gold isotopes.

FOOTNOTES AND REFERENCES

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‡ On leave as Science Advisor to NATO, Paris.

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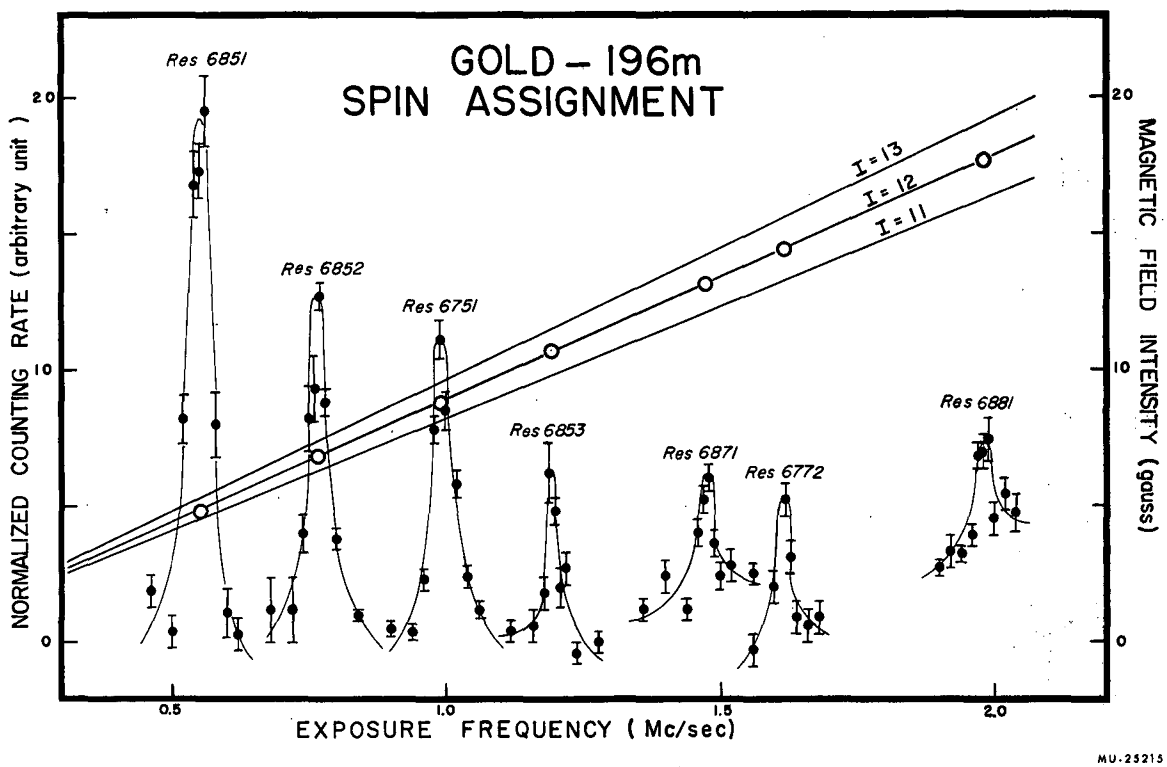
FIGURE LEGENDS

Fig. 1. Resonances of Au^{196m} as observed at several different magnetic fields. The circles represent a correlation of the frequency of each resonance peak with the field intensity at which the resonance was observed. The straight lines are the Zeeman lines for gold, corresponding to different possible spin assignments.

Fig. 2. Spin search at H = 8.94 gauss for radioactive gold produced by Pt(α, p kn)Au reactions.

Fig. 3. A comparison of the decay of the beam activity and the decay of I = 12 activity. The solid curve is a theoretical curve, assuming 9.5-hr Au^{196m} decaying to its ground-state 6.1-day Au^{196}.



GOLD – 196m
SPIN ASSIGNMENT
Res 6851
Res 6852
Res 6751
Res 6853
Res 6871
Res 6772
Res 6881
I = 13
I = 12
I = 11
NORMALIZED COUNTING RATE (arbitrary unit)
MAGNETIC FIELD INTENSITY (gauss)
EXPOSURE FREQUENCY (Mc/sec)
0.5
1.0
1.5
2.0
0
10
20
MU-25215

