High Precision Frequency Measurements in Thermal ^{133}Cs Cell

Vladislav Gerginov, Carol Tanner
Department of Physics, University of Notre Dame
Notre Dame, IN 46556

ABSTRACT

The saturated absorption spectrum of D2 line in Cs was investigated using two diode lasers emitting at 852nm. It was obtained in a 5cm long Cs cell at room temperature. The frequency scale was calibrated using the beat note signal from a fast photodetector on which the two laser beams were combined. In order to eliminate the effect of the reference laser frequency drift, a two-laser beam optical arrangement producing the saturated absorption was used. A simple model giving the number of observed peaks and the frequency intervals between them was developed. The two spectra corresponding to the two ground state components of Cs were fitted using a Lorentz profile as a model function and the obtained frequency intervals were compared with the Cs atom hyperfine splittings.

Keywords: frequency measurements, diode lasers, hyperfine structure, Cs atom, saturation spectroscopy

1. EXPERIMENTAL SETUP

A simplified diagram of Cs energy levels is given in Fig 1 where the measured frequency intervals can be found in References [1,2]

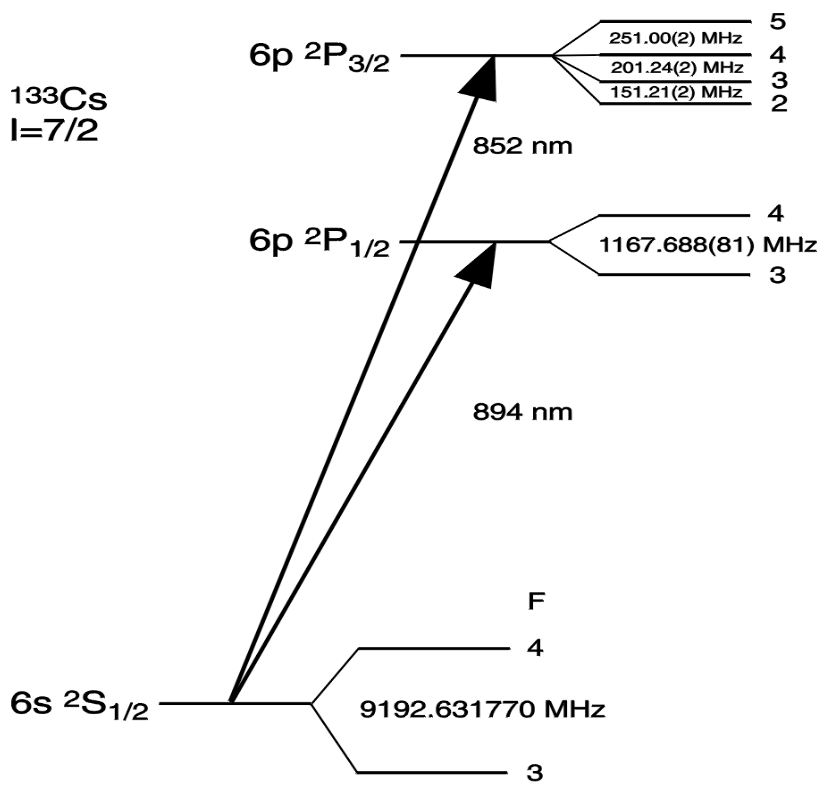

Fig.1. Cs energy levels diagram (not to scale).

Due to the selection rules, the absorption spectrum of each Cs ground state component consists of three transitions. The laser frequencies are tuned to either ground state components by changing the laser injection current. The characteristics of the diode lasers used in the experiment are listed in Table 1:

Laser	λ[nm]	I[mA]	P_{out} [mW]	Linewidth [MHz]	Mode of operation
STC LT50A 03U	852.3	100	50	15	free running

The saturation spectroscopy experiment is illustrated on Fig 2.

