

Line shape measurements of rubidium 5S-7S two-photon transition

P. Morzyński¹, P. Wcisło¹, P. Ablewski¹, R. Gartman¹, W. Gawlik²,
P. Masłowski¹, B. Nagórny¹, F. Ozimek³, Cz. Radzewicz³, M.
Witkowski^{1,4}, R. Ciuryło¹ and M. Zawada¹

¹ Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziądzka 5, PL-87-100 Toruń, Poland

² Institute of Physics, Faculty of Physics, Astronomy and Informatics, Jagiellonian University, Reymonta 4, PL-30-059 Kraków, Poland

³ Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Hoża 69, PL-00-681 Warsaw, Poland

⁴ Institute of Physics, University of Opole, Oleska 48, PL-45-052 Opole, Poland

E-mail: rciurylo@fizyka.umk.pl

Abstract. We report the use of a digital lock to measure the line profile and center frequency of rubidium 5S-7S two-photon transitions with a cw laser referenced to an optical frequency comb. The narrow, two-photon transition, 5S-7S (760 nm), insensitive to first-order in a magnetic field, is a promising candidate for frequency reference.

1. Introduction

The International Committee for Weights and Measures recommended several radiations for the practical realization of the metre. At the border of the visible and near-infrared ranges, in particular, the International Bureau of Weights and Measures (BIPM) recommends the $5S_{1/2}(F=3)-5D_{5/2}(F=5)$ two-photon transition in ^{85}Rb with a standard uncertainty of 5 kHz [1]. Recent development in phase-stabilized optical frequency combs based on mode-locked femtosecond lasers allowed determination of the absolute frequency of a similar transition in Rb, $5S_{1/2}-7S_{1/2}$, which is 100 times weaker than 5S-5D, yet less sensitive to stray magnetic fields. At the 5S-5D transition the rubidium atoms must be carefully shielded against the magnetic field to avoid any linear Zeeman shifts. On the other hand, the 5S and 7S levels have the same Landé g factors which cancels the linear Zeeman shifts in the 5S-7S transition. The ac-Stark effect in the 5S-7S transition is also smaller than in the 5S-5D case. All these factors explain the growing interest in the $5S_{1/2}-7S_{1/2}$ transition in rubidium [2, 3, 4, 5].

2. Experimental arrangement

The details of the experimental set-up and apparatus are described elsewhere [6]. Here, we focus only on the description of the digital lock system and its application to the measurements of the line profile.

The idea of the digital lock is depicted in Fig. 1. An acousto-optic modulator (AOM) driven by a direct digital synthesizer (DDS) square-wave modulates the light frequency with



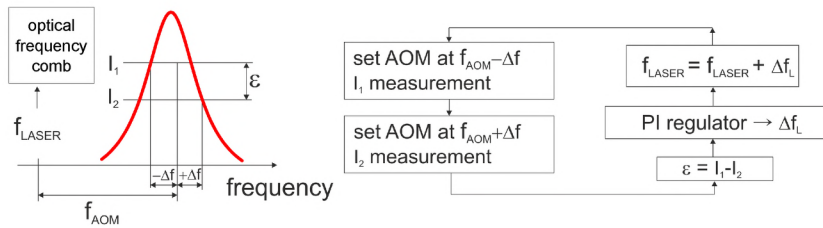


Figure 1. The scheme of the digital lock.

the step $2\Delta f$ equal to the half-width of the line. The AOM carrier frequency f_{AOM} is chosen such that the AOM efficiency with $f_+ = f_{AOM} + \Delta f$ and $f_- = f_{AOM} - \Delta f$ is the same. The microcontroller (Atmel AT91SAM7S), which controls the DDS, counts the photomultiplier pulses from the fluorescence signal of the 6P-5S transition. The error signal for the laser lock is calculated from the difference of the counts corresponding to fluorescence for f_+ and f_- . The software PI regulator in the microcontroller calculates the correction Δf_L and applies it to the TiSa laser. Switching between the f_{\pm} frequencies in the DDS is completed in 150 ns and the acoustic wave needs few μs to completely propagate the frequency changes through the AOM PbMoO₄ crystal. The following acquisition of the photomultiplier pulses takes 38 ms which is long enough to ignore chirping effects from switching the f_{\pm} frequencies. The frequency of the laser f_{LASER} , before shifting by the AOM, is measured in the real-time by an optical frequency comb.

The digital lock can be easily used to measure the line profile (Fig. 2) by changing Δf in the digital lock algorithm and recording accordingly the fluorescence intensity. Furthermore, recording the frequency measured by the optical frequency comb for different Δf detects a potential asymmetry of the line profile.

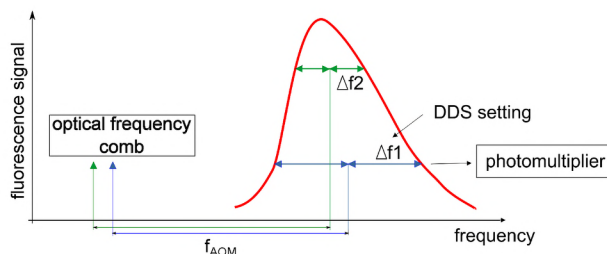


Figure 2. The measurement of the line profile.

