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APPLICATION OF ELECTROMAGNETICALLY INDUCED TRANSPARENCY (EIT) IN QUANTUM COMMUNICATION: A REVIEW

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ABSTRACT

Electromagnetically induced transparency is a promising approach to implement quantum communication in quantum system. In this study, quantum coherence and interference in the excitation pathways of a three-level Λ atomic system leads to the formation of new states of matter (i.e. the dark state). This state decouples itself from the excitation beams leading to phenomena such as coherent population trapping (CPT), electromagnetically induced transparency (EIT). Taking into account quantum coherence and interference in an optically dense electromagnetically-induced transparent medium, we investigate the non-destructive storage and retrieval of single-photon quantum states in the dark state of this dense ensemble of gas phase medium. The storage and retrieval process is based on the intracavity electromagnetically induced transparency by which properties of a cavity filled with three-level Λ-type atoms are manipulated by an external control field. We demonstrate the peculiar case for the storage and retrieval of time-entangled periodic input pulses (a soliton train) in the dark state by adiabatic photon transfer under conditions of dynamical impedance matching. These multiplexed photon states are expected to allow sharing quantum information among many users, and are currently of very high demand for applications in long-distance and multiplexed quantum communication.

Key Words: Electromagnetic Transparency (EIT), Coherent Population Trapping (CPT), Quantum Coherent and interference, Intracavity EIT, Soliton train, Slow light, Three-level Λ-type

INTRODUCTION

Electromagnetically induced transparency (EIT) was first introduced by Haris and his co-workers at Stanford University in 1990 (Haris *et al.*, 1990; Dunn, 2020). It indicated that the optical response of an atomic medium is modified when laser beams lead quantum interference between the excitation pathways which can eliminate absorption and refraction (linear susceptibility) at the resonant frequency of the atomic transition. Slow light, light storage and quantum memory have been implemented based on EIT (Novikova *et al*., 2012).

Electromagnetically induced transparency

(EIT) is a promising approach to implement quantum memory in quantum communication and quantum computing applications. Quantum memory is used to temporary store quantum states and to retrieve them at a later time (Ma *et al*., 2017). When the quantum states are prepared and manipulated using photons, it is called optical quantum memory. Current quantum systems are mainly based on photons and as example, quantum memory can synchronize operations in linear quantum computing (Ma *et al*., 2017).

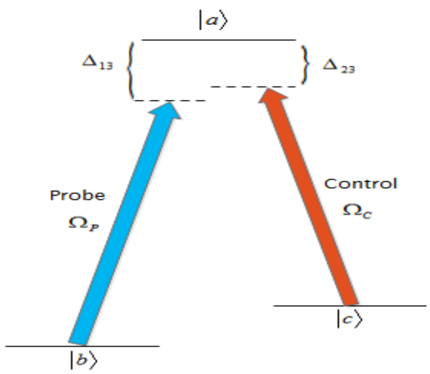
This therefore discusses the mechanism used to accomplish storage of single- photon quantum states. It will be demonstrated later in this paper that EIT is the first step that aids in the storage process. It should be noted that intracavity EIT, will be used to accomplish the storage process. To this extend it is instructive to first understand the concept of EIT. EIT will be studied in a three-level atom interacting with two classical fields, more explicitly the main part of this article will be devoted to EIT theory, but first a more general case of Coherent Population Trapping (CPT) will be described.

Quantum coherent control systems has been given much attention and experimental effort. Its uses range from the possibility of studying fundamental aspects of quantum Physics to quantum information processing. The practical implementation of quantum processing protocols requires coherent manipulation of a large number of coupled quantum systems which is an extremely difficult task. A wide variety of physical systems and phenomena have been proposed as quantum systems. Some of them are trapped ions, atoms in optical lattices, cavity quantum electrodynamics (Cavity QED), as well as the three-level atom.

