Selective Processes between Coherent Population Trapping and Raman Adiabaticity via Electromanetically-Induced Transparency

ECE 695

Jungu Choi

Coherent population trapping (CPT) renders atoms in the ground states of a Λ-like system as shown in Figure 1 virtually irresponsive to excitation by photon. This phenomenon was predicted in the Schrödinger’s equation where in the Λ-like system two resonances were treated independently while coherence between the two ground states was established [1]. The researchers noted that the excited state population dwindles with the strong presence of the coherence between the ground states. This led to the discovery of dark resonance which dates back to as early as 1970s when researchers found out in a three-level Λ-like system coherence in two photon transitions suppresses absorption of photons [2, 3].

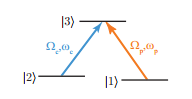


Figure 1. Coherent population trapping (CPT) occurs in the Λ-like system where two beams, coupling and probe beams, resonantly drive the transitions.

CPT prepares atoms in the superposition states, sometimes called dark states, via spontaneous decay and usually takes a long time to reach a steady state since it requires a few cycles of excitation and decay [5, 6]. Intuitively, it may take a very long time if the laser intensity is very small. The amplitude probability of the state dwindles and eventually vanishes in the steady state limit where the system has reached equilibrium. The final states can be expressed in the form as:

Figure 2, from Ref [4], is the plot of the pure imaginary coherence term, , which describes the excitation rate from the state to the state . This term depends highly on the population of the and states and therefore exhibits oscillatory behavior because the population of the ground states oscillate due to excitation and spontaneous decay. It can be seen that after a few cycles of spontaneous decay, the excitation rate shows smaller and smaller oscillation and eventually approaches zero (solid). When decoherence is introduced between the ground states, the excitation rate never approaches zero but does shows damped oscillatory behavior (dashed).

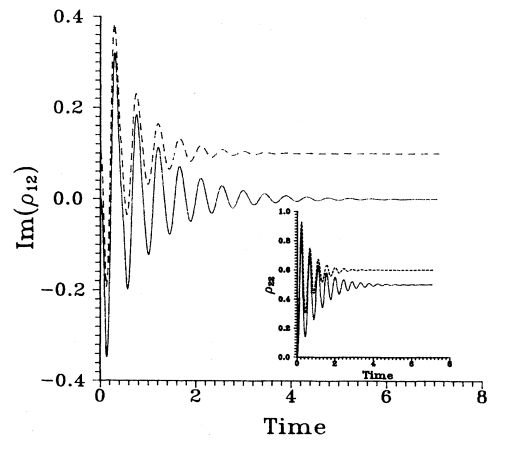


Figure 2. The pure imaginary coherence term, , describing the excitation rate from the ground state to the excited state. The unit of time is a multiple of spontaneous decay time. See text for more. The inset shows the population of the ground state over time.

In the same structure, Raman spectroscopy prepares atoms in the Bloch sphere with two ground states ( and in Figure 1) being the two levels. This process differs in that no direct excitation to the excited state ( in Figure 1) occurs, which is due to the fact that the Raman lasers are far detuned from the resonant frequency. The Raman lasers are usually called, pump laser and Stoke laser (the equivalent of coupling and probe lasers in Figure 1). One of the schemes in Raman spectroscopy exploits adiabatic passage where either the intensity or the detuning of the laser slowly changes to effect complete population transfer from one ground state to the other [6]. Adiabaticity was observed in a multi-level system using a pico-second pulse (at 778.5 nm) with unity transfer efficiency in atomic Rubidium 87 [7]. This experiment exploits the frequency sweep of the pulse bandwidth of ~ 10 nm to transfer atoms in the 5s state to the 5p state (at 780.2 nm) and then to the 5d state (at 775.9 nm).

a red-detuned Raman beams can be slowly scanned to the resonant frequency to observe adiabatic following from one ground state to the other [6]. This phenomenon has been observed in both molecular and atomic systems exhibiting the three level structure. In Ref [7]

[1] E. Arimondo and G. Orriols, Lett. Nuovo Cimento 17, 333 (1976)

[2] G. Alzetta, A. Gozzini, L. Moi, and G. Orriols, Nuovo Cimento 36B, 5 (1976).

[3] H. R. Gray, R. M. Whitley, and C. R. Stroud, Opt. Lett. 3, 218 (1978).

[4] I. V. Jyotsna and G. S. Agarwal, Phys. Rev. A 52, 3147 (1995).

[5] M. O. Scully and M. S. Zubairy, Quantum Optics (Cambridge University Press, Cambridge 1997).

[6] N. V. Vitanov, T. Halfmann, B. W. Shore, and K. Bergmann Annu. Rev. Phys. Chem. 2001. 52:763–809

[7] B. Broers, H. B. van Linden van den Heuvell, and L. D. Noordam, Phys. Rev. Lett. 69, 2062 (1992).