3. Results

The examples of the measured profiles are presented in Fig. 3. The two series of graphs correspond to the measurements of the ^{87}Rb $F=2-F'=2$ and ^{85}Rb $F=3-F'=3$ transitions for different intensities of the probing light. In the two-photon spectroscopy the counter-propagating beams are not focused, the transition is characterized by a power-broadened Lorentzian profile. The measurement accuracy may be reduced at the line center where the digital lock is less precise because of small value of the fluorescence derivative with respect to the laser frequency leading to underestimation of measured fluorescence at given frequency.

In Table 1 we present the measured frequencies of four $5S_{1/2}-7S_{1/2}$ transitions in ^{87}Rb and ^{85}Rb . With the knowledge of the hyperfine splitting of the $5S_{1/2}$ state [7, 8] the hyperfine A constants of the $7S_{1/2}$ state were derived (94678.4(2.3) kHz for ^{85}Rb 7S and 319747.9(2.3) kHz for ^{87}Rb 7S) as well as the $5S_{1/2}-7S_{1/2}$ transition isotope shift (131529.6(6.6) kHz) [6].

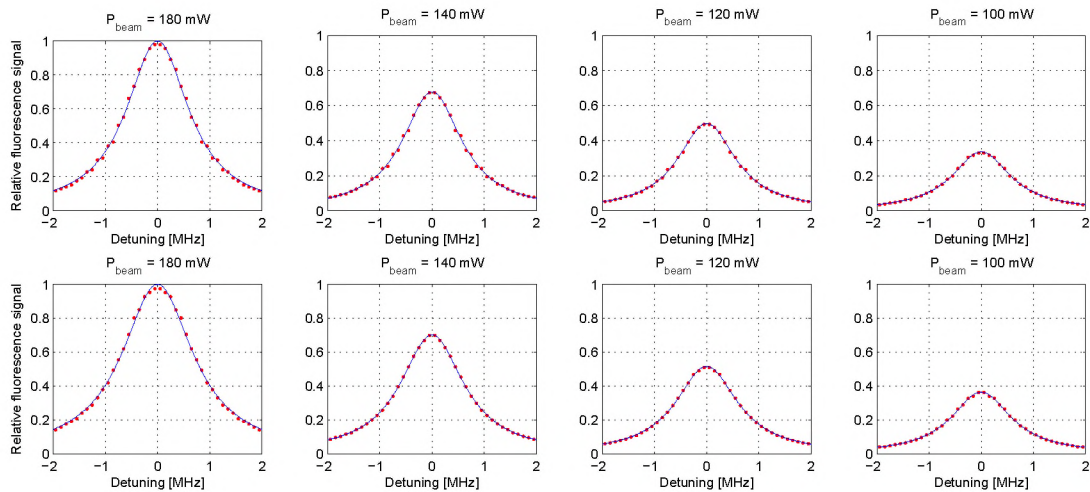


Figure 3. The measurements of the ^{87}Rb $F=2-F'=2$ (top) and ^{85}Rb $F=3-F'=3$ (bottom) transitions for different intensities of the probing light.

Table 1. Measured absolute frequencies of the two-photon $5S_{1/2}-7S_{1/2}$ transitions [6].

Transitions	Frequency [kHz]
^{85}Rb $F=2-F'=2$	394399282854.2(2.4)
^{85}Rb $F=3-F'=3$	394397907005.6(2.8)
^{87}Rb $F=1-F'=1$	394400482036.5(3.8)
^{87}Rb $F=2-F'=2$	394397384443.1(2.6)

4. Conclusion

We present the use of a digital lock to measure the line profile and center frequency of rubidium $5S_{1/2}-7S_{1/2}$ two-photon transitions. We have performed a series of measurements of the line profile and the absolute frequency of the $5S_{1/2}-7S_{1/2}$ transitions in rubidium vapor with a cw laser referenced to an optical frequency comb. We have also estimated the A constants of the hyperfine splitting of the $7S_{1/2}$ state and the isotope shift between ^{85}Rb and ^{87}Rb of the $5S_{1/2}-7S_{1/2}$ transition.

Acknowledgments

This work has been performed in the National Laboratory FAMO in Toruń and supported by the Polish National Science Centre Projects No. 2012/07/B/ST2/00235 and 2013/11/NST2/00846 and the TEAM Project of the FNP, co-financed by the EU within the European Regional Development Fund.

References

- [1] Bureau International des Poids et Mesures (BIPM), in *Report of the 86th Meeting of the Comité International des Poids et Mesures*, (BIPM, Sèvres, France, 1997)
- [2] Chui H C, Ko M S, Liu Y W, Shy J T, Peng J L and Ahn H 2005 *Opt. Lett.* **30** 842
- [3] Marian A, Stowe M C, Felinto D and Ye J 2005 *Phys. Rev. Lett.* **95** 023001
- [4] Pandey K, Kiran Kumar P V, Suryanarayana M V and Natarajan V 2008 *Opt. Lett.* **33** 1675

- [5] Barmes I, Witte S and Eikema K S E 2013 *Phys. Rev. Lett.* **111** 023007
- [6] Morzynski P, Wcislo P, Ablewski P, Gartman R, Gawlik W, Maslowski P, Nagorny B, Ozimek F, Radzewicz C, Witkowski M, Ciurylo R and Zawada M 2003 *Opt. Lett.* **22** 4581
- [7] Bize S, Sortais Y, Santos M S, Mandache C, Clairon A and Salomon C 1999 *Europhys. Lett.* **45** 558
- [8] Arimondo E, Inguscio M and Violino P, 1971 *Rev. Mod. Phys.* **49** 31