DISTINCTION BETWEEN ELECTROMAGNETICALLY INDUCED TRANSPARENCY (EIT) AND AUTLER-TOWNES SPLITTING (ATS): A CONCEPTUAL APPROACH

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ABSTRACT

Coherent interactions of light with multilevel atoms can alter their optical response via quantum interference in a variety of applications such as ultraslow light propagation, light storage, transition dipole moments. In past few years, a lot of work has been carried out to realize 'E-field sensing' through a Rydberg-atom based metrology system. EIT and ATS in the presence of RF have been reported rigorously to understand the new methodology. In this work, a conceptual investigation has been done to differentiate between two similar looking quantum interference phenomena. The equations of evolution of the system has been derived and the element corresponding to probe absorption is analyzed using different analytical techniques. Both the phenomena are obtained theoretically. The EIT has been understood as a destructive interference and ATS has been understood as gap induced between the two absorption profiles.

THE NEW SPECTROSCOPIC APPROACH

- A four-level cascade theoretical Rubidium-85 atomic model is considered in this work
- Levels I1> and I2> in the figure 2 corresponds to $5S_{1/2}$ and $5P_{3/2}$ states respectively, coupled by a weak probe laser of 780nm
- I2> and I3> states are coupled by a strong control laser of 480nm
- The control laser ensures that the atom is excited to the Rydberg state
- I3> and I4> are two excited Rydberg states, and are coupled with the applied RF energy
- EIT or AT splitting is possible in the cascade three-level system, of which one level is the Rydberg states

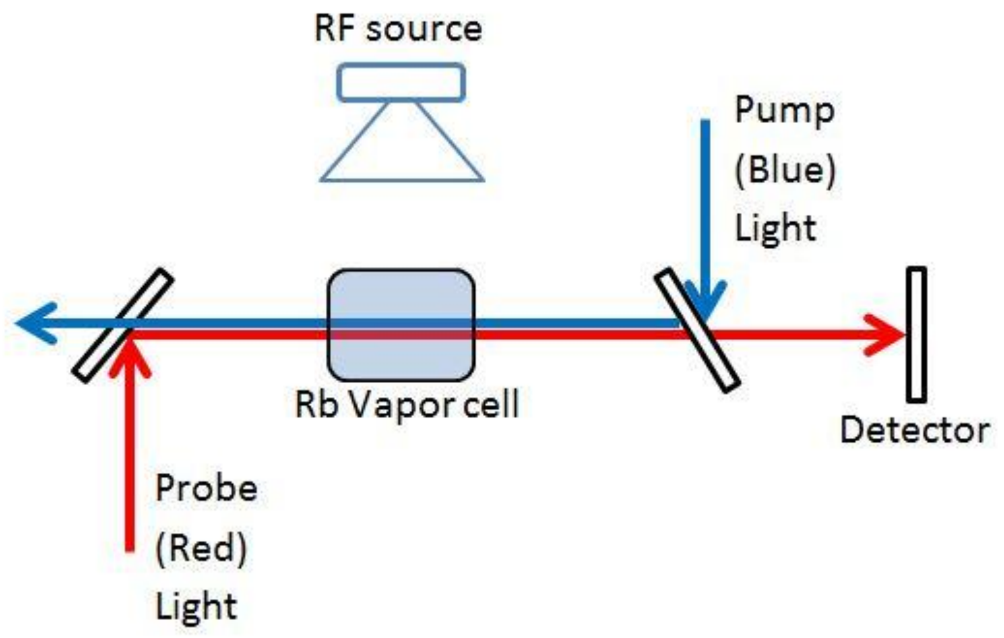

Figure 1. Schematic diagram of the setup considered for E-field measurement with the help of EIT and ATS

