Formation of strongly shifted EIT resonances using “forbidden” transitions of Cesium

R. Momier[1,2,*], A. Sargsyan[2], A. Tonoyan[2], D. Sarkisyan[2] and C. Leroy[1]

[1] Laboratoire Interdiscplinaire Carnot de Bourgogne, UMR 6303 CNRS - Université de Bourgogne, 21000 Dijon, France
[2] Institute for Physical Research, NAS of Armenia, Ashtarak-2, 0203 Armenia
*rodolphe.momier@u-bourgogne.fr / momier.rodolphe@gmail.com

Abstract

Atomic transitions satisfying $\Delta F = \pm 2$ of alkali atoms have zero probability in zero magnetic field (they are so-called ”forbidden” transitions) but experience a large probability increase in an external magnetic field. These transitions are called magnetically induced (MI) transitions. In this paper, we use for the first time the σ⁺ MI $F_g = 3 \rightarrow F_e = 5$ transitions of Cesium as probe radiation to form EIT resonances in strong magnetic fields (1 - 3 kG) while the coupling radiation frequency is resonant with $F_g = 4 \rightarrow F_e = 5$ σ⁺ transitions. The experiment is performed using a nanometric-thin cell filled with Cs vapor and a strong permanent magnet. Due to the large frequency shift slope of the MI transitions (4 MHz/G), it is possible to form contrasted and strongly frequency-shifted EIT resonances. Preliminary calculations performed considering Doppler-broadened three level systems in a nanocell are in reasonable agreement with the experimental measurements.

Theory

We perform the calculations using a simple density matrix model for a three-level Λ-system:

$$\dot\rho_{32} = i\Omega_c(\rho_{22}-\rho_{33}) + i\Omega_p\rho_{21}^* - (i\Delta_c + \gamma_{31}/2)\rho_{32}$$
$$\dot\rho_{31} = i\Omega_c(\rho_{11}-\rho_{33}) + i\Omega_p\rho_{21} - (i\Delta_p + \gamma_{32}/2)\rho_{31}$$
$$\dot\rho_{21} = i\Omega_c^*\rho_{31} - i\Omega_p^*\rho_{32} + (i\Delta_R + \Gamma_{21})\rho_{21}$$

where Δ_c (resp. Δ_p) is the detuning of the couling (resp. probe) laser to the upper state.

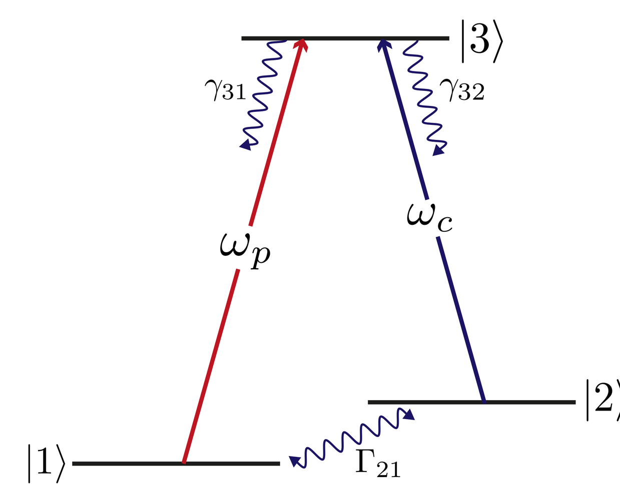


Figure 1: Three level system used in the calculations. The total decay rate [1] is $\Gamma_{33} = (\gamma_{31} + \gamma_{32})/2$.The dephasing rate of coherence between the ground state is $\Gamma_{21} = (2\pi t)^{-1}$ where t is the time of flight of the atoms through the cell (at the most probable thermal velocity).