Coherence effects in three-level atom system bring about two interesting but related phenomena: CPT and EIT. These concepts are closely related and one precedes the other. A discovery was made by Cohen-Tannoudji (2015) that the fluorescence from a gas of sodium atoms vanishes when the splitting of the hyperfine levels of the atoms matches the mode spacing of the applied multimode laser. The discovery of CPT has led to the realization that an otherwise opaque medium could be rendered transparent by the application of two coherent laser fields that allows foe optical pumping between allowed transitions for which all the population (atoms and their electrons) decay into dark non – absorbing state (dark state). This later on led to the realization of the concept of Electromagnetically Induced Transparency (EIT).

Experiment on EIT was first demonstrated by (Boller *et al*., 1991) using a gas of strontium atoms. It was then later, other researchers advances the study to include measuring the associated reduction of the speed of light. For instance, Zafar and Salim (2015) conducted an experiment and reported that light could move as low as 17 m/s. This findings therefore clear a path that for the understanding of the potential applications of EIT in the field of quantum information processing as it was demonstrated that the laser pulses could not only be slowed down, but in fact brought to a complete stop in the medium. It thus became possible to use the medium as a quantum memory, transferring the quantum state of free-field photons to the ensemble of gas phase atoms and retrieval of these states.

It was reported that EIT can be used as a



regulatory center to compress and spatially stop the probe pulse, consequently regenerating pulse at a later time in a cloud of cold sodium atoms (Liu *et al*., 2001). Light consist of photons, so photons can be made ideal carriers of quantum information because: they travel at the speeds of 300,000km/s, they are robust and readily available (Fleischhauer & Juzeliūnas, 2016.). On the other hand atoms present reliable and long-lived storage and processing units. Therefore, the challenge is to develop a technique for coherent transfer of quantum information carried by light to atoms and vice versa. In other words it is necessary to have a quantum memory that is capable of ”storing” and ”releasing” quantum states on the level of individual photon qubits. Such a device needs to have a stringent requirement of coherence in order to achieve a unidirectional transfer (from field to atoms or vice versa)

The Atomic Framework

Electromagnetically Induced Transparency (EIT) can be observed in multilevel systems but it is most pronounced in three levels systems. The basic EIT system is comprised of a quantum system with three energy levels $|a\rangle$, $|b\rangle$, $|c\rangle$ with energies $\hbar\omega_a$, $\hbar\omega_b$, $\hbar\omega_c$ respectively that interact through the atomic dipole with two coherent classical laser fields.

Figure 1: Three-level Λ system interacting with a probe and control laser. Δ_{13} and Δ_{23} are the one photon detunings of the probe and the coupling fields respectively. lasers and couple the $|b\rangle \leftrightarrow |a\rangle$ and $|c\rangle \leftrightarrow |a\rangle$ transitions respectively

We will assume the fields are monochromatic and we ignore the spatial dependence of the fields, only writing down the fields at the location of the atom. This is appropriate in the dipole approximation or long wavelength approximation, where we assume that the wavelength of the fields are much longer than the size of the atom, so that we can neglect any variations of the field over the extent of the atom. This is generally appropriate for optical transitions, since atomic dimensions have $\mathring{A}$ scales, while optical wavelengths are hundreds of nm. The interaction Hamiltonian is given by eq.(1.4)where $\vec{d} = \vec{d}_{ij}\left(|i\rangle\langle j| + |j\rangle\langle i|\right)$ is the transition dipole moment between levels $|i\rangle$ and $|j\rangle$ and $\vec{E}$ is the electric field of the two laser fields. The fields are nearly resonant with transitions $|b\rangle \leftrightarrow |a\rangle$ and $|c\rangle \leftrightarrow |a\rangle$ respectively, while the transition

$|b\rangle \leftrightarrow |c\rangle$ is dipole forbidden due to selection rules (Shore, 2008). There are three possible configurations of a three level system: lambda (Λ), Vee (V) and the ladder (Ξ). Throughout this article, lambda system will be employed as it is commonly used for implementing quantum memory shown in fig. 1. The Λ three level system is the basis for various coherent phenomena such as CPT (Vitanov *et al*., 2017), Stimulated Raman adiabatic passage (STIRAP) (Pillet *et al*., 1993), lasing without inversion (LWI) (Al-Nashy *et al*., 2018), Ultraslow light propagation (Tsakmakidis *et al*., 2017), Pulse matching and phase correlation (Haris *et al*., 1999), and two photon absorption (Lin *et al*., 2019). The two classical laser fields are called the probe and control (or pump).

