Generation of EIT resonances with $\Delta F = +2$ transitions of Cs D_2 line

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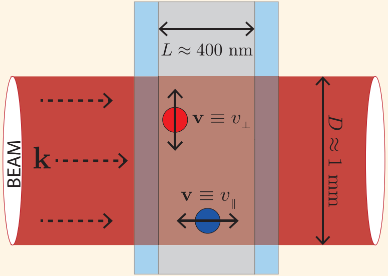
Laser **P**hysics 2023, Ashtarak, Armenia

Overview

Nanometric-thin cells



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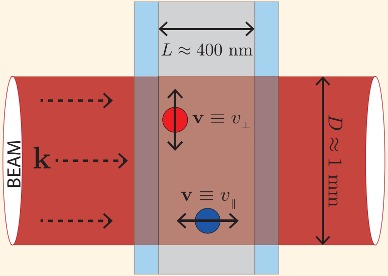

Time of flight of an atom orthogonal to the laser:

$$t_D = \frac{D}{v} = \frac{10^{-3}}{300} \approx \boxed{3\ \mu\text{s}}$$

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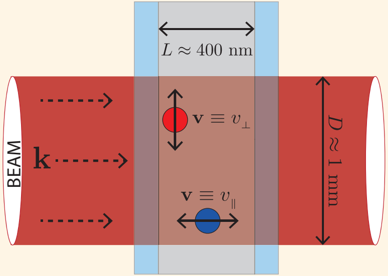

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TOF of an atom parallel to the laser:

$$t_L = \frac{L}{v} = \frac{400 \cdot 10^{-9}}{300} \approx \boxed{1.3\ \text{ns}}$$

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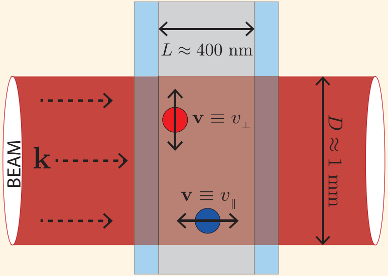

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Important remark

The geometry of the cell virtually kills all the Doppler broadening! Only atoms flying orthogonally to the laser have time to participate to the signal ($t_L \ll \tau$) but $\mathbf{k} \cdot \mathbf{v} = 0$ for those atoms, since $\mathbf{k} \parallel v_\parallel$.

Nanometric-thin cells

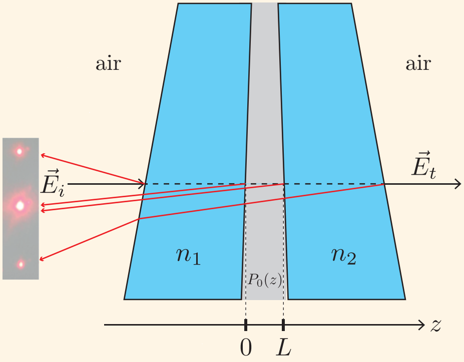
The cell behaves like a FP cavity. Formally, the transmitted field reads[1]:

$$S_t \approx 2t_{10}t_{02}^2 E_i \mathcal{R}\{I_f - r_1 I_b\}/|F|^2$$

where I_f and I_b are forward and backward integrals of the atomic polarization

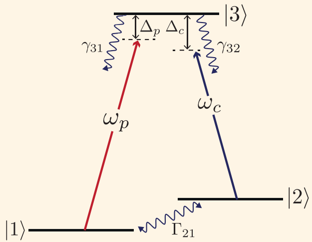
$$I_f = \frac{ik}{2\epsilon_0}\int_0^L P_0(z)\mathrm{d}z$$

$$I_b = \frac{ik}{2\epsilon_0}\int_0^L P_0(z)\exp(2ikz)\mathrm{d}z\,.$$



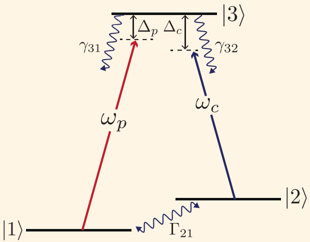
[1] G. Dutier et al. *J. Opt. Soc. Am. B* 20.5 (2003), pp. 793–800