The absorption profile is given by [2,3]:

$$\langle A\rangle = \frac{-4\pi\omega_p N t_2^2 t_1}{cu\sqrt{u}}\frac{E_p}{|F|^2}\int_0^{+\infty} v_z M(v_z)\mathrm{d}v_z \int_0^{L/v}\mathrm{d}t$$
$$\times\,\mathrm{Im}\Big\{\mu_{31}\Big[\rho_{31}^+\Big(t,\Delta_p^+,E_{p0}(v_z t)\Big)\Big(1-r_1e^{2ik_pv_zt}\Big)$$
$$+\,\rho_{31}^-\Big(t,\Delta_p^-,E_{p0}(L-v_zt)\Big)\Big(1-r_1e^{2ik_p(L-v_zt)}\Big)\Big]\Big\}.$$

Experimental setup

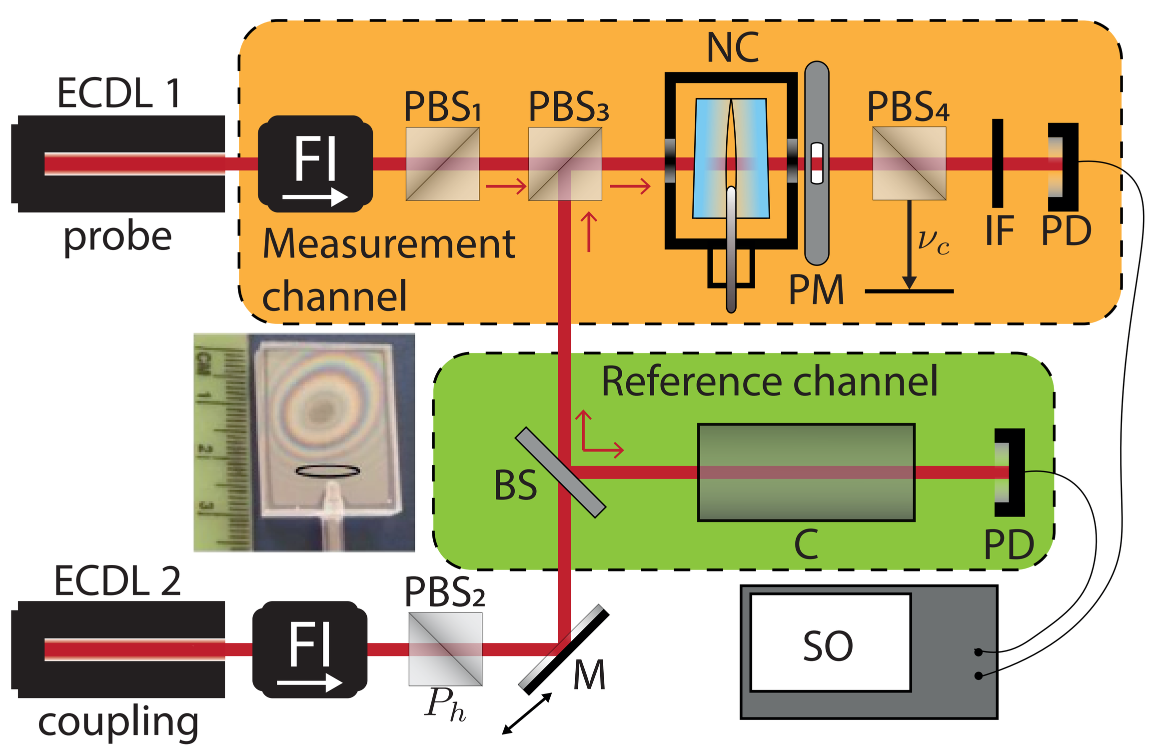


Figure 2: Scheme of the experimental setup. The orange channel allows to form EIT resonances in the absorption spectrum of Cs using a nanometric-thin cell, and the green channel is used to measure the saturated absorption (SA) of a usual long cell for reference.

