Hyperfine density shifts of ^{107}Ag in He, Ne, Ar, and N_2. V

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(Received 29 July 1976)

High-temperature spin-exchange optical pumping was used to measure the density shifts of the hyperfine splitting of ^{107}Ag in He, Ne, Ar, and N_2. Measurements over a limited temperature range also yielded linear temperature dependences. The respective results for the fractional shift, $\partial\Delta\nu/\partial\rho\nu_0$ (in 10^{-9} Torr^{-1}), are 40.6 ± 1.4, 26.2 ± 0.2, 14.2 ± 0.9, and 33.6 ± 2.6 and for the linear temperature dependence, $\partial^2\Delta\nu/\partial T\partial\rho\nu_0$ (in 10^{-12} Torr^{-1}°C^{-1}), are 13.3 ± 1.5, 5.0 ± 0.6, -6.4 ± 1.2, and -4.9 ± 0.8.

In a previous series of papers[1-4] we presented hyperfine-density-shift measurements for a variety of atoms. Attempts to predict these results, which require a knowledge of both the interatomic potential and the effect on the electron-spin density of a buffer-gas atom, have proven difficult. Especially extensive measurements have been made on hydrogen and the alkalis[5-10] (the so-called group IA elements). All of the above elements have $^2S_{1/2}$ ground states. The present measurements for silver provide the first results for a group IB element, for which the valence electron occurs after a closed d shell. To illustrate, the last few shells for Rb, Ag, and Cs are ... $(4p)^6 5s$, ... $(4p)^6(4d)^{10}5s$, and ... $(4d)^{10}(5s)^2(5p)^6 6s$, respectively. A comparison of the resulting hyperfine-density shifts will be given after the experimental procedures have been described. The linear temperature dependences of the shifts will also be presented.

Spin-exchange optical pumping was used to polarize the silver atoms in their ground states. Circularly polarized rubidium resonance radiation was used to orient rubidium atoms, and the resulting polarization was transferred through spin-exchange collisions to the silver. Disorientation of the silver atoms by an rf field was transferred through collisions back to the rubidium and detected as a change in the absorption of the rubidium resonance radiation. Each cell also contained a buffer gas.

The measurements were performed on the ^{107}Ag isotope. The nuclear spin is $\frac{1}{2}$ and the ground-state hyperfine structure is similar to that of hydrogen. The free-atom hyperfine splitting was taken to be 1 712 512 111 Hz.[11] The ($F=1$, $m_F = \pm 1 \longleftrightarrow F=0$, $m_F=0$) transitions were measured and averaged to eliminate the linear magnetic-field dependence. The quadratic terms in the magnetic-field strength were of the order of 10^{-2} Hz. A detailed diagram of the apparatus is given in Fig. 1.

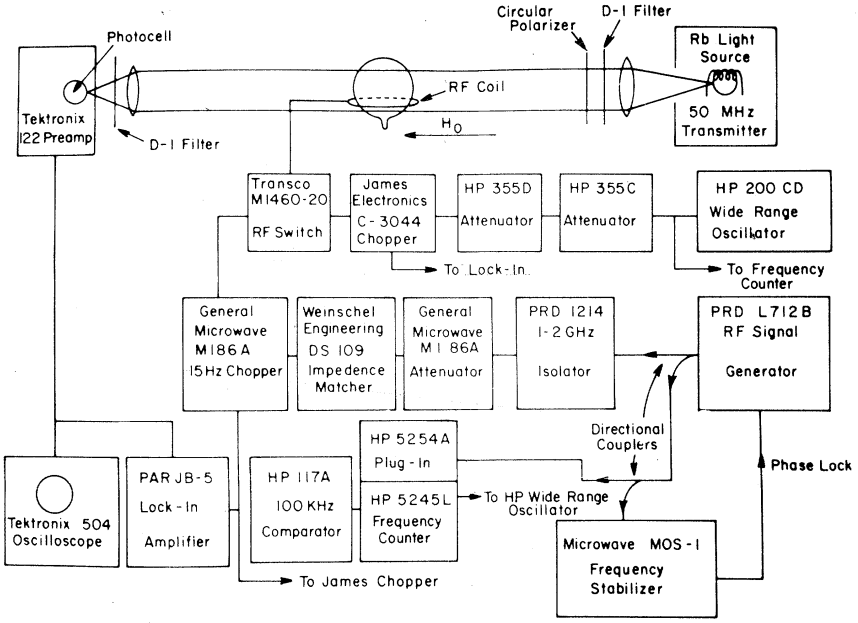

FIG. 1. Block diagram of the optical pumping apparatus and the related electronics.

TABLE I. Density shift and its temperature dependence for the HFS of ^{107}Ag.