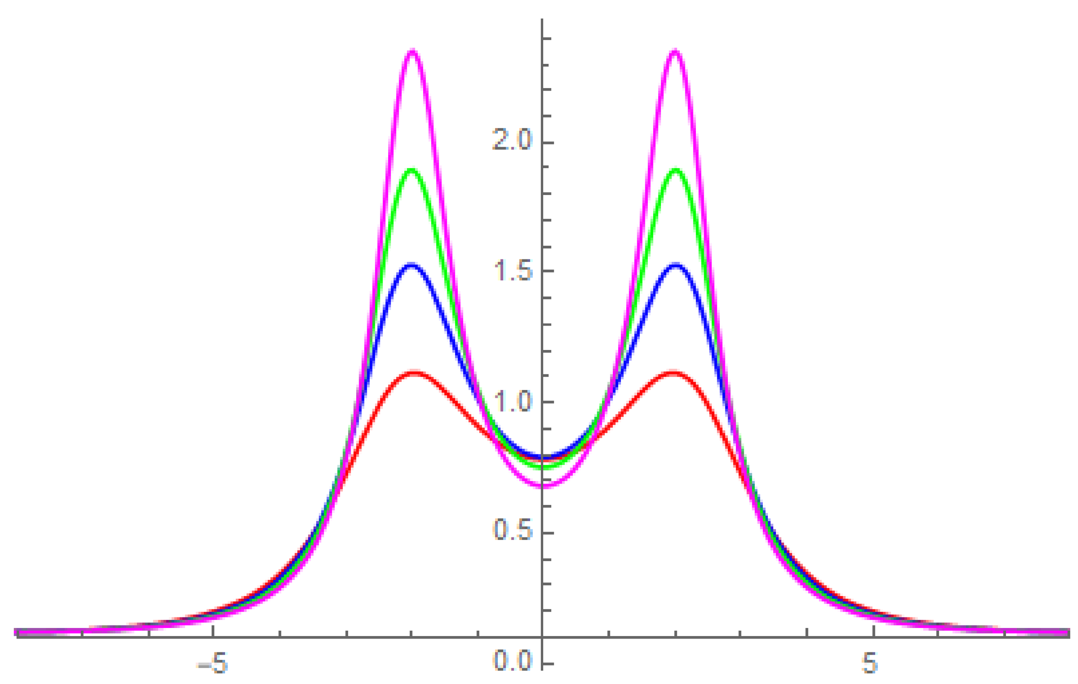

Figure 3. EIT observed as dip in the absorption profile for various values of detuning

ELECTROMAGNETICALLY INDUCED TRANSPARENCY (EIT)

- Electromagnetically induced transparency (EIT) is a quantum interference phenomenon which transforms an initially absorbing medium into a transparent medium for a particular frequency
- In the case when the Rabi frequency of the control field is weaker than Doppler width, the probability amplitudes of the two transitions destructively interfere
- In figure 3 we demonstrate the nature of dip induced in the absorption profile for various values of the detuning 'Δ'

AUTLER-TOWNES SPLITTING (ATS)

- Autler-Townes splitting occurs when the Rabi frequency of control field is stronger than the Doppler width of the probe transition.
- In figure 4 we demonstrate the variations in the gap between the two resonances for various values of the Rabi frequency of RF field 'Ω_{rf}'
- In the considered case, we understood that the additional RF field splits the EIT phenomenon and thus can be related to the dynamic Stark-shift or Autler-Townes Splitting; the split is equal to Rabi frequency of RF field 'Ω_{rf}'

SUSCEPTIBILITY AND ANALYTICAL METHOD

- The equations of evolution for the density matrix elements are obtained by using a standard approach
- Susceptibility of the probe laser field is a function of density matrix element ρ_{21} and is given by:

$$\chi = \frac{2N_0\wp_{12}}{\varepsilon_0 E_p}\rho_{21}$$

- Real and Imaginary part of the χ gives the dispersion and absorption of the probe in the medium respectively

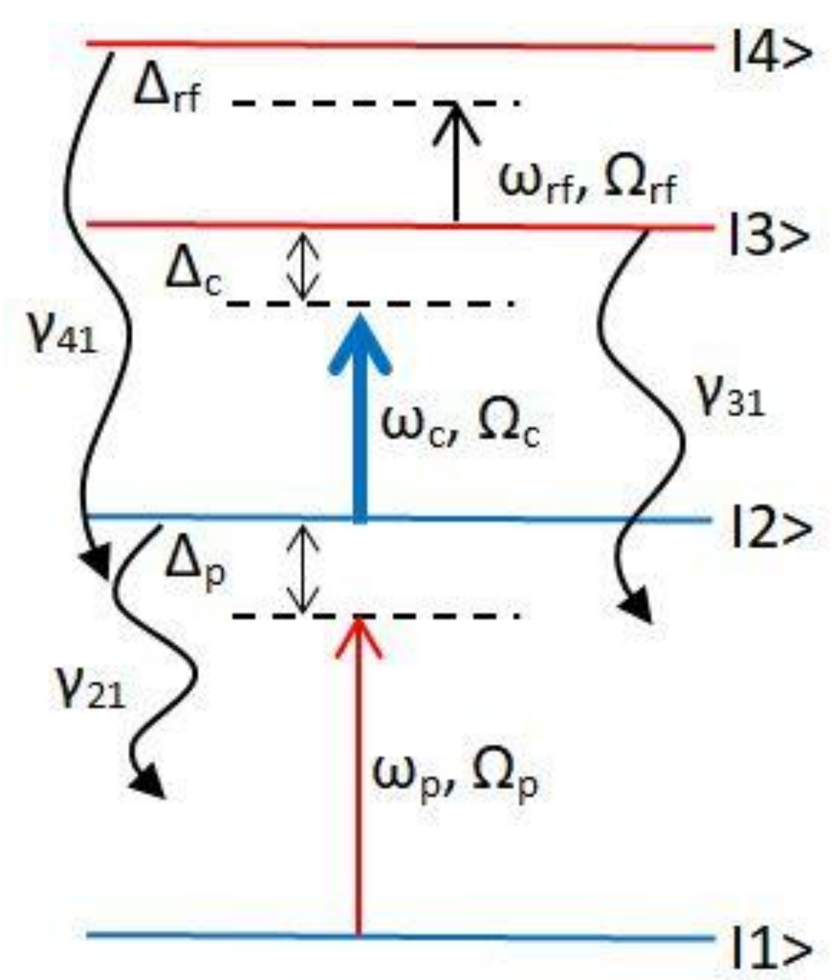

Figure 2. Schematic diagram of four-level cascade model ; Δ_p is the detuning of the probe field, Δ_c is the detuning of the control field, and Δ_{rf} is the detuning of the RF field ; γ_{ij} is the transition decay rate of corresponding states ; ω is the frequency of the applied energy.