Coherent Population Trapping (CPT)

The Coherent Population Trapping (CPT) was first discovered as a decrease in the fluorescence emission from sodium atoms in a vapor cell (Lin *et al*., 2021). It was understood to arise from the fact that these atoms were being optically pumped into the dark non-absorbing state by the excitation beams, in other words the atoms were coherently trapped in the dark state hence the concept of CPT. The dark state is created by the destructive interference between the excitation pathways from two meta-stable levels (states) to a common excited level.
Similar to the two-level atom discussed in section 1.2, the non-interacting Hamil- tonian of fig.1 is given as:

$$H_{atom} = \hbar\omega_a |a\rangle\langle a| + \hbar\omega_b |b\rangle\langle b| + \hbar\omega_c |c\rangle\langle c| \qquad \text{Eq. (1)}$$

As for the interaction Hamiltonian $\left(H = -\vec{d}.\vec{E}\right)$, it is modified since $\vec{E} = \vec{E}_p + \vec{E}_c$ are the probe and coupling electric field and the dipole moment $\vec{d} = \vec{d}_{ij}\left(|i\rangle\langle j| + |j\rangle\langle i|\right)$ interact with each field coupling the two different transitions. The interaction Hamiltonian is therefore given by:

$$H = \tfrac{\hbar\Omega_p}{2}\left(|a\rangle\langle b| + |b\rangle\langle a|\right) + \tfrac{\hbar\Omega_c}{2}\left(|a\rangle\langle c| + |c\rangle\langle a|\right) \qquad \text{Eq. (2)}$$

where $\Omega_p = -\frac{\vec{d}_{ab}.\vec{E}_{PO}}{\hbar}$ and $\Omega_c = -\frac{\vec{d}_{ac}.\vec{E}_{c0}}{\hbar}$ are the probe and coupling field Rabi frequency, and $\vec{E}_p = \vec{E}_{po}\cos\omega_p t$, $\vec{E}_c = \vec{E}_{co}\cos\omega_c t$ respectively. Combining eqs. (1) and (2) and applying the rotating wave approximation (RWA), the Hamiltonian in matrix form is:

$$H = \frac{\hbar}{2}\begin{pmatrix} 0 & 0 & \Omega_p^* \\ 0 & 2\delta & \Omega_c^* \\ \Omega_p & \Omega_c & 2\Delta_{13} \end{pmatrix} \qquad \text{Eq. (3)}$$

where $\delta = \Delta_{13} - \Delta_{23}$ is the two-photon detuning and Δ_{13} and Δ_{23} are the standard one-photon detuning as shown in fig.1. It is visible from fig.1 that the bare ground levels are coupled to the light field so we search for a new set of basis. By diagonalising eq. (3) to the orthonormal basis $|a\rangle, |B\rangle, |D\rangle$ we obtain:

$$|B\rangle = \frac{\Omega_p |b\rangle + \Omega_c |c\rangle}{\sqrt{\Omega_p^2 + \Omega_c^2}} \qquad \text{Eq. (4)}$$

$$|D\rangle = \frac{\Omega_c |b\rangle - \Omega_p |c\rangle}{\sqrt{\Omega_p^2 + \Omega_c^2}} \qquad \text{Eq. (5)}$$

By evaluating the transition matrix elements of the new bases, we find:

$$\langle a|H|B\rangle = \tfrac{\hbar}{2}\sqrt{\Omega_p^2 + \Omega_c^2}\,, \qquad \text{Eq. (6)}$$

$$\langle a|H|D\rangle = 0\,, \qquad \text{Eq. (7)}$$

$$\langle D|H|B\rangle = \hbar\delta \tfrac{\Omega_p \Omega_c}{\Omega_p^2 + \Omega_c^2}\,. \qquad \text{Eq. (8)}$$

Equation (7) shows that there is no dipole transition between $|D\rangle$ and the excited state $|a\rangle$ hence the state is decoupled from the excited state. Also, at two-photon resonance, it is totally decoupled from the state $|B\rangle$. The state $|D\rangle$ is termed the dark state since the population (electron and atom) at that state will not absorb the laser light anymore. It is called the trapped state because the population at this stage cannot exist through the interaction Hamiltonian (H_{int}). As long as the laser light is on, the population will eventually be pumped to the dark state due spontaneous emission (Steck, 2012). The process of creating a medium with completely trapped population is called CPT. The dark state being formed as superposition of the ground states, has a much larger life time.

