Precision measurement of the hyperfine structure of the ^{133}Cs $6P_{3/2}$ state

Carol E. Tanner and Carl Wieman
Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards, P.O. Box 0440, Boulder, Colorado 80309-0440
and Physics Department, University of Colorado, Boulder, Colorado 80309
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We report measurements of the hyperfine structure of the $6P_{3/2}$ state of atomic ^{133}Cs($I=7/2$). A frequency-stabilized laser diode is used to perform crossed-beam laser spectroscopy of the Cs $6S_{1/2}(F=3,4)\rightarrow 6P_{3/2}(F')$ transitions. From the measured hyperfine splittings, we determine the coefficients of the magnetic dipole (A) and electric quadrupole (B) contributions to the hyperfine structure. Our results are $A=50.275(3)$ MHz and $B=-0.53(2)$ MHz.

The comparison of experimental and theoretical parameters of hyperfine structure is one of the most stringent tests of atomic wave functions near the nucleus. In particular, it is one of the best ways to explore the relativistic, core polarization, and correlation effects of the electrons which are sources of difficulty in accurate atomic structure calculations. At present, such calculations are of particular interest to the study of parity nonconservation (PNC) in atoms because the weak force is a short-range electron-nucleon interaction. The interpretation of PNC measurements in the $6S_{1/2}\rightarrow 7S_{1/2}$ transition of atomic cesium requires precise knowledge of atomic wave functions near the nucleus. The experimental determination of hyperfine structure in alkali-metal atoms is reviewed in Ref. 1. Here, we report precise measurements of the hyperfine splittings in the $6P_{3/2}$ state of ^{133}Cs. Figure 1 shows the hyperfine structure of this state. From these measurements, we determine the coefficients for the magnetic dipole and electric quadrupole contributions to the hyperfine structure.

In the approximation that J is a good quantum number, the hyperfine energy is given by

$$W=hA(\mathbf{I}\cdot\mathbf{J})+hB\frac{6(\mathbf{I}\cdot\mathbf{J})^2+3(\mathbf{I}\cdot\mathbf{J})-2(\mathbf{I}\cdot\mathbf{I})(\mathbf{J}\cdot\mathbf{J})}{2I(I-1)2J(J-1)} \quad (1)$$

for states where $J=L\pm\frac{1}{2}$. A and B are, respectively, the coefficients of the magnetic dipole and electric quadrupole contributions to the hyperfine structure. Measurements of A and B are most conveniently compared to relativistic hyperfine structure calculations through the effective operator formalism developed by Sandars and Beck where A and B are related to various radial matrix elements.[2,3]

The hyperfine structure of the Cs $6P_{3/2}$ state has been previously measured by a number of groups using optical double resonance, atomic beam magnetic resonance, and level crossing techniques. We have been able to improve upon the precision of these measurements using the method described in Ref. 4 for measuring the Stark shift of the $6P_{3/2}$ state. A highly collimated beam of atomic Cs intersects a linearly polarized laser beam at right angles. The laser radiation is produced by a frequency-stabilized laser diode with a 20-kHz line width. The laser beam is linearly polarized to prevent optical pumping effects. The laser intensity is 13 μW/cm^2 so each atom absorbs, on the average, one photon as it traverses the 0.7-cm-diam. laser beam. This low transition rate further reduces the probability of optically pumping the atoms, which would cause a frequency shift of the resonance in the presence of stray magnetic fields.

A frequency scan of the Cs beam fluorescence is shown in Fig. 2. We measured the three frequency intervals shown between adjacent hyperfine levels. To avoid the uncertainties encountered in determining changes in laser frequency, the following procedure was used to measure each interval. First, the laser frequency was locked to one hyperfine transition [for example, $6S_{1/2}(F=4)\rightarrow 6P_{3/2}(F'=5)$] in a saturated absorption cell. Then, a portion of the laser output was shifted in frequency, using an acousto-optic modulator (AOM). This shifted light intersected the atomic beam after passing through a single-mode optical fiber which fixes its position. The modular frequency was adjusted to bring the light into resonance, with first one, and then the other of the two allowed hyperfine transitions ($F'=4$ and $F'=3$) in the atomic beam. The center of each resonance was determined as in Ref. 4. The measured frequency splitting between the resonances ($\Delta\nu_{43}$) was the difference in the two AOM-drive frequencies needed to excite the two transitions. This approach made the exact laser frequency unimportant, and the quantity of interest, the interval between the

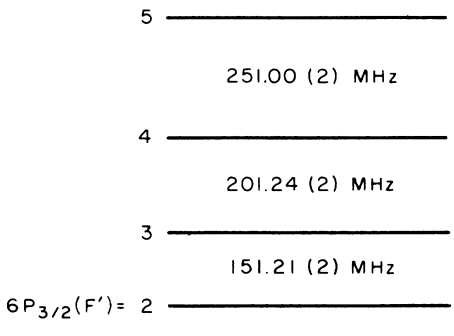

FIG. 1. Hyperfine structure of ^{133}Cs $6P_{3/2}$ and our measured splittings.

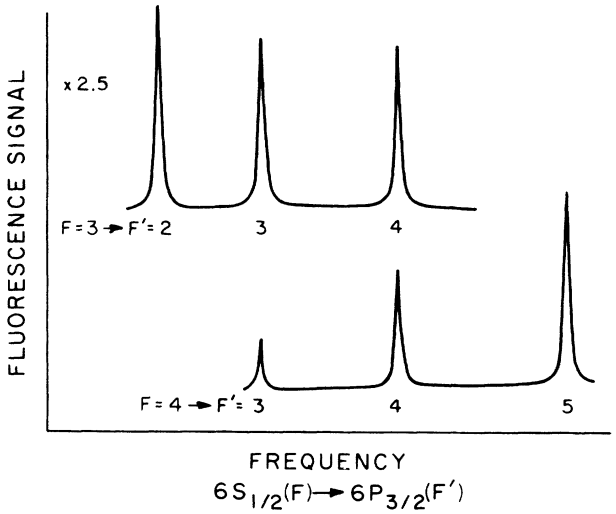

FIG. 2. Fluorescence spectra of the $6S_{1/2}(F) \rightarrow 6P_{3/2}(F')$ transitions.

resonances, was the difference between two easily measured radio frequencies. By locking the laser to different transitions in the saturated absorption cell, we were able to use this method to measure all three intervals. Our measured hyperfine splittings are shown in Fig. 1.

Using Eq. (1), the measured hyperfine splittings in terms of the magnetic dipole (A) and electric quadrupole (B) coefficients are

$$\begin{aligned} 5A + \tfrac{5}{7}B &= 251.00(2)\ \text{MHz}\ , \\ 4A - \tfrac{2}{7}B &= 201.24(2)\ \text{MHz}\ , \\ 3A - \tfrac{5}{7}B &= 151.21(2)\ \text{MHz}\ . \end{aligned} \tag{2}$$

The precision in the frequency intervals is limited by the measured drift in the lock point of the laser. The measurements are independent of laser polarization. The systematic errors introduced by stray magnetic fields and ac Stark shifts are negligible being less than 100 Hz. Using the method of least squares, we determine the coefficients:

$$A = 50.275(3)\ \text{MHz}\ , \tag{3}$$

$$B = -0.53(2)\ \text{MHz}\ . \tag{4}$$

These results are in good agreement with the results reviewed in Ref. 1, but are, respectively, a factor of 20 and 13 more precise. Our results are consistent in that A and B determined from all pair combinations in (2) agree to within the uncertainties.

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