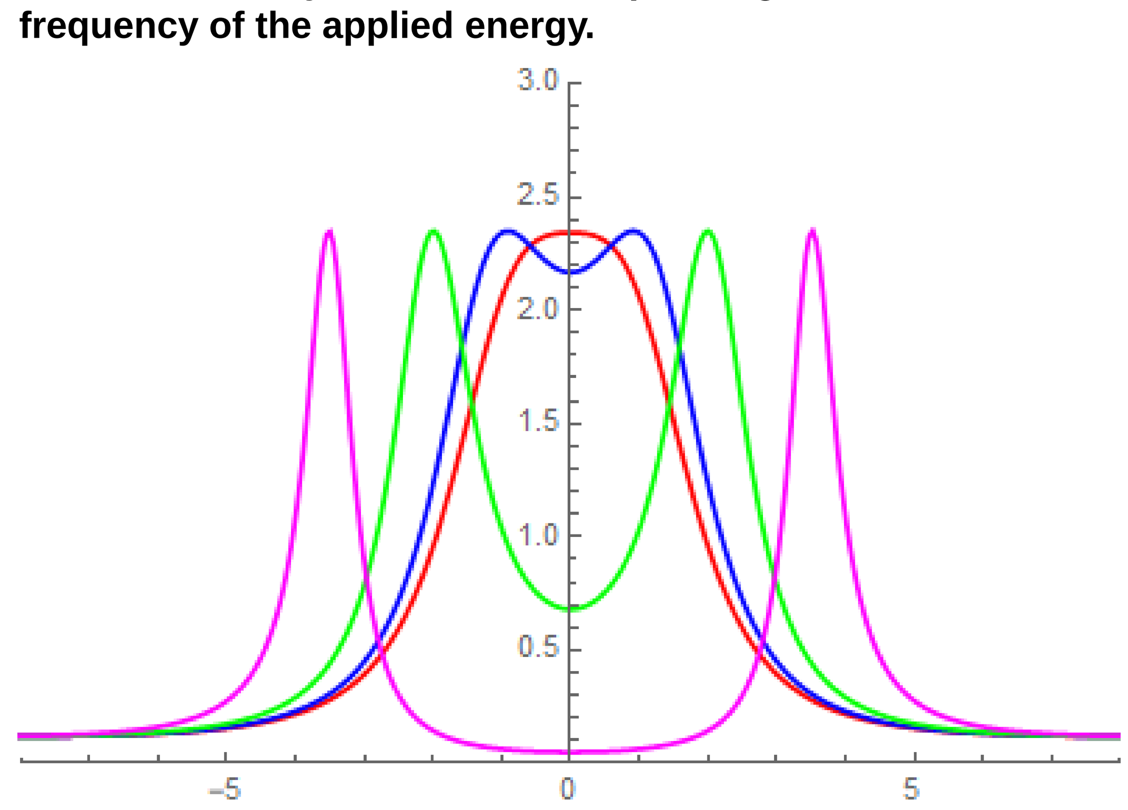

Figure 4. ATS observed as a gap induced in the absorption profile; obtained for different values of control Rabi frequency

- The Density Matrix element 'ρ_{21}' of the excited system is given as

$$\rho_{21} = \frac{i\Omega_p}{2\left[i(\Delta_p - \gamma_{21}) + \dfrac{\frac{\Omega_c^2}{4}B}{AB + \frac{\Omega_{RF}^2}{4}} \right]}$$

where $A = i(\Delta_p + \Delta_c) - \gamma_{31}$

$B = i(\Delta_p + \Delta_c + \Delta_{RF}) - \gamma_{41}$

- The above expression is solved as per the Spectrum Decomposition Method and can be decomposed to the form

$$\rho_{21} = \Omega_p\left[\frac{A_+}{(\Delta_p - \Delta_{p+})} + \frac{A_-}{(\Delta_p - \Delta_{p-})}\right]$$

$$A_\pm = (\Delta_{p\pm} - i\Gamma)/(\Delta_{p+} - \Delta_{p-})$$

where, $\Delta_{p\pm}$ are the poles of the ρ_{21}, and all other parameters have their usual meaning

- The obtained expressions are lengthy and are not reported here
- Instead of Maxwell distribution for velocity of the atoms, we have considered the Lorentzian velocity distribution and is given by

$$f = \frac{v_T}{\sqrt{\pi}(v_T^2 + v^2)}$$

where $v_T = \sqrt{\dfrac{2K_BT}{M}}$ is the most probable speed

RESULTS

- We have presented a theoretical study for EIT resonance and the behavior of it in the presence of an rf driving field.
- EIT observed as dip in the absorption profile for various values of detuning
- ATS observed as a gap between two resonances; obtained for different values of control Rabi frequency

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