Magnetically induced transitions

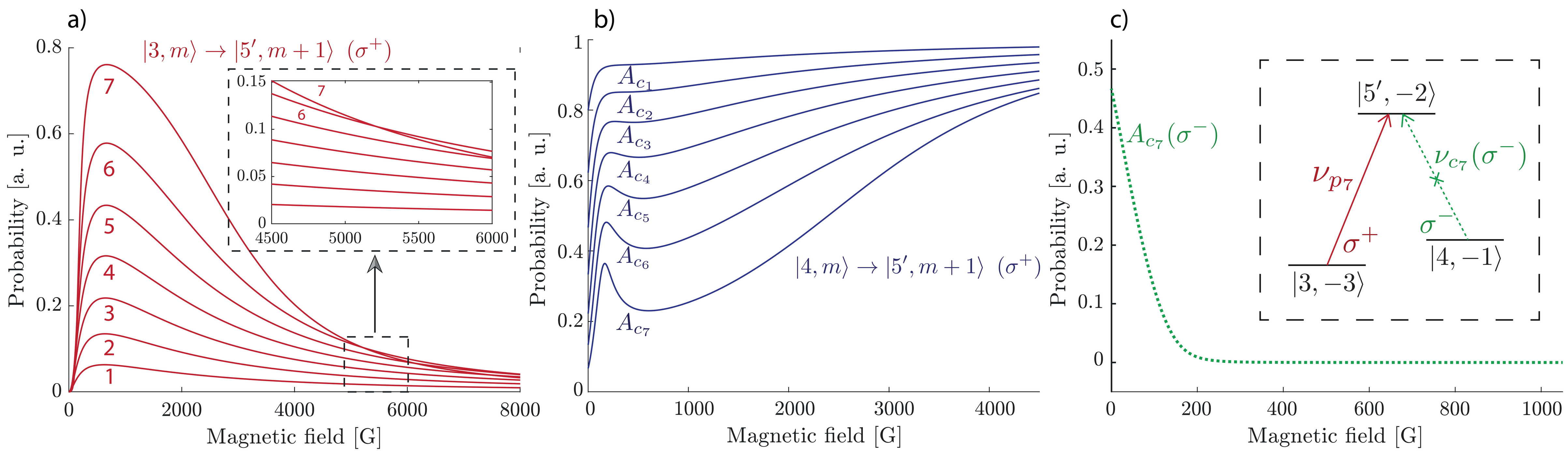
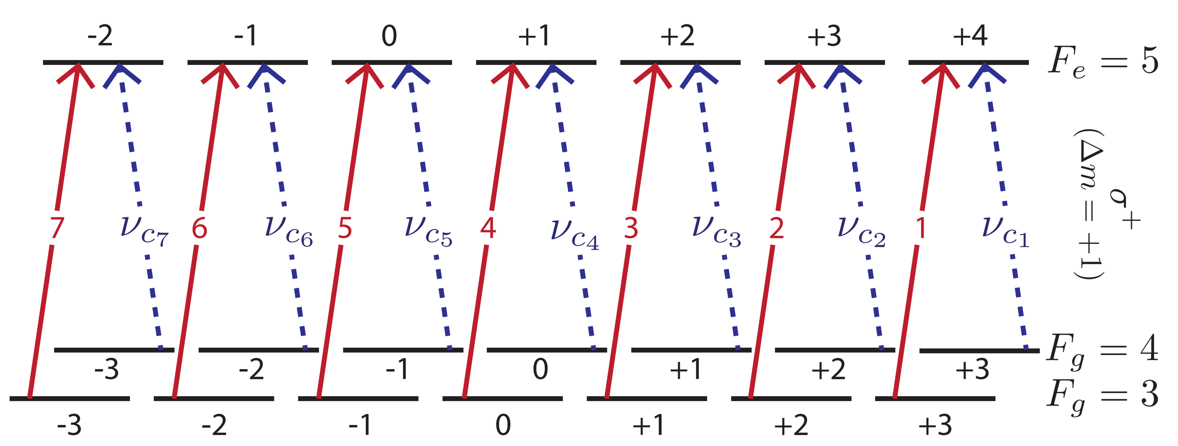


Figure 3: Magnetic field dependence of the D_2 line Zeeman transitions of Cs. a) $F_g = 3 \rightarrow F_e = 5$ σ⁺ transitions. b) $F_g = 4 \rightarrow F_e = 5$ σ⁺ transitions. c) Transition $|4, -1\rangle \rightarrow |5', -2\rangle$ (σ⁻). This transition forms a Λ-system with the transition $|3, -3\rangle \rightarrow |5', -2\rangle$ (as shown in the inset). Its probability tends to 0 as the magnetic field increases, therefore forming EIT resonances at high magnetic fields requires both probe and coupling to be σ⁺-polarized.



$|F,m_F\rangle$ is just a notation for visualization, as the states would be better described in the $|J,m_J,I,m_I\rangle$ basis.

Figure 4: Scheme of the Cs D_2 line σ⁺ transitions between $F_g = 3, 4$ and $F_e = 5$. The probe frequency is scanned across transitions 1 to 7, and the coupling frequencies are resonant with the $F_g = 4 \rightarrow F_e = 5$ transitions, forming seven Λ-systems. Only the states involved in the process are shown.