The Electromagnetically Induced Transparency Theory

The concept of Electromagnetically Induced Transparency (EIT) theory states that if two coherent laser beams is propagate through the same medium neither of these laser beams will be absorbed. An explanation of the concept of EIT using CPT will be explained. Unlike the case of CPT in which the redistribution of atomic population is the main focus, in the EIT process the population is initially in state *b* and remains in the state throughout the interaction. Technically the difference between the two phenomena is that in CPT both laser fields have comparable intensities while in EIT systems the coupling field is much more intense than the probe field $\left(i.e.\,\Omega_c \gg \Omega_p\right)$. This strong interacting coupling field affects the probe field through the atomic system leading to many dynamical and spectroscopically effects (Bernien *et al*., 2017)

Quantum Interference

The Electromagnetically Induced Transparency (EIT) can be viewed as a quantum interference effect when coherent superposition of atomic states inhibits optical transitions via destructive interference under conditions of strong coupling field (i.e $\Omega_c >> \Omega_p$) and the control laser shifts the atom away from the line centre of the AC Stark effect (Lang *et al*., 2020). This can be understood as the creation of new dressed states of the coupled atom-photon system (Wilson *et al*., 2007), where the shift is equal to the Rabi frequency of the control laser. The accompanying absorptions of the probe lasers splits into a classic Autler-Townes doublet and exhibits enhanced transparency at the line centre - a transparency which is now induced by the coherent laser. Thus, EIT can be regarded as modification of the properties of the media by the strong control laser field, while the weak probe field only plays the role of measuring the modification of the medium.

Electromagnetically Induced Transparency (EIT) and Susceptibility of the Media

In the applied EIT system, the transition between the two lower levels is not zero and the system is governed by several decay and decoherence mechanisms. To get a proper description of real EIT systems, we will use the optical Bloch equation (OBE). Using the interaction Hamiltonian for EIT system, we use the OBEs here over the amplitude equation because we want to incorporate damping arising from spontaneous emission of the excited state $\left|a\right\rangle$. Considering this Hamiltonian

and the simplification $\omega_p = \omega_1,\ \omega_c = \omega_2,\ \Delta_{23} = \Delta_2,\ \Delta_{13} = \Delta_1$, we derive the optical Bloch equations:

$$i\dot{\sigma}_{bb} = i\gamma_b\sigma_{aa} - \tfrac{\Omega_1}{2}e^{-i\omega_1 t}\sigma_{ab} + \tfrac{\Omega_1^*}{2}e^{i\omega_1 t}\sigma_{ba}, \qquad \text{Eq. (9)}$$

$$i\dot{\sigma}_{cc} = i\gamma_c\sigma_{aa} - \tfrac{\Omega_2}{2}e^{-i\omega_2 t}\sigma_{ac} + \tfrac{\Omega_2^*}{2}e^{i\omega_2 t}\sigma_{ca} \qquad \text{Eq. (10)}$$

$$i\dot{\sigma}_{cc} = -i\tfrac{\gamma_b+\gamma_c}{2}\sigma_{ab} - \omega_a\sigma_{ab} - \tfrac{\Omega_2^*}{2}e^{i\omega_2 t}\sigma_{cb} + \tfrac{\Omega_1^*}{2}e^{i\omega_1 t}\left(\sigma_{aa} - \sigma_{bb}\right) \qquad \text{Eq. (11)}$$

$$i\dot{\sigma}_{ac} = -i\tfrac{\gamma_b+\gamma_c}{2}\sigma_{ac} - \omega_c\sigma_{ab} - \tfrac{\Omega_1^*}{2}e^{i\omega_1 t}\sigma_{bc} + \tfrac{\Omega_2^*}{2}e^{i\omega_2 t}\left(\sigma_{aa} - \sigma_{cc}\right) \qquad \text{Eq. (12)}$$

$$i\dot{\sigma}_{bc} = \omega_c \sigma_{bc} - \tfrac{\Omega_1}{2} e^{-i\omega_1 t} \sigma_{ac} + \tfrac{\Omega_2^*}{2} e^{i\omega_2 t} \sigma_{ba} \quad \text{Eq. (13)}$$

