Analysis of Rydberg-EIT with room temperature ^{87}Rb atoms

A. Cinins[1], T. Kirova[1], M. Auzinsh[2]
[1] *Institute of atomic physics and spectroscopy, University of Latvia, Skunu street 4, Riga LV1586, Latvia*
[2] *Laser Centre, University of Latvia, Zellu street 23, Riga LV-1002 Latvia*
E-mail: `arturs.cinins@lu.lv`

Electromagnetically induced transparency (EIT) is an quantum interference phenomenon, which induces a transparency window within a narrow spectral range around an absorption line of a medium [1]. EIT in a three level ladder scheme involving an atomic Rydberg level enables researchers to gain spectroscopic information on Rydberg levels, and can be used for frequency stabilization of lasers [2]. With the aid of sub-Doppler spectroscopy methods, narrow EIT structures can be observed in thermal media, such as vapor cells. Preceding studies [3, 4] have augmented the textbook three-level system model of the EIT in cold media [5] to account for thermal effects such as Doppler broadening and transition effects. However, most studies up to date have been concerned with broadening (or narrowing) of the EIT structure, while influence of thermal effects on overall EIT signal contrast is relatively unexplored.

A recent experimental study [6] has revealed a significant discrepancy of EIT response in weak probe field regime between cold and thermal media. In thermal vapors there exists an optimal intensity of the probe field, which yields the best EIT peak contrast. The optimal intensity value is stable with respect to parameters of the highly excited Rydberg state, coupling field intensity and laser field polarizations. A model three-level excitation scheme can be shown to behave similarly, if decoherence of optical coherence terms is introduced in the model. Transit relaxation is an important cause for decoherence in thermal vapor cells, where cell volume greatly exceeds the volume of laser beams. This relaxation mechanism not only leads to decay of optical coherences, but also interferes with optical pumping, modifying the equilibrium populations of magnetic sublevels of the atomic ground state. To properly account for transit relaxation, a model including full Zeeman sublevel structure of the atomic energy levels was devised. The model for Rydberg-EIT in ^{87}Rb atoms accounts for a weakly probed hyperfine cycling transition of the D_2 line $5^2S_{1/2}F = 2 \to 5^2P_{3/2}F = 3$. The excited state is strongly coupled to a Rydberg state $nS_{1/2}$, $nD_{3/2}$ or $nD_{5/2}$ with negligible hyperfine splitting. In the model Rydberg states are assumed metastable, as their lifetimes can greatly exceed the characteristic transit relaxation time. Nearby hyperfine components of intermediate excited level $5^2P_{3/2}F = 3$ are not expected to have a significant impact on the overall EIT response of the sample. For some velocity groups the resonance conditions for transition $5^2S_{1/2}F = 2 \to 5^2P_{3/2}F = 2 \to Ry$ would be met indeed, however larger transit relaxation times associated with these velocity groups allow their population to decay into the dark $5^2S_{1/2}F = 1$ state.

Numerical simulations have revealed that increasing probe laser intensity initially leads to improved EIT contrast as the ground state becomes more polarized. At larger probe intensities, when optical pumping fully overpowers the transit relaxation, the EIT contrast resumes to the “usual” exponential decay with increasing probe intensity. The critical value of probe intensity therefore primarily depends on properties of the D_2 transition and on vapor temperature in the cell. It is expected to be largely stable with respect to the choice of the coupling transition and coupling field intensity.

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