

Coherent Population Trapping on the Second Resonance Line of Potassium

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We present the observation of coherent population trapping resonances on the second resonance line of potassium: $4s^2S_{1/2} \rightarrow 5p^2P_{3/2}$ with wavelength of 404.4 nm. Moreover, a transfer of the coherent population trapping 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 404.4 nm violet line.

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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 used in 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 404.4 nm.

2. Experimental results and discussion

Pure potassium vapor or that with 30 Torr of Ne added are excited by single-frequency laser light at 404.4 nm (Fig. 1) and the CPT resonances are registered in the 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 404.4 nm or the produced by cascade transitions 770.1 nm fluorescence is measured. Two appropriate filters are used to distinguish and perform measurements with the violet (404.4 nm) or infrared (770.1 nm) line separately. The cells are shielded against stray magnetic fields. The laser beam diameter is $d = 0.8$ mm.

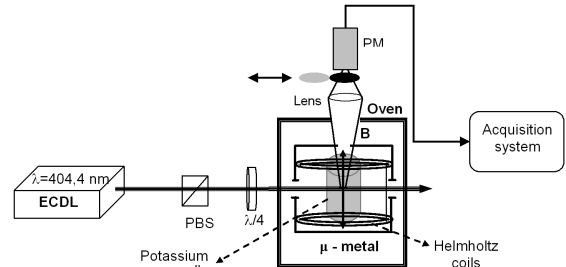


Fig. 1. Experimental setup.

The scheme of the relevant transitions is presented in Fig. 2. Irradiating K atoms by 404.4 nm light, coherent superposition of ground state Zeeman sublevels is induced at $B = 0$, which is measured by 404.4 nm 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 404.4 nm. Let us 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 404.4 nm transition (Fig. 3).

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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 404.4 nm 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.

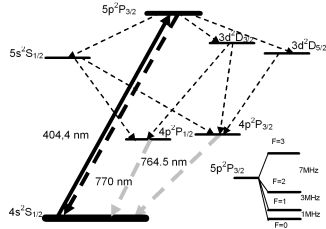


Fig. 2. Scheme of the transitions relevant to the 404.4 nm coherent resonance formation and its transfer by cascade transitions.

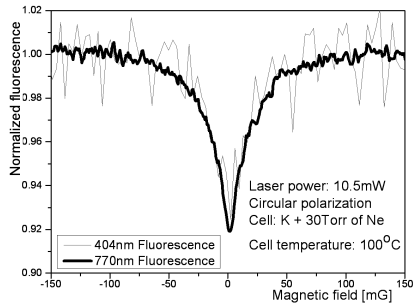


Fig. 3. CPT resonances obtained when irradiating K atoms contained in a cell buffered by 30 Torr of Ne by 404.4 nm circularly polarized light. Resonance observed in 404.4 nm fluorescence (grey line) and infrared fluorescence (black line).

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].

In the cell containing alkali vapor and 30 Torr of Ne (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. Let us 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.

The situation is different in the vacuum cell containing pure K atoms. Measuring the 404.5 nm fluorescence

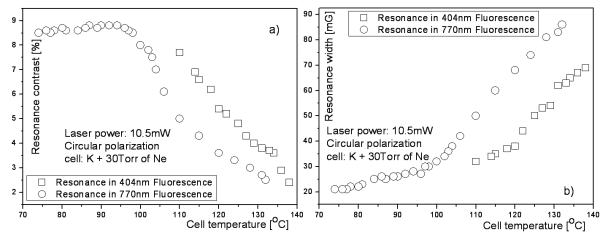


Fig. 4. Resonance contrast (a) and width (b) observed in 404.4 nm and infrared fluorescence with 404.4 nm excitation. The contrast is determined by the resonance amplitude to the fluorescence out of the resonance ratio.

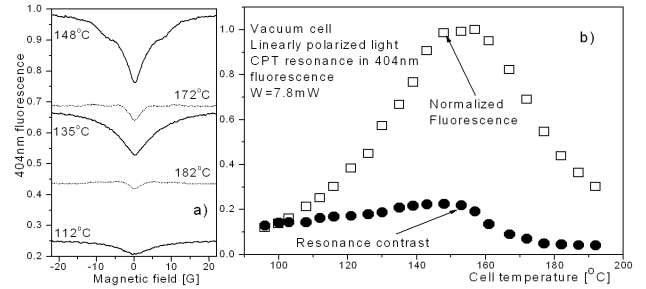


Fig. 5. CPT resonance in 404.4 nm fluorescence, for non-buffered cell and linearly polarized 404.4 nm light, at different cell temperature; (b) 404.4 nm fluorescence amplitude, measured outside the resonance and CPT resonance contrast as functions of cell temperature.

(Fig. 5), a dark CPT resonance is observed in the entire examined cell temperature interval (100–190 °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. Let us note the reduction of the fluorescence amplitude after this temperature (Fig. 5), showing strong trapping of the 404.5 nm 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. Figure 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 compared to time-of-flight broadening [2]. Thus, the strong increase of the K pressure could result in some narrowing of the CPT resonance.

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 °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 °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.

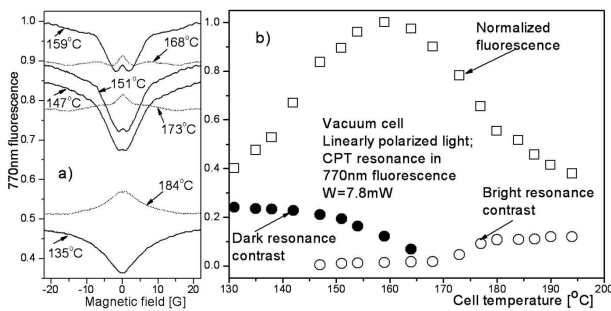


Fig. 6. (a) CPT resonance in the infrared fluorescence, for non-buffered cell and linearly polarized 404.4 nm light; (b) infrared fluorescence, and CPT dark (filled circles) and bright (empty circles) resonance contrasts vs. cell temperature.

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] D. Budker, M. Romalis, *Nature Phys.* **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).