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Authors:	Ting-Ju Chen, Jeng-En Chen, Tze-Wei Liu, Hsin-Hung Yu, Ko-Han Chen, Ya-Fen Hsiao, Ying-Cheng Chen, and Wang-Yau Cheng
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Absolute frequency of cesium atom $6S_{1/2}$-$6D_{3/2}$ Doppler-free two-photon transition

Ting-Ju Chen[1], Jeng-En Chen[1], Tze-Wei Liu[1,2], Hsin-Hung Yu[1], Ko-Han Chen, Ya-Fen Hsiao[2], Ying-Cheng[2] Chen and Wang-Yau Cheng[1]
[1]*Physical Department, National Central University, Taoyuan 32001, Taiwan*
[2]*Institute of atomic and molecular science (IAMS), Academia Sinica, Taipei10617, Taiwan*
Corresponding author: wycheng@phys.ncu.edu.tw

Abstract: We determined the absolute frequency of ^{133}Cs $6S_{1/2}$-$6D_{3/2}$ two-photon transition, our novel scheme enabled the resolution to address the nuclear magnetic octupole.
OCIS codes: (120.3940) metrology; (020.2930) hyperfine structure

1. Introduction

A cesium-stabilized 884-nm diode laser could be a convenient and reliable optical frequency reference once the absolute frequency was unveiled, especially a hand-sized version has been demonstrated [1]. Note that the second harmonic generation of a frequency-stabilized 884-nm radiation could be easily calibrated by Ytterbium ion primary standard at 435.5 nm, which is another advantage for this wavelength. In our previous work [2] we were aware that the transition frequency determined from sealed glass cell was not “absolute”. Therefore, in this report we prepared the cesium atoms in a high-vacuum (10^{-11}-torr) glass cell and detected the two-photon absorption at near a cesium dispenser which was heated by a constant current, to avoid the collision with any other gases. It is long recognized that the light shift is inevitable in two-photon transition that a main shortcoming for the related secondary standard. A good news is that we found almost no light shift in the *F=4→F'=5* transition. The other main feature in this report is that we obtained the hyperfine constants including nuclear magnetic octupole interaction. The high resolution in this report was mainly attributed to the assistance of a Ti:sapphire comb laser by which we were able to point-by-point sketching the entire hyperfine lineshape with each point knowing exactly its optical frequency, and that improved high-precision curve fitting. We found that the octupole-interaction hyperfine constant deduced from cesium 6D-level has the value six times larger than what has been deduced from 6P-level in 2003 [3].

2. Experimental setup

Fig. 1 shows the simplified schematic diagram of our experimental arrangement where the cesium cell #1 was for stabilizing master-laser frequency; the cesium cell #2 and cell #3 were for resolving the unperturbed $6D_{3/2}$ hyperfine spectrum. The master laser system in Fig. 1 yielded 500 mW laser power after two isolators. Eventually we achieved 36-mW phase-modulated radiation at before entering into cesium cell #1 (Cs #1) and 50-mW unmodulated radiation at before entering into another window of the same cesium cell. We used a signal generator, whose time base was referring to a Symmetricom 5071a cesium clock, to modulate the electric-optical modulator (EOM) at the modulation frequency (Δ) larger than 200 MHz. One 30-kHz sinusoidal modulation was further sent into the FM input of the aforementioned signal generator to dither the sidebands that resulted in a 4-MHz dither-width in optical frequency. The Cs #2 and Cs #3 spectrometers in the slave laser system actually share the same laser frequency (f_{slave})

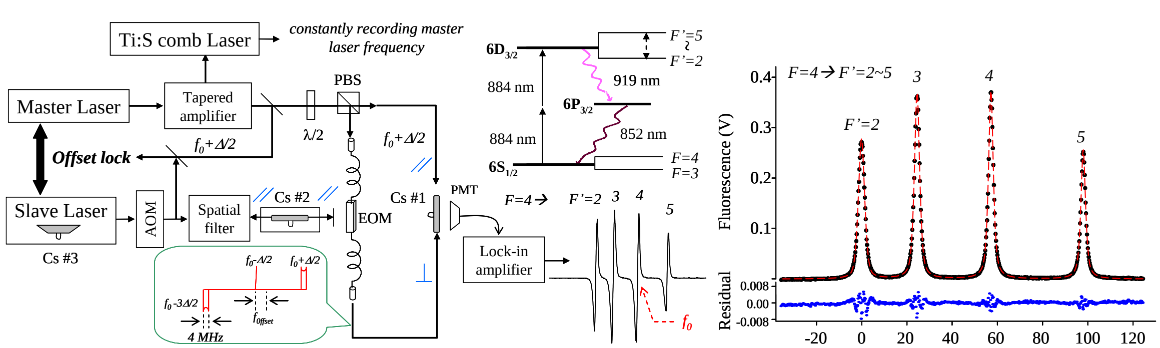

Fig. 1 simplified block diagram of the experimental setup and the related spectrum. Δ: EOM modulation frequency with 4-MHz sideband dither width; *f0*: center frequency of *F=4◊F'=4* hyperfine transition; f_{offset}: offset frequency between master laser and slave laser.