EIT in a nanocell



[2] Y. Pashayan-Leroy et al. *J. Opt. Soc. Am. B* 24.8 (2007), pp. 1829–1838

[3] B. W. Shore. *The theory of coherent atomic excitation*. New York: Wiley, 1990



The absorption profile is[2]:

$$\langle A \rangle = \frac{-4\pi\omega_p N t_2^2 t_1}{cu\sqrt{u}} \frac{E_p}{|F|^2} \int_0^{+\infty} v_z M(v_z)\mathrm{d}v_z \int_0^{L/v} \mathrm{d}t$$
$$\times \operatorname{Im}\left\{\mu_{31}\left[\rho_{31}^{+}\left(t, \Delta_p^{+}, E_{p0}(v_z t)\right)\left(1 - r_1 e^{2ik_p v_z t}\right)\right.\right.$$
$$\left.\left. + \rho_{31}^{-}\left(t, \Delta_p^{-}, E_{p0}(L - v_z t)\right)\left(1 - r_1 e^{2ik_p (L - v_z t)}\right)\right]\right\},$$

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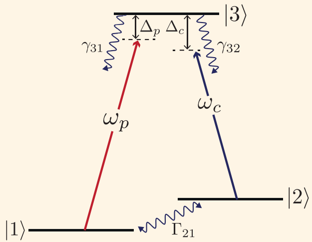

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$$\left.\left.+\,\rho_{31}^{-}\left(t,\Delta_p^{-},E_{p0}(L-v_z t)\right)\left(1-r_1 e^{2ik_p(L-v_z t)}\right)\right]\right\},$$

where the coherences are obtained from the Liouville equation of motion[3]:

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

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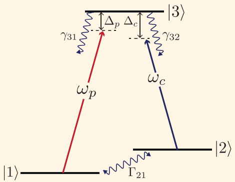
We use three-level systems consisting in $\Delta F = +1$ and $+2$ transitions[4]:



[4] A. Sargsyan et al. *J. Quant. Spectrosc. Radiat. Transf.* 303 (2023), p. 108582

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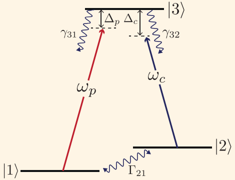

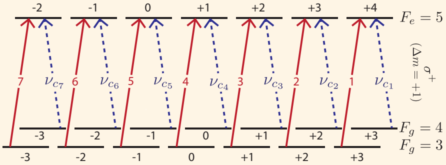

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Magnetically-Induced Transitions

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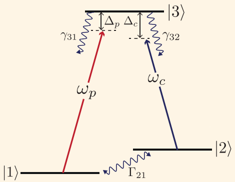

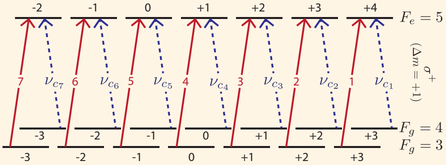

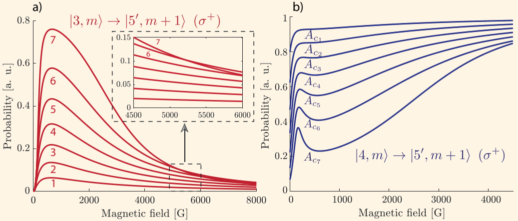

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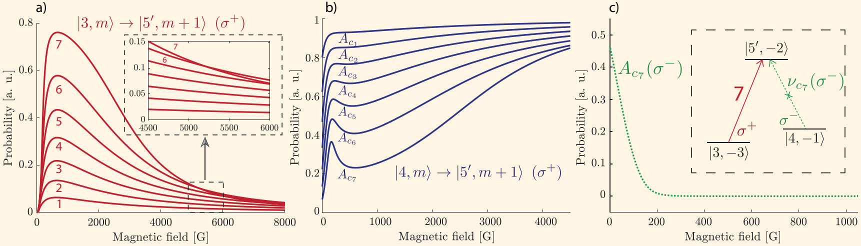

Difference between σ^+ and σ^- transitions

$\Delta m = -1$ (σ^-) transitions vanish (their probabilities tend to 0) as the magnetic field increases, thus both probe and coupling beams need to be σ^+-polarized (as seen in panel c).