Here γ_b and γ_c are the population decay rates from the excited states $|a\rangle$ to $|b\rangle$ and $|c\rangle$ Respectively. In order to get rid of the fast oscillating terms, we define a set of slowly-varying quantities as:

$$\hat{\sigma}_{ab} = e^{-i\omega_1 t} \sigma_{ab},\ \hat{\sigma}_{ba} = e^{i\omega_1 t} \sigma_{ba} \quad \text{Eq. (14)}$$

$$\hat{\sigma}_{ac} = e^{-i\omega_2 t} \sigma_{ac},\ \hat{\sigma}_{ca} = e^{i\omega_2 t} \sigma_{ca} \quad \text{Eq. (15)}$$

$$\hat{\sigma}_{bc} = e^{i(\omega_1 - \omega_2)t} \sigma_{bc},\ \hat{\sigma}_{cb} = e^{-i(\omega_1 - \omega_2)t} \sigma_{cb} \quad \text{Eq. (16)}$$

$$\hat{\sigma}_{ii} = \sigma_{ii},\ i = a, b, c\,. \quad \text{Eq. (17)}$$

The OBEs in terms of the slowly-varying variables becomes:

$$i\dot{\tilde{\sigma}}_{bb} = i\gamma_b \hat{\sigma}_{aa} - \tfrac{\Omega_1}{2} \tilde{\sigma}_{ab} + \tfrac{\Omega_1^*}{2} \tilde{\sigma}_{ba}, \quad \text{Eq. (18)}$$

$$i\dot{\tilde{\sigma}}_{cc} = -i\gamma_c \hat{\sigma}_{aa} - \tfrac{\Omega_2}{2} \tilde{\sigma}_{ac} + \tfrac{\Omega_2^*}{2} \tilde{\sigma}_{ca}, \quad \text{Eq. (19)}$$

$$i\dot{\tilde{\sigma}}_{ab} = -i\tfrac{\gamma_b + \gamma_c}{2} \hat{\sigma}_{ab} - \Delta_1 \hat{\sigma}_{ab} - \tfrac{\Omega_2^*}{2} \hat{\sigma}_{cb} + \tfrac{\Omega_1^*}{2} \left(\tilde{\sigma}_{aa} - \hat{\sigma}_{bb} \right), \quad \text{Eq. (20)}$$

$$i\dot{\tilde{\sigma}}_{ac} = -i\tfrac{\gamma_b + \gamma_c}{2} \hat{\sigma}_{ac} - \Delta_2 \hat{\sigma}_{ab} - \tfrac{\Omega_1^*}{2} \hat{\sigma}_{bc} - \tfrac{\Omega_2^*}{2} \left(\tilde{\sigma}_{aa} - \hat{\sigma}_{cc} \right) \quad \text{Eq. (21)}$$

$$i\dot{\tilde{\sigma}}_{bc} = \left(\Delta_2 - \Delta_1 \right) \hat{\sigma}_{bc} - \tfrac{\Omega_1}{2} \sigma_{ac} + \tfrac{\Omega_2^*}{2} \hat{\sigma}_{ba}\,. \quad \text{Eq. (22)}$$

