# Dynamics of Electromagnetically Induced Transparency in Orthogonal States

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**Abstract**
According to our work, we assert that the dynamics of electromagnetically induced transparency in lambda type atomic system by taking the basics in line with the quantum mechanical aspects. We wonder that incorporating the condition for electromagnetically induced transparency to happen is a meaningful arm to generating a conclusion for a considerable quantum optical system; lambda type atomic system. In this work, mainly quantum interference of light generated from an atomic system has been studied significantly. Accordingly, the mathematical result shows that the quantum interference is due to spontaneous decay rate of the atom from the upper energy state to two ground energy states and sufficiently affects the transparency of the medium. To have such transparency we must have initially the atom in the upper physical state.
**Keywords:** Electromagnetically induced transparency, Orthogonal states, Interference, Light, Lambda system.

## 1. Introduction
In the past several years Electromagnetically Induced Transparency (EIT) have developed into a very active research area and which leads to be taken powerful investigations with a valuable result in the area of quantum optics. Much of these work in the early to mid1990's focused on using EIT for lasing without inversion (LWI). In LWI, EIT suppresses stimulated absorption but not stimulated emission such that when population is injected into the excited state gain is achieved without inversion [1-5].

EIT has also been applied to various precession measurement tasks such as magnetometer [6-9], spectroscopy [10, 11], and improving frequency standards [12]. The value of EIT for precession measurement is due to the fact that the transparency resonance can be very narrow e.g. an EIT line width with a full width at half maximum (FWHM) of 20-100 of Hz is not uncommon [13, 14], making EIT a very sensitive meter for the Raman detuning and any environmental changes which affect it. Other subjects that have been studied in connection with EIT Include coherent Raman scattering [15], four-wave mixing [16-20], generating single photons [15, 21], generating correlated photons [22-24], and number squeezing of optical fields [25].

In addition to the research discussed above there has been a tremendous amount of related work that provides valuable context for our research. Due to the sheer volume of work related to quantum coherence and coherent transients in multi-level systems, our review cannot be comprehensive. We focus on the most important historical developments and those experiments that are closely related to the EIT Kerr effect. In this work we have analyzed the fundamental quantum optical properties of lambda type atomic system at steady state.

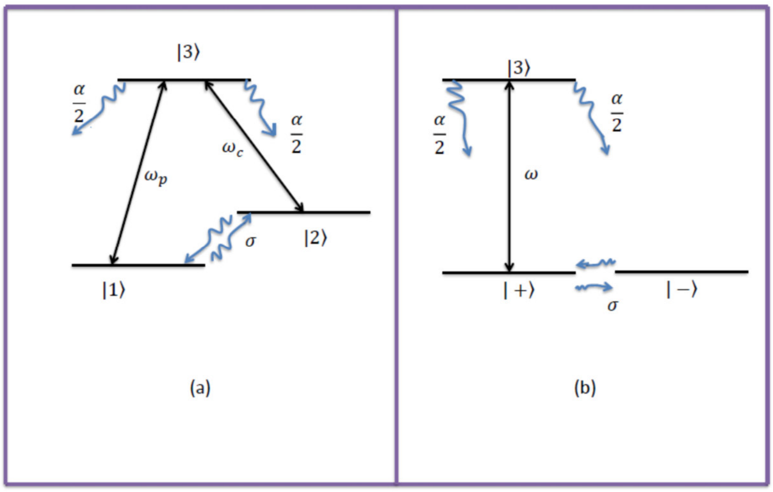


Figure 1.1: A schematic representation of lambda atomic system in physical basis (a) and bright/dark states which shown in (b). To understand the electromagnetically induced transparency (EIT), it is important considering the schematic diagram being created in (b).

