Optical frequency measurements of 6s $^2S_{1/2}$ - 6p $^2P_{3/2}$ transition in ^{133}Cs using an atomic beam and a femtosecond laser frequency comb

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Abstract: High-resolution spectroscopy and a femtosecond laser frequency comb are used to determine the optical frequencies between the components of the D_2 line in ^{133}Cs. The accuracy of <10 kHz is 10x better than previous results.
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The cesium atom plays an important metrological role as the primary frequency standard and is used in many high-precision experiments. It has been extensively studied in order to test atomic theory and even the Standard Model through measurements of various matrix elements as well as the parity nonconservation amplitude [1]. The accurate interpretation of the experimental results requires better knowledge of the atomic structure, especially the matrix elements between the lowest atomic states.

Using a highly collimated atomic beam and a laser heterodyning system consisting of a reference and probe laser, we are able to resolve the position of the different spectral components with a kHz accuracy [2,3]. The beat note between the probe and reference laser is used to calibrate the fluorescence spectrum to better than 5 kHz per data point. The beat note between the reference laser and a tooth of the femtosecond laser frequency comb is used to find the absolute frequency of the probe laser with an accuracy around 10 kHz per data point (limited by the stability of the reference laser). The recorded fluorescence spectra are then fitted with an appropriate model, resulting in the absolute position of each spectral component with better than 10 kHz accuracy, a result similar to measurements in rubidium [4].

The femtosecond laser frequency comb consists of 1 GHz Ti:sapphire femtosecond laser that directly emits a broad spectrum extending from ~650 to 1000 nm [5]. Both the carrier-envelope offset frequency and the comb spacing are phase locked to stable signals synthesized from a Hydrogen maser [6]. The frequency of the Hydrogen maser is calibrated by the NIST cesium fountain clock with an uncertainty well below $1x10^{-14}$. Thus, all elements of the frequency comb have the same uncertainty.

In order to evaluate the final uncertainties in our data, a careful analysis of possible systematic effects is in progress. The known systematic uncertainties come from residual magnetic fields (1 kHz), optical pumping (2 kHz), and the Doppler effect that is due to the deviation from the perfect right angle between the atomic and the laser beam directions (5 kHz).

Figure 1 shows the preliminary record of eight frequency measurements of the optical transitions between the 6s $^2S_{1/2}$ ($F_g = 4$) ground state component and the three excited state hyperfine components 6p $^2P_{3/2}$ ($F_e = 3$, 4 and 5). In this plot, the data for each of the three transitions is offset by its weighted mean (given in figure caption). The error bars are a quadrature sum of the statistical uncertainty and the systematic uncertainty on each day. Upon completion of the measurements, we expect the frequencies between the different components of the ground and excited states to be measured with an uncertainty of better than 10 kHz, an order of magnitude improvement over the previous results [7].

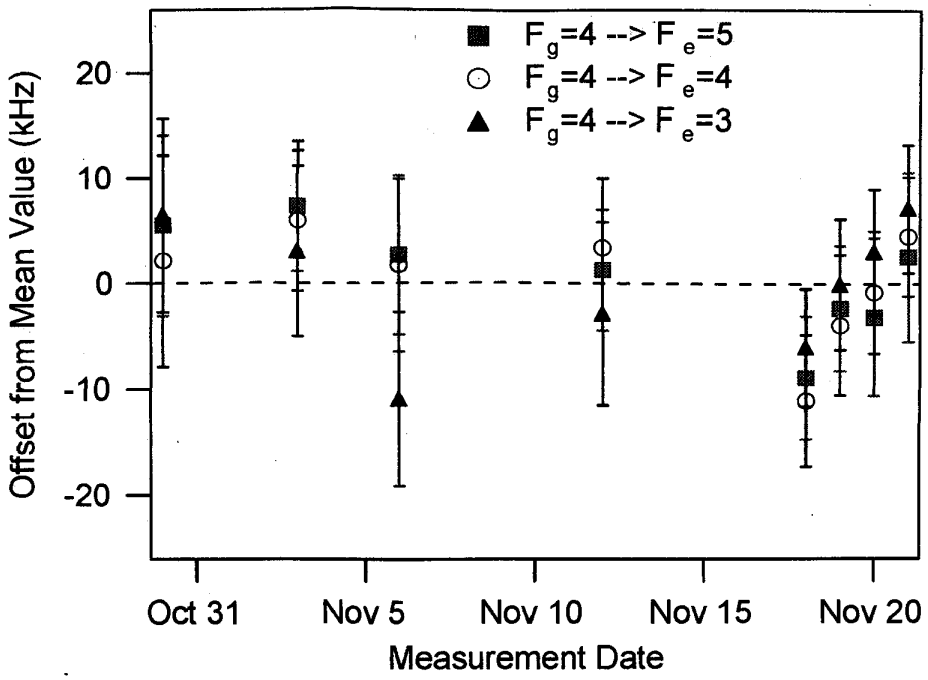

Figure 1: Measured optical frequencies between the 6s $^2S_{1/2}$ (F_g = 4) ground state and the three excited state hyperfine components 6p $^2P_{3/2}$ (F_e = 3, 4 and 5). The weighted mean values for the three transitions are as follows: F_g=4 - F_e=3: 351 721 508 208.7 kHz; F_g=4 - F_e=4: 351 721 709 492.6 kHz; F_g=4 - F_e=5: 351 721 960 585.7 kHz. The preliminary estimate of the uncertainty of these frequencies is 10 kHz.

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