COHERENT POPULATION TRAPPING ON THE SECOND RESONANCE LINE OF POTASSIUM

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We present the observation of Coherent Population Trapping (CPT) resonances on the second resonance line of Potassium: $4s^2S_{1/2} \rightarrow 5p^2P_{3/2}$ with wavelength of 404.4nm. Moreover a transfer of the CPT resonance occurs to the excited $4p^2P_{1/2}$ and $4p^2P_{3/2}$ states of the first resonance line due to cascade transitions. This transfer is evidenced by the observation of narrow resonances at the infrared $4s^2S_{1/2} \rightarrow 4p^2P_{1/2}$ and $4s^2S_{1/2} \rightarrow 4p^2P_{3/2}$ transitions when alkali excitation is performed at the 404.4nm violet line.

1. Introduction

Coherent Population Trapping (CPT) phenomenon has mainly been studied on the D_1 and D_2 lines of alkali atoms due to the widely available single-mode near-infrared laser diodes. The promising to many applications CPT spectroscopy can now be extended to the violet/blue spectral region due to the progresses in the development of semiconductor lasers emitting at these spectral regions. Potassium is a promising candidate for efficient preparation of CPT resonances involving single optical transition due to the fact that the optical transitions between its hyperfine structure (hfs) levels on the D_1 and D_2 lines exhibit significant overlapping that helps in overcoming the hfs optical pumping [1]. Potassium vapor is used in the most sensitive optical pumping atomic magnetometers operating at high temperatures, in order to achieve high vapor densities and narrow resonances [2-4].

In this communication we present our experimental results related to the CPT resonance preparation on the second resonance line of Potassium: $4s^2S_{1/2} \rightarrow 5p^2P_{3/2}$ transition with wavelength of 404.4nm.

2. Experimental results and discussion

Potassium atoms, contained in buffered by 30 Torr of Ne or evacuated cell, are excited by single-frequency laser light at 404.4nm (Fig.1) and the CPT resonances are registered in Hanle configuration, monitoring atomic fluorescence dependence on an orthogonal to the atomic orientation or

alignment magnetic field B, which is varied around B = 0. Experiments are performed by using both circularly or linearly polarized light. The 404.4nm or the produced by cascade transitions 770.1nm fluorescence is measured. Two appropriate filters are used to distinguish and perform measurements with the violet (404.4nm) or infrared (770.1nm) line separately. The cells are shielded against stray magnetic fields. The laser beam diameter is d = 0.8mm.

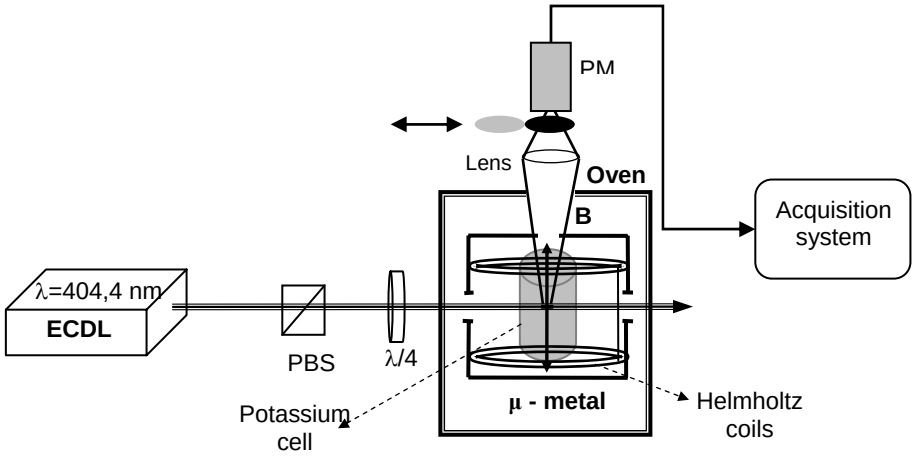

Fig 1. Experimental setup.