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Formation of strongly shifted EIT resonances using "forbidden" transitions of Cesium

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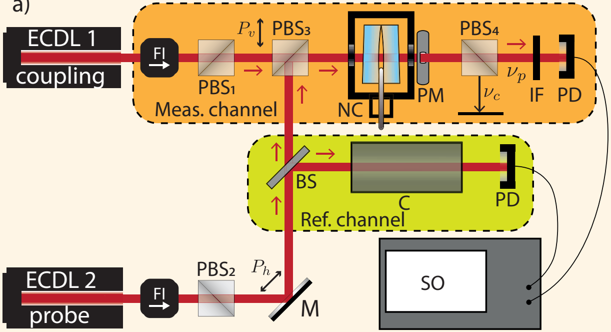
ABSTRACT

Atomic transitions satisfying $F_e - F_g = \Delta F = \pm 2$ (where F_e stands for excited and F_g stands for ground state) of alkali atoms have zero probability in zero magnetic field (they are so-called "forbidden" transitions) but experience a large probabilty 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^+ ($\Delta m_F = +1$) MI transitions $F_g = 3 \rightarrow F_e = 5$ 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. The thickness of the vapor column is 852 nm, corresponding to the Cs D_2 line transition wavelength. Due to the large frequency shift slope of the MI transitions ($\sim$ 4 MHz/G), it is possible to form contrasted and strongly frequency-shifted EIT resonances. Particularly, a strong 12 GHz frequency shift is observed when applying an external magnetic field of $\sim$ 3 kG. Preliminary calculations performed considering Doppler-broadened three level systems in a nanocell are in reasonable agreement with the experimental measurements.

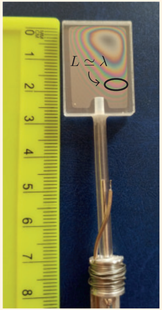
Recently published in J. Quant. Spectrosc. Radiat. Transf.

Experimental setup

a)



b)



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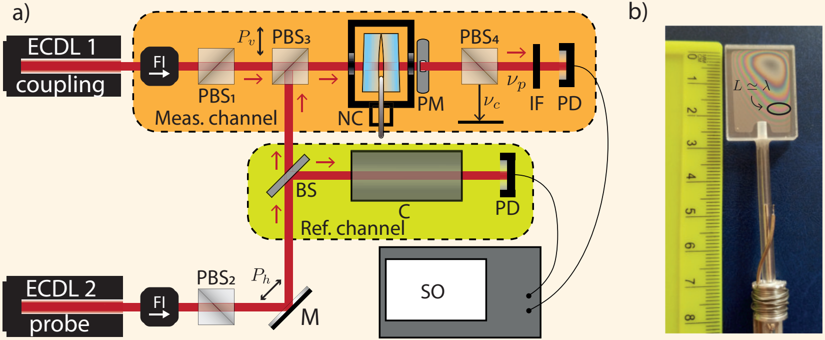
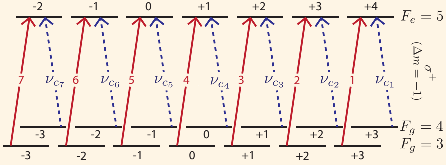


Experimental parameters

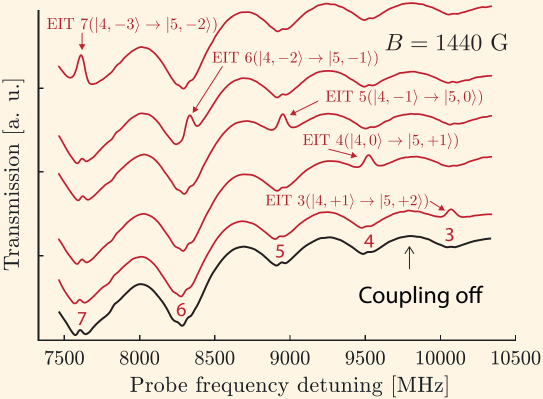
The cell temperature is 100 °C. The coupling and probe powers are 20 and 0.1 mW respectively. The reference cell is centimetric.