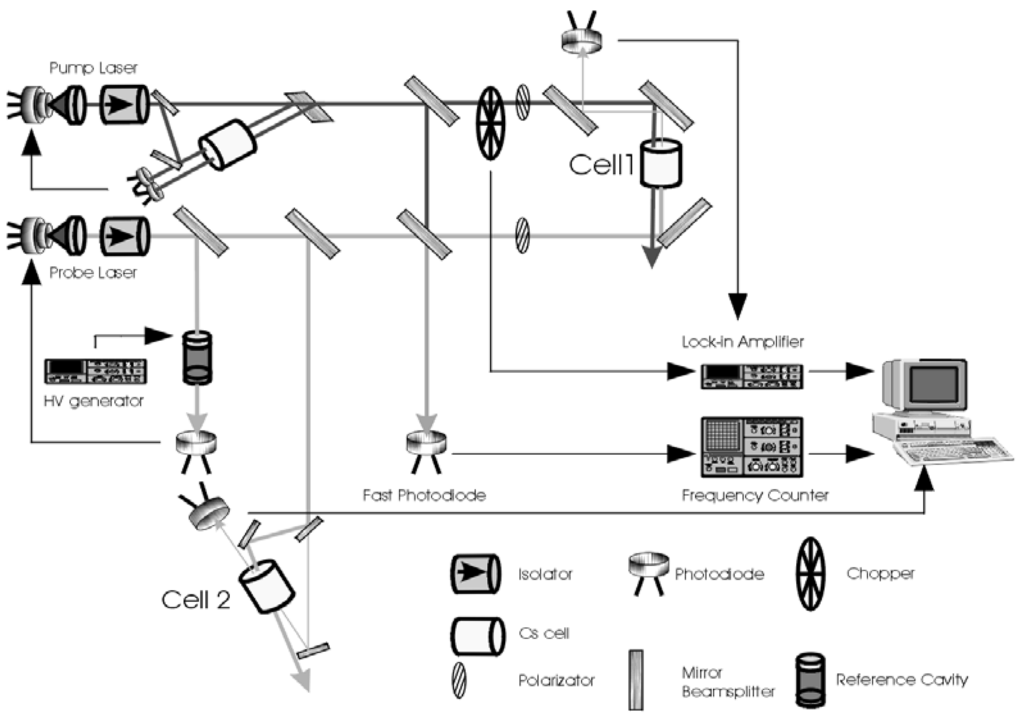

Fig.2. Experimental Setup for Saturated Absorption Measurements.

One of the lasers is dither-free locked to the side of a saturated absorption peak [3] in Cs and the other to the side of the resonance of a reference confocal Fabry-Perot cavity (1.25GHz FSR and finesse of 100), respectively. They are sent through a Cs cell (Cell 2 on Fig 2) in opposite directions and with orthogonal polarizations to avoid optical feedback. The saturated absorption signal in this case is created with two independent laser fields [4,5]. The laser locked to the Cs transition is used as a pump laser (15mW/cm^2) and is chopped with a wheel chopper at 2000Hz. The other laser is scanned changing the Fabry-Perot cavity length with a PZT, and the detected signal (0.8mW/cm^2) is sent to a lock-in amplifier. Parts of the two laser beams are sent to a fast photodetector (New Focus Model 1537) and the beat note frequency is measured with a HP 5342A frequency counter at a rate of 20 Samples/s and accuracy of 100kHz.

2. RESULTS

The obtained spectra for the two ^{133}Cs ground states are shown on Fig 3 (F=3) and Fig 4 (F=4).

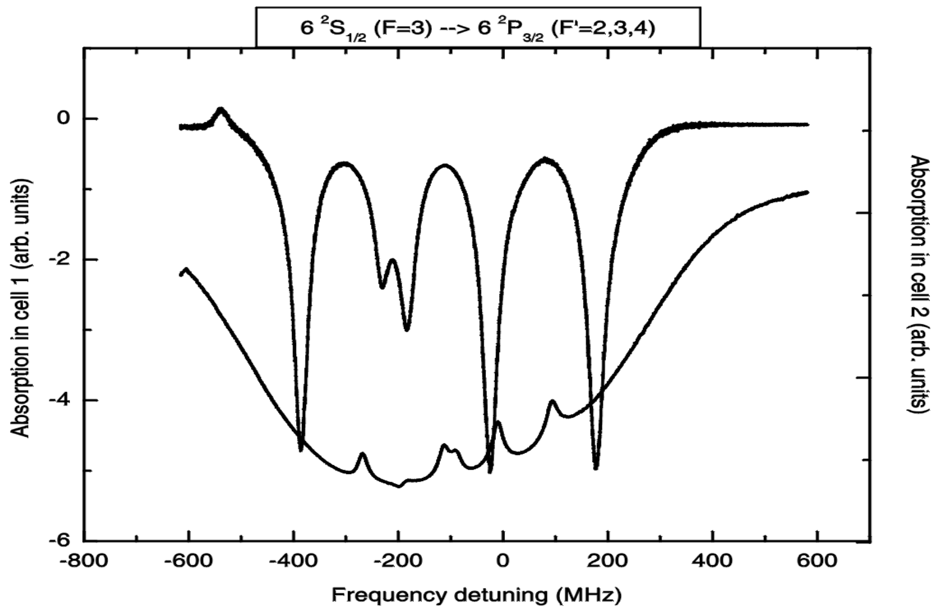

Fig.3. Cs Saturated Absorption From 6 $^2S_{1/2}$ (F=3) Ground State.