The scheme of the relevant transitions is presented in Fig.2. Irradiating K atoms by 404.4nm light, coherent superposition of ground state Zeeman sublevels is induced at B = 0, which is measured by 404.4nm fluorescence as a function of magnetic field. The coherent resonance (atomic polarization) is transferred to the excited levels of the first resonance line. The transfer is evidenced by the observation of a narrow CPT resonance in the fluorescence from the $4p^2P_{1/2}$ and $4p^2P_{3/2}$ levels (infrared lines) when the alkali excitation is performed at 404.4nm. Note that (for low cell temperature) even after multiple cascade transitions, the resonance observed on the infrared lines has much better signal/noise compared to that on the 404.4nm transition (Fig.3). One of the most important advantages of our technique is provided by the fact that when observing the CPT resonance on the infrared lines, the exciting laser light at 404.4nm can be completely filtered thus avoiding the noise due to the scattered laser light, which is one of the main drawbacks for applications of coherent resonances for precise measurements. Hence, the utilization of the second resonance line can lead to the improved sensitivity of the CPT based sensors.

It should be pointed out that in alkali atoms, the atomic polarization transfer due to cascade transitions has been observed and studied in early works on alkali hyperfine structure and lifetime measurements [5].

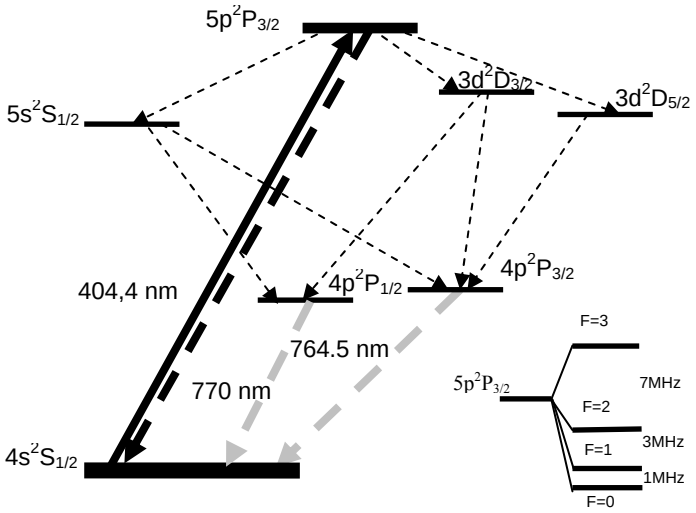

Fig 2. Scheme of the transitions relevant to the 404.4nm coherent resonance formation and its transfer by cascade transitions

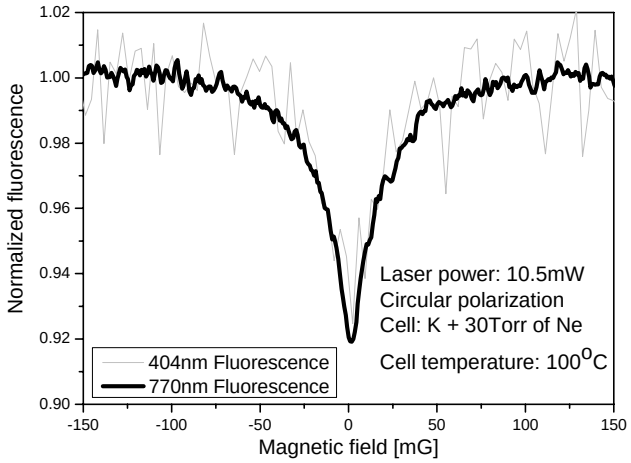

Fig.3 CPT resonances obtained when irradiating K atoms contained in a cell bufferd by 30Torr of Ne by 404.4nm circularly polarized light. Resonance observed in 404.4nm fluorescence (grey line) and infrared fluorescence (black line).