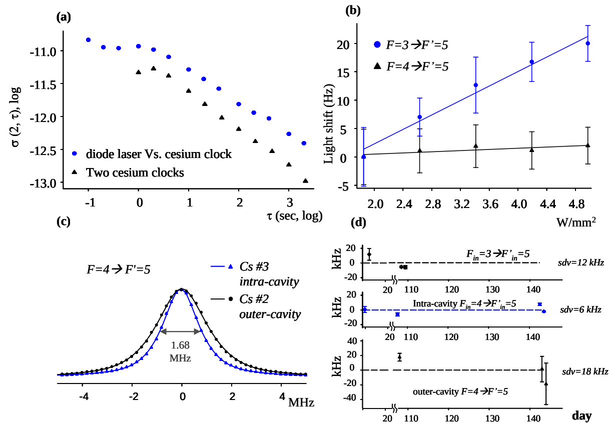

Fig. 2 (a) two sample Allan deviation; (b). The light shift of F=4→ F'=5 transition is almost not perceived; (c) Spectra resolved simultaneously from Cs #2 and Cs#3, see text; (d) Repeatability comparisons between different transitions and different cells, for four months.

Table 1. New hyperfine constants that are one order of magnitude higher precision than previous experiments

Hyperfine coupling constant	This work (MHz)	Ref[5] $6S_{1/2}F=3$(MHz)	Ref[6] (MHz)	Ref [4] (MHz)
A	16.3255(9)	16.17(17)	16.34(3)	16.30(15)
B	0.084 (21)	0.11(127)	-0.1(2)	<8
C	-0.004(1)			

which could be expressed as $f_{slave} = f_{master} + f_{offset} = f_0 - (\Delta/2) + f_{offset}$. The offset lock reached a level of mini-Hz. The intracavity cell #3 yielded excellent frequency repeatability as well as near-nature-linewidth spectrum, due to the facts of perfect beam overlapping and wider cavity waist (~ 0.8 mm).

3. Experimental results

From Fig. 2 (a) we found that master laser has very similar Alan deviation to cesium clocks. Fig. 2 (b) reveals that the 6S→6D transition of different hyperfine level yield quite different AC stark shift (light shift). We found an almost zero light shift for the *F=3→F'=4* and *F=4→F'=5* transitions. This is due to the fact that the transition amplitude from lower level to intermediate state is almost the same as the transition amplitude from the intermediate state to the upper level, and causes the cancelation of the two-photon transition rate. Fig. 2 (c) presents two different lineshapes simultaneously resolved by different cesium cells (Cs #2, Cs #3) from which one can easily find that the intracavity cell (Cs #3) yielded much narrower linewidth (blue triangle). We consider the linewidth discrepancy originated mainly from the transit broadening since we found that all of the *F=4→F'=2~5* transitions have the same 760 kHz additional linewidth like what have shown in Fig. 2 (c). Since laser linewidth (100 kHz) and collision broadening (few of ten kHz) could almost be ignored in our experiment, we consider the linewidths (HWHM) resolved from intracavity Cs #3 were near the natural linewidth. We also conclude that *F=4→F'=2~5* transitions were more appropriate to be a reliable optical reference as well as more appropriate to be used for determining the hyperfine constants rather than *F=3→F'=2~5* transitions since they are not sensitive to the both light power and magnetic field. This conclusion can be further proved by comparing the repeatability of *F=3→F'=5* and *F=4→F'=5* transitions for four months, as illustrated in Fig. 2 (d). The frequency repeatability in one day was around 1 kHz to 4 kHz (depend on different days) for intracavity spectrometer (Cs #3) and 6 kHz to 10 kHz for outer-cavity spectrometer (Cs #2). The standard deviation of 4-month observation on *F=4→F'=5*, presented in Fig. 2 (d), was still kept within two sigma of one-day error but the *F=3→F'=5* frequency repeatability for 3.5 month observation was obviously degrading. We also found that the outer-cavity spectrometer yielded relative worse frequency repeatability and the reason was unclear. However, we have to measure the absolute frequency by the outer-cavity scheme since we needed to keep the cell in high vacuum. Therefore, we quote conservatively 72 kHz (four sigma of measured repeatability) as the error of our absolute frequency measurement, that is

$6S_{1/2}F=4 - 6D_{3/2}$ F=5: 338 595 897 162 (72) kHz
$6S_{1/2}F=3 - 6D_{3/2}$ F=5: 338 600 493 491 (72) kHz

4. References

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