Experimental results

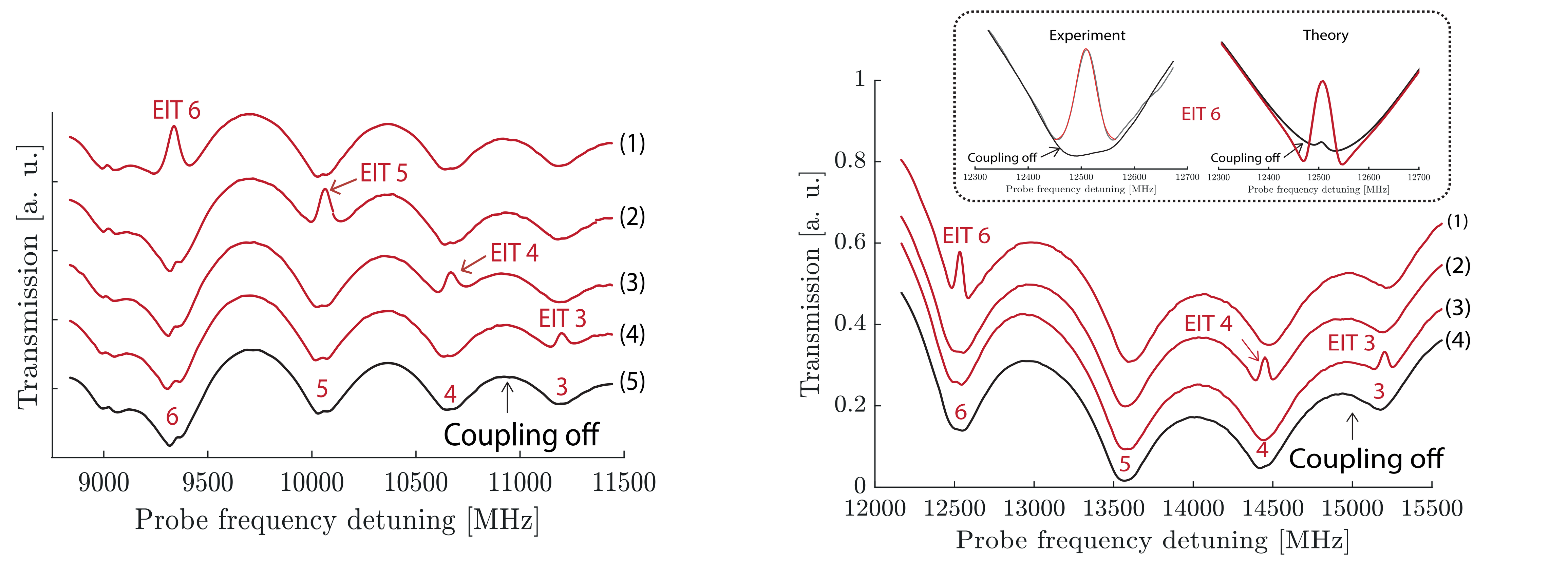


Figure 5: Probe transmission spectra of the Cs nanocell (L = λ = 852 nm). Lines 1 to 3 show four EIT resonances, labelled EIT 4, EIT 5 and EIT 6. The external longitudinal magnetic field is $B = 1770$ G on the left, and $B = 2880$ G on the right. The left part of the inset is a zoom on EIT 6, fitted with a Gaussian profile (FWHM 35 MHz) and compared with theory. The intensity of the coupling radiation was 18 mW/cm². Red: coupling on, black: coupling off. Small VSOP peaks are visible on each atomic transitions formed by the probe radiation. Their typical linewidth is 40-50 MHz. Zero frequency corresponds to the transition frequency of Cs D_2 line.

Transitions 1 to 7 (Fig. 4) can still be easily recorded up to $B = 8$ kG. In that case, their frequency shift reaches around 34 GHz from the Cs D_2 line transition frequency, allowing to use these EIT resonances as frequency reference [3].

References

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Conclusion

We use for the first time forbidden transitions of Cs to form EIT resonances. This is made possible by using a nanometric-thin cell. Due to the behavior of the Zeeman transitions, these EIT resonances are strongly shifted with respect to the Cs D_2 line transition frequency and are good candidates to serve as frequency reference. Narrower EIT resonances could be obtained by using coherently coupled beams derived from a single laser.

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