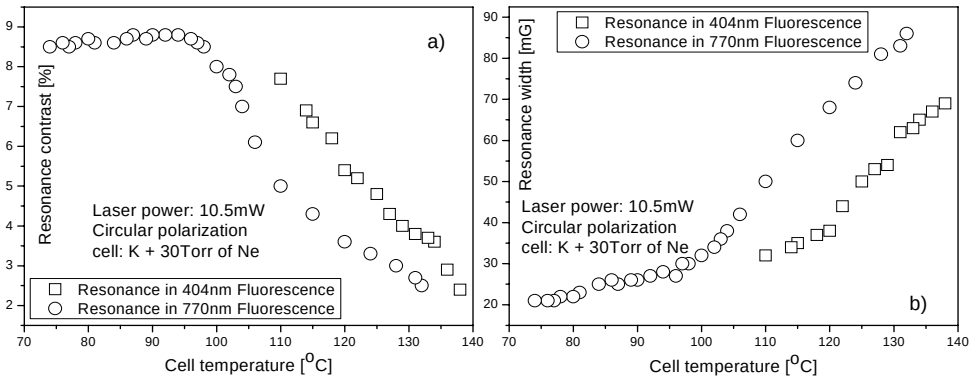

Fig.4 Contrast (a) and width (b) of the resonances observed in 404.4nm and infrared fluorescence when irradiating the buffered K cell by 404.4nm light.

In the buffered by 30Torr of Ne cell (Fig.4), only dark resonances are observed for both lines, showing contrast reduction and line-width broadening over 100°C cell temperature, which can be attributed to ground-state coherence relaxation in result of K-K spin-exchange collisions [2]. The resonances in the violet fluorescence are with higher contrast and lower width than those in the infrared one. Note that the first type resonances are not presented for cell temperature below 110°C due to the poor signal/noise ratio (see Fig.3). The fluorescence outside the resonance rises with the cell temperature, for both violet and infrared lines.

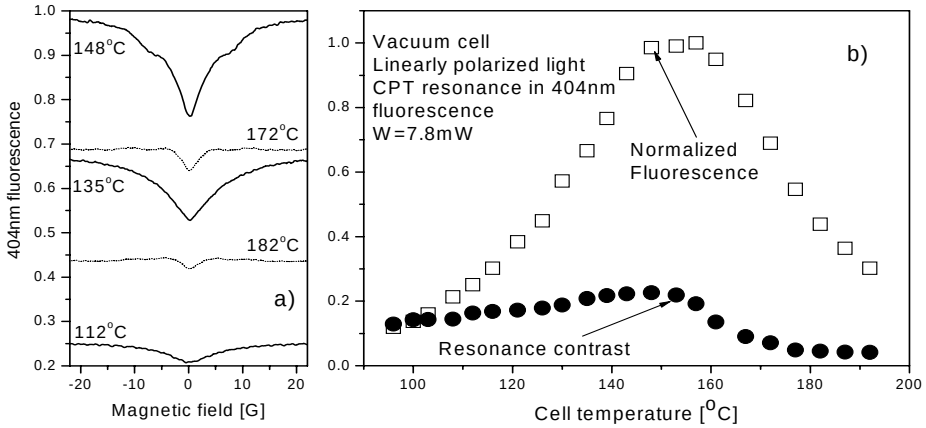

Fig.5 (a) CPT resonance in 404.4nm fluorescence, for non-buffered cell and linearly polarized 404.4nm light, at different cell temperature; (b) 404.4nm fluorescence amplitude, measured outside the resonance and CPT resonance contrast as functions of cell temperature.

The situation is different in the vacuum cell containing pure K atoms. Measuring the 404.5nm fluorescence (Fig.5), a dark CPT resonance is observed in the entire examined cell temperature interval (100°C-190°C). The width of the resonance observed in the vacuum cell is about two orders of magnitude larger than that for the buffered cell. For the first cell, some narrowing of the CPT resonance is demonstrated as the cell temperature increases over 150°C, which is attributed to the strong rising of density of K atoms. Note the reduction of the fluorescence amplitude after this temperature (Fig.5), showing strong trapping of the 404.5nm fluorescence by absorption and reemission processes. The radiation trapping leads to ground-state coherence relaxation [6] and some destruction of the CPT resonance. As it has been shown [7-9], the resonance destruction is more effective at its wings, while at its center the resonance is more resistant. Thus, the resonance destruction can result in its narrowing. Fig.5 shows that the resonance stays stable around its center with the atomic density rising.