Such simplification can be use as the assumption that the atoms are initially in state $|b\rangle$, $|a\rangle \leftrightarrow |c\rangle$ transition is driven by a strong resonant coupling field while the $|a\rangle \leftrightarrow |b\rangle$ transition is driven by a weak probe field, that is $\Omega_2 \gg \Omega_1$ and $\Delta_2 = 0$. Then the population will roughly stay in $|b\rangle$, and we can vary Δ_1 to obtain the evolution of the system. Choosing $\sigma_{bb} = 1$ and $\sigma_{aa} = \sigma_{cc} = 0$, the steady state solution of the OBE is given by:

$$\hat{\sigma}_{ba} = \frac{\Omega_1}{2\Delta_1 + i\gamma - \frac{|\Omega_2|^2}{2\Delta_1 + i\frac{|\Omega_2|^2}{\gamma}}} \approx \frac{2\Delta_1 \Omega_1}{\left(4\Delta_1^2 - |\Omega_2|^2 + i2\Delta_1 \gamma \right)}, \quad \text{Eq. (23)}$$

where $\gamma \equiv \gamma_b + \gamma_c$ and we have neglected the term $\frac{|\Omega_2|^2}{\gamma}$ since it is small. Neglecting the inhomogeneous broadening, the slowly-varying amplitude of the polarization density for the probe field is given by:

$$P = Nd_{ab}\hat{\sigma}_{ba} = \epsilon_0 \chi \varepsilon, \qquad \text{Eq. (24)}$$

where d_{ab} is the dipole moment for the $|a\rangle \leftrightarrow |b\rangle$ transition, $\chi = \chi' + i\chi''$ is the susceptibility and N is the atom density. Using $\Omega_1 = -2\frac{d_{ab}\varepsilon_1}{\hbar}$ we obtain:

$$\chi' = \frac{4Nd_{ab}^2}{\epsilon_0 \hbar} \frac{\Delta_1\left(|\Omega_2|^2 - 4\Delta_1^2\right)}{\left(4\Delta_1^2 - |\Omega_2|^2\right)^2 + 4\Delta_1^2\gamma^2}, \qquad \text{Eq. (25)}$$

$$\chi'' = \frac{4Nd_{ab}^2}{\epsilon_0 \hbar} \frac{2\Delta_1^2\gamma}{\left(4\Delta_1^2 - |\Omega_2|^2\right)^2 + 4\Delta_1^2\gamma^2} \qquad \text{Eq. (26)}$$

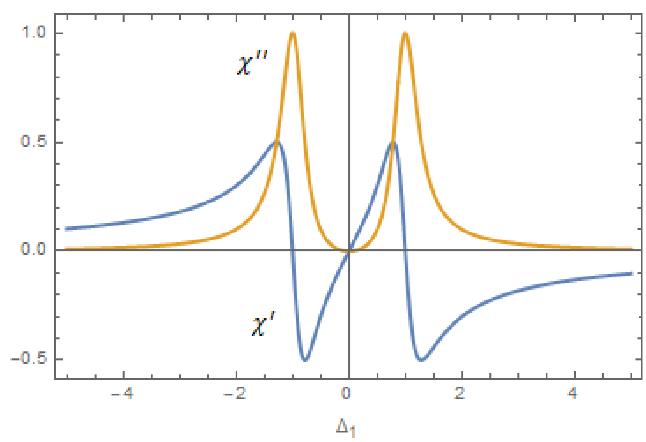


Figure 2: The real and imaginary part of the susceptibility against the detuning values of $\Omega_2 = 2$, $\gamma = 1$ and $k = \frac{2Nd_{ab}^2}{\epsilon_0 \hbar} = 1$.

The real and imaginary parts of the susceptibility as a function of the detuning Δ_1 is plotted in fig.

2. It can be seen that at $\Delta_1 = 0$ (i.e. at two-photon resonance) both χ' and χ'' are zero. The real part of the susceptibility χ' is related to the probe dispersion, while the imaginary part χ'' is related to the probe absorption. Hence, at $\Delta_1 = 0$ there is neither absorption nor dispersion. In simple terms the medium becomes transparent.