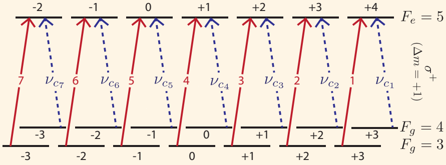
The probe beam is scanned across transitions 3 to 7, while the coupling is subsequently tuned to form the corresponding three-level system.

Example

The top-most curve is obtained with ω_c resonant with $|4,-3\rangle \rightarrow |5,-2\rangle$.

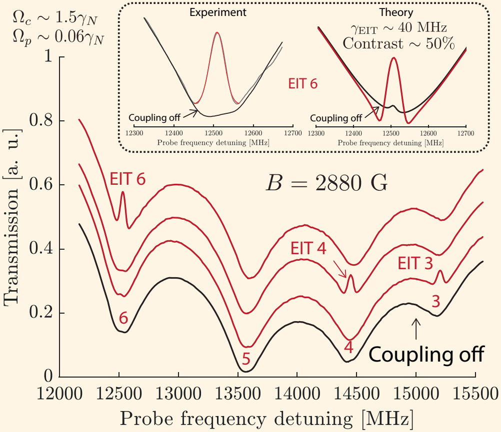


Experimental results



Experiment vs. Theory

The theoretical linewidth is consistent with the experiment. Dips are visible in the exp. spectra due to the FP nature of the cell ($L = \lambda$). The contrast and depth of the resonances are typical of what one would expect from the EIT process.



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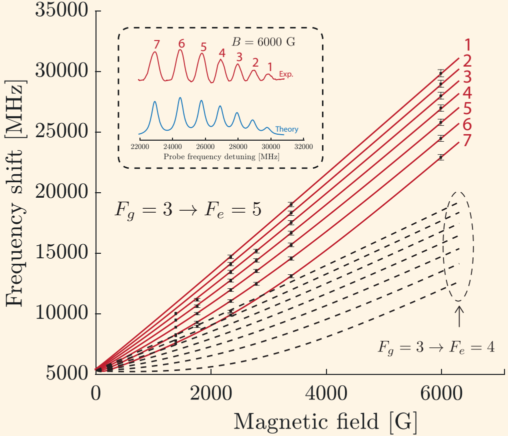

Frequency separation

At 6 kG, both groups ($\sigma^+\ \Delta F = +1$ and $\sigma^+\ \Delta F = +2$) are easy to record and are well separated in frequency: clean non-polluted spectrum. Due to the strong frequency shift of these transitions (up to ~ 4 MHz/G), these EIT resonances are good candidates for laser locking in the Paschen-Back regime, far from the D_2 line transition frequency (30 GHz at 8 kG).

Conclusion

- We used Λ-systems consisting in σ^+ $\Delta F = +2$ transitions of Cs D_2 line to form EIT resonances.

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- Further theoretical investigation is needed (involve more states and more decay rates for more accuracy).

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- Further theoretical investigation is needed (involve more states and more decay rates for more accuracy).
- Narrower resonances could be obtained by using a longer cell (less inelastic atom-window collisions, **but** more Doppler broadening of the spectra) or by using coherently coupled probe and coupling beams derived from a single narrow laser.

Thank you for your attention!

R. Momier

Dr. Armen Sargsyan

Dr. Ara Tonoyan

Prof. Dr. David Sarkisyan

Prof. Dr. Claude Leroy

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