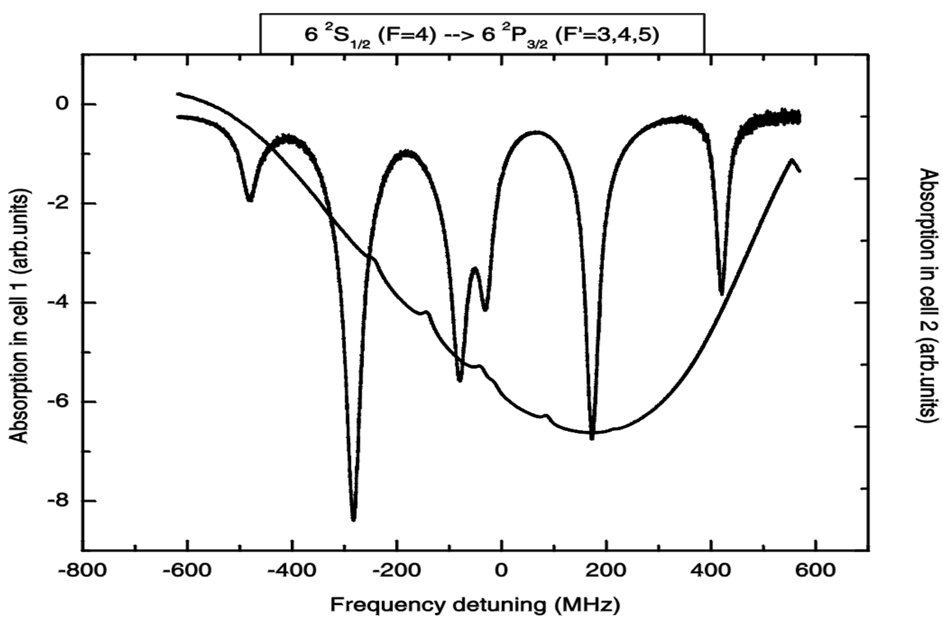

Fig.4. Cs Saturated Absorption From 6 $^2S_{1/2}$ (F=4) Ground State.

The laser frequency scan was calibrated to an accuracy of 1.3kHz/MHz for F=3 and 0.5kHz/MHz for F=4 ground states. The optical pumping effect due to the orthogonal laser polarizations is visible on Fig 3 (F=3) as increased absorption peak.
The two spectra consist of 6 peaks each (as in the one-laser saturated absorption), see Fig 3 and Fig 4. The simplified model of the velocity groups and the frequency spacings is shown on Fig 5.