Slow Light

A careful look at the plot in fig. 2 of the real part of the susceptibility shows a sharp slope. This sharp slop about the two-photon resonance creates a scenario where the derivative of the refractive index is large with respect to a normal medium. We define the phase and group velocity as:

$$\upsilon_p = \frac{\omega}{k}, \quad \upsilon_g = \frac{d\omega}{dk} \qquad \text{Eq. (27)}$$

where ω and k are the frequency and wavenumber of the light field respectively. In a vacuum, the group velocity and phase velocity are $\upsilon_g = \upsilon_p = c$. For the propagation of a laser in a medium, the phase velocity is modified as:

$$\upsilon_p = \frac{\omega}{k} = \frac{c}{n'}, \qquad \text{Eq. (28)}$$

where $n(\omega) = \frac{ck}{\omega}$. Therefore, taking the derivatives of $n(\omega)$, we obtain:

$$\frac{dn(\omega)}{d\omega} = \frac{c}{\omega}\left(\frac{1}{\upsilon_g} - \frac{1}{\upsilon_p}\right), \qquad \text{Eq. (29)}$$

which yields

$$\upsilon_g = \frac{c}{n' + \omega \frac{dn'}{d\omega}} = \frac{1}{\frac{1}{\upsilon_p} + \frac{\omega}{c}\frac{dn'}{d\omega}}. \qquad \text{Eq. (30)}$$

From this expression of the group velocity, we see that in order to make υ_g significantly different from υ_p strong dispersion (i.e large $\left|\frac{dn'}{d\omega}\right|$) is required. Different types of media exhibit strong dispersion. However, in many of these different media, strong dispersion is associated with absorption. In EIT material, on the other hand, the strong dispersion region coincides with weak absorption.

In order to have an insight into slow light, we can relate the index of refraction to the susceptibility. The index of refraction is given by $n = n' + in''$ and is related to the susceptibility as $n = \sqrt{1+\chi} \approx 1 + \frac{\chi}{2}$). Choosing the real part of χ', we have $n' \approx 1 + \frac{\chi'}{2}$, hence:

$$\frac{dn'}{d\omega} = \frac{1}{2}\frac{d\chi'}{d\omega} = \frac{2Nd_{ab}^2}{\in_0 \hbar}\frac{1}{|\Omega_2|^2} \quad \text{Eq. (31)}$$

Since $\omega \frac{dn'}{d\omega}$ can be significantly larger than one, we obtain:

$$\upsilon_g = \frac{c}{\omega \frac{dn'}{d\omega}} \approx \frac{\in_0 \hbar |\Omega_2|^2 c}{2Nd_{ab}}. \quad \text{Eq. (32)}$$

From eq. (32) we see that υ_g decreases as the intensity of the control field decreases, this provides a key tool to control υ_g. In the experiment [9], the speed of light was decelerated to the speed of a bicyclist (the group velocity was decelerated to 17*m/s*). This is more than seven order of magnitude less than *c* and the group velocity of light was reduced (slowed down) due to EIT. In the current record for slow light in an EIT medium, they slowed down the group velocity of light to 8*m/s* in a warm thermal Rubidium vapour (Budker *et al*., 1999).

Stopped Light

The concept of slow light deliberated in the previous section poses the following question. Is it possible to stop light entirely? From eq. (32), by adiabatically reducing the coupling laser intensity, while the probe laser is inside the atomic sample, the group velocity can actually be brought down to zero. The probe laser then remains spatially compressed inside the atomic medium until the coupling beam is switched on again, which causes the stored probe pulse to be released again. In common terms, stopped light can be explained as follows: first the probe pulse passes through the EIT media while the coupling laser is on. Once all the probe pulse is accommodated inside the atomic medium, turning off the coupling laser will cause the probe pulse to be absorbed completely in the medium. When the coupling laser is turned back on after a period of time, the original probe laser (pulse) will emerge. This effect of stopped light was first observed by Liu (Liu *et al*., 2001). Specht *et al*., (2011) were able to use the approach in coherently storing a single photon in a single atom. Other explanations for storage of light in EIT can be given in the context of spin wave polarization (Fleischhauer *et al*., 2000)

CONCLUSION

The present paper described the theoretical background of EIT and its application in Quantum communication. The formation of a dark state was first examined. The population was later shown to be pumped in the dark state due to the combined probe and control resonant fields. For strong coupling (i.e. when $\Omega_c >> \Omega_p$), the probe laser light was able to pass through the medium without being absorbed. With the susceptibility of the EIT media, light was shown to slow down by adiabatically decreasing the control laser field. In the case when the coupling laser is adiabatically reduced to zero, the probe laser field gets stored (absorbed).

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