Transit relaxation effect on Rydberg–EIT spectra in thermal ^{87}Rb vapor

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Electromagnetically induced transparency (EIT) occurs when two light fields couple two distinct quantum states to a third state. When the Raman resonance condition is met, destructive interference between different excitation pathways induces a narrow transparency window in otherwise opaque medium [boller1991]. This effect has enabled demonstration of a wide variety of novel phenomena, including slow and stored light [2, 3]. Thermal vapor EIT spectrum allows optical detection of Rydberg states, and provides a convenient way to stabilize laser frequencies on the corresponding optical transition. Preceding studies [4, 5] have augmented the textbook three-level system model of the EIT in cold media [6] to account for various thermal effects such as Doppler broadening of the absorption spectrum and transition effects due to finite size of the laser beams.

For precision spectroscopy applications vapor pressure within a vapor cell is usually kept low enough for collisional broadening to be negligible. However, sufficiently large mean free path introduces transit effects due to finite size of the laser beams. Particle exchange between the excitation region where optical pumping takes place and the surroundings where equilibrium population distribution is preserved departs behavior of the system from that of a pure three-level system. Since optical pumping cannot be properly introduced in a three-level ladder excitation scheme, a model accounting for the full magnetic sublevel structure is devised instead. The model for Rydberg-EIT in ^{87}Rb atoms accounts for a weakly probed hyperfine cycling transition of the $D2$ line $5^2S_{1/2}F = 2 \rightarrow 5^2P_{3/2}F = 3$. The excited state is strongly coupled to a Rydberg state $nS_{1/2}$, $nD_{3/2}$ or $nD_{5/2}$ with negligible hyperfine splitting. Long–term interaction with the laser fields would allow the population leakage into "dark" ground level $5^2S_{1/2}F = 1$ via cascade relaxation of the Rydberg state. The model assumes that lifetime τ_{R} of the upper level significantly exceeds the average time t_{transit} an atom spends in the excitation region, and for the purposes of this study the Rydberg states are considered metastable.

Extensive numerical simulations have revealed that transit relaxation at low probe field intensities reduces contrast of the EIT response. The contrast improves with increasing probe field intensity as polarization of the atomic ground level due to optical pumping becomes more prominent, and reaches a maximum before reverting to exponentially decreasing behavior characteristic to three-level systems when the optical pumping dominates over the transit relaxation. The value of probe field intensity at which the highest EIT contrast is observed is primarily determined by temperature of the vapor and properties of the probe transition, and is largely stable with respect to properties of the strongly coupled transition and intensity of the coupling laser. This behavior resembles experimental observations reported in a recent study [7].

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