An additional reason for the resonance narrowing can be related to the strongly increased atomic density, which prevents to some extent the K atoms from collisions with the cell walls. Those collisions are the main source of spin relaxation in the vacuum cell. For this cell, the resonance broadening due to the K-K spin-exchange collisions is negligible compare to time-of-flight broadening [2]. Thus, the strong increase of the K pressure could result in some narrowing of the CPT resonance.

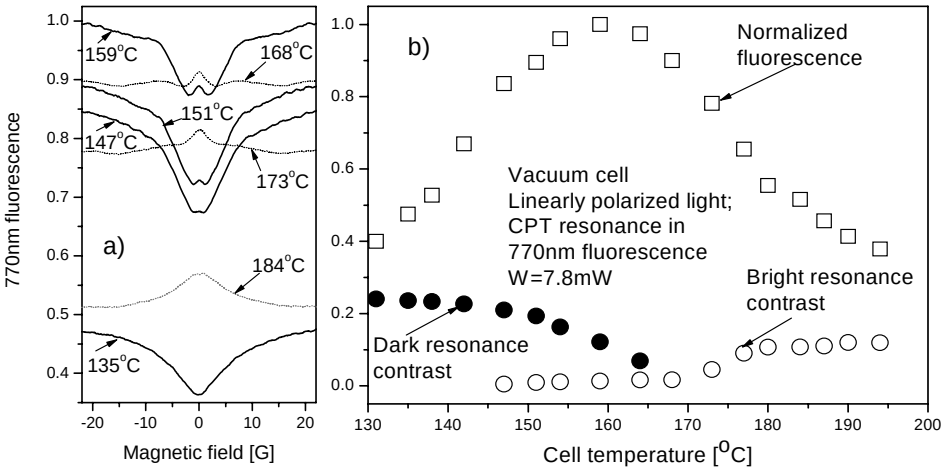

Fig.6 (a) CPT resonance in the infrared fluorescence, for non-buffered cell and linearly polarized 404.4nm light; (b) infrared fluorescence, and CPT dark (filled circles) and bright (empty circles) resonance contrasts vs. cell temperature.

In case of the infrared fluorescence measurement (Fig.6), the CPT resonance is of similar width and contrast, also exhibiting narrowing with the cell temperature. However, the resonance observed in the infrared fluorescence is dark only till cell temperature about 150^{o}C and after that a narrow bright resonance appears on the bottom of the dark one. The new bright resonance enhances its amplitude with atomic density, and over cell temperature of 165^{o}C, only bright resonance remains. The resonance sign reversal could be related to the much stronger radiation trapping, which takes place for the infrared than that for the violet fluorescence. After numerous emission-absorption cycles on the way to the detection point, the minimum absorption at the resonance center could lead to maximum measured fluorescence, thus reversing the resonance. However, the reasons for the resonance sign reversal are not yet clarified in a reliable way.

The CPT resonance transfer by cascade transitions is of importance for the study of processes in optically thick alkali atom vapour used in important basic experiments recently. The CPT resonance preparation on the second resonance line can be useful for practical applications, due to the possibility to avoid the laser intensity noise in precise measurements.

Acknowledgments

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References

[1] S. Gozzini, S. Cartaleva, A. Lucchesini, C. Marinelli, L. Marmugi, D. Slavov, T. Karaulanov, Eur. Phys. J. D 53, 153 (2009).
[2] Budker Dmitry, Romalis Michael, Optical magnetometry, Nature Physics 3, 227 (2007).
[3] S. J. Seltzer, P. J. Meares, M. V. Romalis, Phys. Rev. A 75, 051407(R) (2007).
[4] S. J. Seltzer, M. V. Romalis, http://arxiv.org/abs/0906.3054v1
[5] C. Tai, W. Happer, R. Gupta, Phys. Rev. A 12, 736 (1975).
[6] A. B. Matsko, I. Novikova, M. O. Scully, G. R. Welch, Phys. Rev. Lett. 87, 133601 (2001).
[7] F. Renzoni, E. Arimondo, Europhys. Lett. 46, 716 (1999).
[8] F. Renzoni, A. Lindner, E. Arimondo, Phys. Rev. A 60, 450 (1999).
[9] F. Renzoni, E. Arimondo, Phys. Rev. A 58, 4717 (1998).