Fig. 1

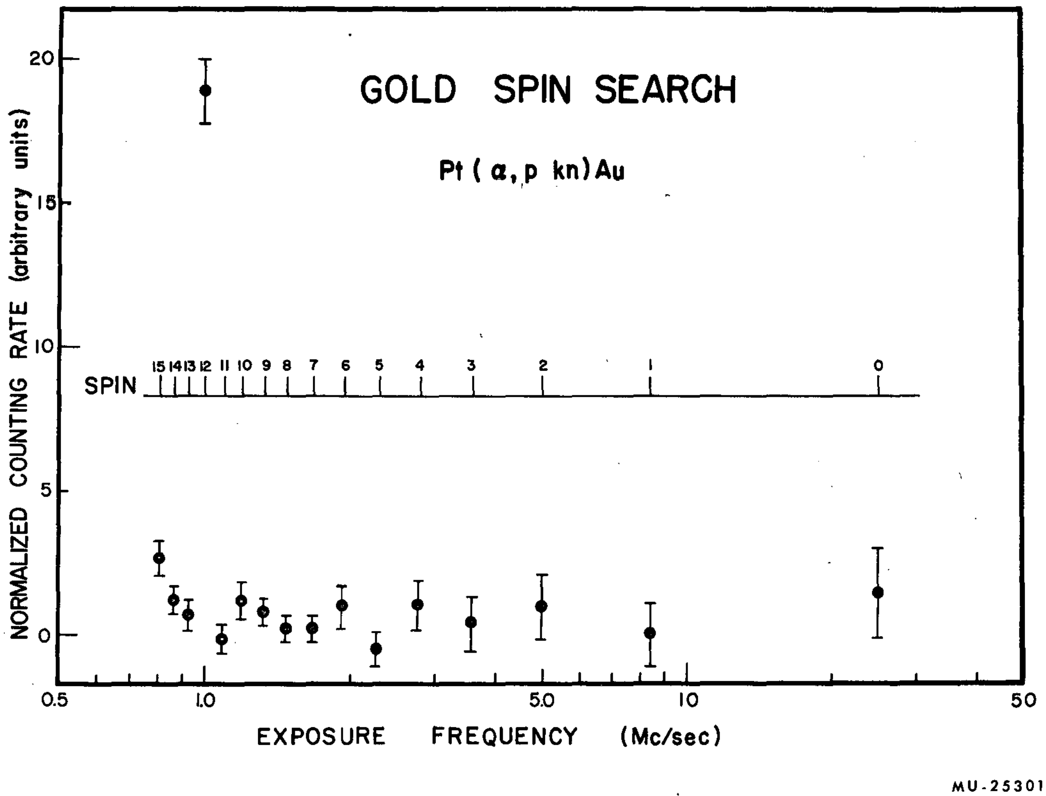

GOLD SPIN SEARCH
Pt (α, p kn) Au
NORMALIZED COUNTING RATE (arbitrary units)
20
15
10
5
0
SPIN
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
0.5
1.0
5.0
10
50
EXPOSURE FREQUENCY (Mc/sec)
MU-25301

Fig. 2

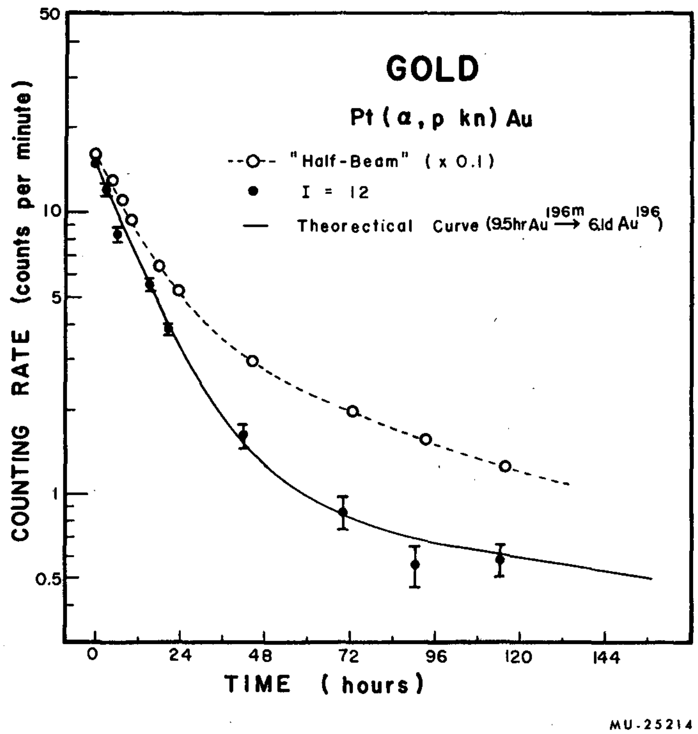

GOLD
Pt (α, p kn) Au
"Half-Beam" (x 0.1)
I = 12
Theorectical Curve (9.5hr Au196m ⟶ 6.1d Au196)
COUNTING RATE (counts per minute)
TIME (hours)
50
10
5
1
0.5
0
24
48
72
96
120
144
MU-25214

Fig. 3