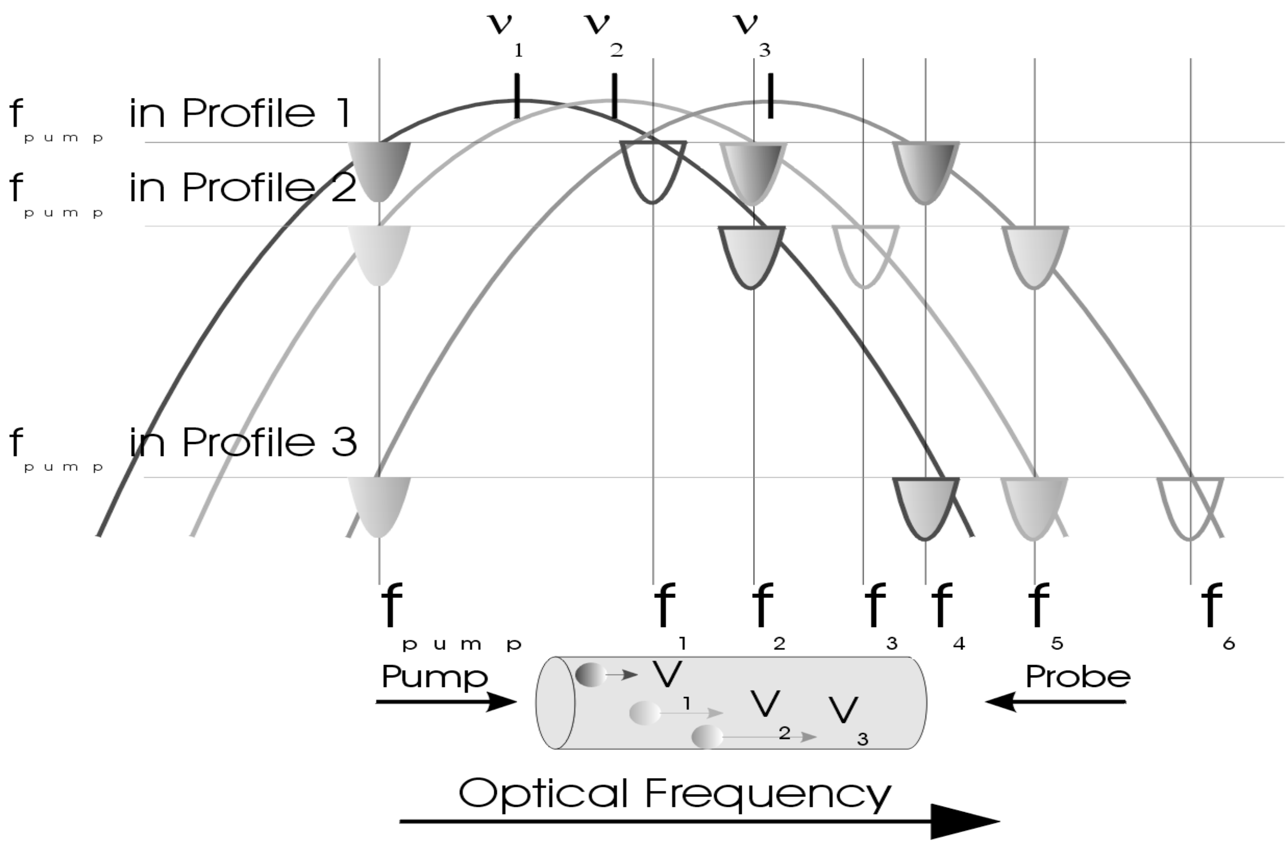

Fig.5. Identification of Saturatied Absorption Peaks.

The pump laser is detuned to the lower frequencies with respect to the three transitions in Cs accessible from a given ground state. It depopulates the ground state for three different velocity groups moving in the direction of the pump beam. The counterpropagating laser can interact with each of these velocity groups at three different optical frequencies giving a peak in the absorption. The peak frequencies f_i (i=1 to 6) with respect to the transition frequencies ν_j (j=1 to 3), are given in Table 2:

f_1	f_2	f_3	f_4	f_5	f_6
$2\nu_1-f_{pump}$	$\nu_1+\nu_2-f_{pump}$	$2\nu_2-f_{pump}$	$\nu_1+\nu_3-f_{pump}$	$\nu_2+\nu_3-f_{pump}$	$2\nu_3-f_{pump}$
f_1-f_1	f_2-f_1	f_3-f_2	f_4-f_3	f_5-f_4	f_6-f_5
0	$\nu_2-\nu_1$	$\nu_2-\nu_1$	$(\nu_1-\nu_2)+(\nu_3-\nu_2)$	$\nu_2-\nu_1$	$\nu_3-\nu_2$

Table 2

The resulting peak data in the spectrum of the probe laser is obtained using Lorentz profiles as a fitting function. An analysis with a Voigt profile will be done in the future. The results are summarized in Table 3 and Table 4 for F=3,4 ground state components:

Peak (F=3)	Peak Width $\Delta\nu_i$ [MHz]	Interval $(\nu_{i+1}-\nu_i)$ [MHz]	Error $\delta(\nu_{i+1}-\nu_i)$ [MHz]	Error from cal. $\delta(\Delta\nu_i)$ [MHz]	Total Error [MHz]	^{133}Cs atom [2] [MHz]
1	28.81	-	-	-	-	-
2	41.42	150.59	0.44	0.20	0.48	151.21
3	47.31	155.25	0.16	0.21	0.26	151.21
4	41.54	48.78	0.18	0.06	0.19	50.03
5	44.14	158.33	0.11	0.21	0.23	151.21
6	48.85	202.64	0.06	0.27	0.27	201.24

Table 3

Peak (F=4)	Peak Width $\Delta\nu_i$ [MHz]	Interval $(\nu_{i+1}-\nu_i)$ [MHz]	Error $\delta(\nu_{i+1}-\nu_i)$ [MHz]	Error from cal. $\delta(\Delta\nu_i)$ [MHz]	Total Error [MHz]	^{133}Cs atom [2] [MHz]
1	44.51	-	-			
2	46.34	196.45	0.16	0.16	0.23	201.24
3	51.43	202.34	0.08	0.17	0.19	201.24
4	31.72	51.63	0.11	0.04	0.11	49.76
5	35.34	202.91	0.09	0.17	0.19	201.24
6	23.13	246.87	0.06	0.21	0.21	251.00

Table 4

3. ACKNOWLEDGEMENTS

Financial support for this work was provided by the Division of Chemical Sciences, Office of Basic Energy Sciences, Office of Science at the U.S. Department of Energy under Contract No. DE-FG02-95ER14579.

4. REFERENCES

1. Th. Udem, J. Reichert, R. Holzwarth, T.W. Hänsch, Phys.Rev.Lett., **82**, 18, 3568, 1999.
2. C. E. Tanner, C. Wieman, Phys.Rev.A, **38**, 3 1616, 1988.
3. W. Demtröder ,"Laser Spectroscopy", Springer-Verlag, 1996.
4. H. R. Schlossberg, A. Javan, Phys.Rev.Lett., **17**, 25, 1242, 1966.
5. Letokhov, Chebotayev, "Nonlinear Laser Spectroscopy", Springer-Verlag 1977.