Buffer gas	Temperature at which density shift measured (°C)	Density shift (Hz Torr^{-1})	Temperature range over which temperature dependence measured (°C)	Temperature dependence (10^{-3}Hz °C^{-1} Torr^{-1})
Neon	830	44.9 (0.4)	807–887	8.6 (1.1)
Argon	852	24.3 (1.5)	811–868	−11.0 (2)
Nitrogen	825	57.5 (4.4)	791–862	− 8.3 (1.4)
Helium	794	69.6 (2.4)	804–862	23.0 (3)

The cells were constructed from 300 cm^3 spherical quartz flasks. They contained a fraction of a gram of rubidium, powdered silver, and a buffer gas. In order to make our experimental results more easily comparable with previous results, we have specified the buffer-gas density in terms of an equivalent pressure (in Torr) at 298 °K. The density of the buffer gas at the time of the measurement differs from that when the cell was filled for two reasons. The first is the easily corrected for decrease due to the expansion of the quartz. The second is caused by the leakage of the buffer gas (principally helium and to a lesser extent neon) through the quartz walls. The method used to correct for the latter effect has been described previously.[3,12]

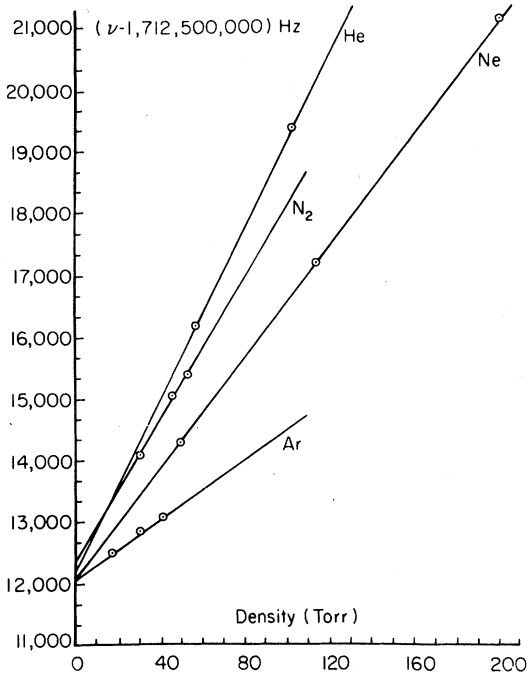

FIG. 2. Plot of the measured density shifts of ^{107}Ag in He, Ne, Ar, and N_2. The results of least-squares fits to the data are given in Table I.

The experiment was performed in a shielded solenoid with a small magnetic field (~5 mG) applied to the sample. In order to provide sufficient silver density, the cell was heated to between 790 and 890 °C.[13] This temperature range was the maximum we could attain, and was necessary in order to determine the temperature dependence of the density shift. Over the above range a linear fit to the data was sufficient.

In order to determine the temperature dependence of the density shifts, data were taken both with the temperature increasing and decreasing, and the results averaged. This procedure helps to cancel out the effects of the buffer-gas leakage through the walls.

The data for the density shifts is shown in Fig. 2 and listed along with the temperature dependence of the shifts in Table I. The fractional-density shifts were computed by dividing by the free-atom hyperfine frequency already given.

Table II lists fractional-density shifts for the hydrogen-like atoms, including silver. Two things

TABLE II. Approximate fractional-density shifts of the hydrogen-like atoms. The numbers listed here are taken directly from the references and have not been adjusted for differences in the gas filling temperatures or the more significant difference in measuring temperatures.

Element	Fractional-density shifts (10^{-9} Torr^{-1}) He	N_2	Ne	Ar
H	4.1 [a]		2.88 [b]	− 4.77 [b]
Li	77.7 [d]		40.5 [c]	− 5.3 [c]
Na	73.4 [d]	49 [d]	45 [d]	3 [d]
K	94 [e]	71.2 [f]	51 [e]	− 1 [e]
Rb	108 [g]	79.4 [g]	58.96 [g]	− 7.9 [g]
Cs	114.2 [h]	96.8 [h]	63.1 [h]	−20.6 [h]
Ag	40.6 [i]	33.6 [i]	26.2 [i]	14.2 [i]

[a] Reference 5.
[b] Reference 1.
[c] Reference 6.
[d] Reference 7.
[e] Reference 8.
[f] Reference 3.
[g] Reference 9.
[h] Reference 10.
[i] Present work.

are immediately noteworthy about the results. The first is the smallness of the fractional shifts for silver in comparison with the shifts for Rb and Cs. The second, and more striking result, is the fact that the shift in argon, for silver, is positive, while it is negative for both Rb and Cs. Unfortunately, detailed attempts to predict these shifts tend to be complicated, involving many cancellations between large numbers, and only detailed calculations could indicate if this anomalous result has special significance.

The authors would like to express their appreciation for support provided by the Central University Research Fund of the University of New Hampshire, which was essential for the completion of this work. The National Science Foundation was also instrumental in making the work possible. Finally, for numerous helpful discussions, we would like to thank B. Bean, L. C. Balling, and J. J. Wright.

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