## 2. Result and Discussion

Electromagnetically induced transparency (EIT) is the result of quantum interference between multiple transitions to a single electronic state. In order to obtain this interference the initial electronic states must be mutually coherent (i.e. the medium is coherently prepared). Here we consider the lambda type atomic system both the physical basis and bright/dark basis. Our analysis is based on the schematic representation depicted in Figure 1.1. We define the bright and the dark state respectively as

$$|+\rangle = \frac{\omega_p|1\rangle - \omega_c|2\rangle}{\omega}, \tag{1}$$

and

$$|-\rangle = \frac{\omega_p^*|1\rangle + \omega_c^*|2\rangle}{\omega}, \tag{2}$$

where $\omega = \sqrt{\omega_p^2 + \omega_c^2}$, is the bright Rabi frequency, and we call $\omega_p = \mu_p E_p/\hbar$ and $\omega_c = \mu_c E_c/\hbar$ are the probe and coupling Rabi frequencies. The Probe and Rabi frequencies are continuous wave monochromatic fields.
There are two processes moving atoms from the bright to the dark state; optical pumping $R$ and population exchange between ground states $\sigma$. The optical pumping rate from the bright state to the dark state is

$$R = \frac{\alpha\omega^2/4}{\omega^2 + \Delta^2\alpha/\alpha' + \alpha\alpha'} \tag{3}$$

where $\alpha$ is the spontaneous decay rate constant out of state $|3\rangle$, $\alpha' = \frac{\alpha}{2} + \alpha''$ is the transverse decay rate constant and $\alpha''$ is the decoherence due to dephasing (no change in population) with $\Delta$ is detuning frequency. Thus, the total decay rate constant from the bright to dark state would be having the following rate expressions:

$$R_{|+\rangle\to|-\rangle} = R + \sigma/2 \tag{4}$$

There are also two processes transferring atoms from the dark to bright state; non-zero Raman detuning resulting in phase change for the coherence between ground states, and population exchange between ground states $\sigma$. Thus, the rate of population transfer from the dark state to the bright state is

$$R_{|-\rangle\to|+\rangle} = \sigma/2 + \delta_R/R \tag{5}$$

where $\delta_R$ is the Raman detuning.
In balancing the number of atom in the bright and dark state, the number density in the bright state has an expression of

$$N_+ = \frac{NR_{|-\rangle\to|+\rangle}}{R_{|-\rangle\to|+\rangle} + R_{|+\rangle\to|-\rangle}} \tag{6}$$

Anomalous expression for the number density in dark state would be

$$N_- = \frac{NR_{|+\rangle\to|-\rangle}}{R_{|-\rangle\to|+\rangle} + R_{|+\rangle\to|-\rangle}} \tag{7}$$

where the total number density of the atom is $N = N_+ + N_-$, and the absorption of optical field[1] is

$$A = \beta L \propto \frac{\sigma R + \delta_R^2}{R^2 + \sigma R + \delta_R^2} \tag{8}$$

where β is absorption coefficient and L is the length of the medium.
There are two predominant ideas the held by the number density for bright state;

1) The electromagnetically induced transparency condition which is $R > \sigma$
2) If the first condition satisfied and the probe and coupling fields are near single photon resonance, the line shape of the transparency resonance is approximately Lorentzan with a line width of 2R for full width at half maximum (FWHM).

We see that from the figure 1.2, the fundamental transition frequency determines the rate at which the atoms decay from the upper physical state to the lower bright state. As the curves plotted in this figure tells us, the merit idea would be drawn as a conclusion that signifies the dependence of rate on the central resonance frequency. Thus, as this transition frequency increases the rate of atoms decayed from the upper physical electronic level to the resulted bright state increases. It is also trivial to put an idea in line with this figure which says that spontaneous decay of some atoms with decay rate α is the predominant factor affecting the rate on the other hand. Therefore; as we notice from the curves configuration in this figure a sentence come up with a meaningful concept that relates the rate and the spontaneous decay. That is when spontaneous decay of atoms from the upper level to an arbitrary electronic states increases, the resulted rate increases.

[1]Optical fields are incoherent when they have large uncorrelated phase fluctuations.

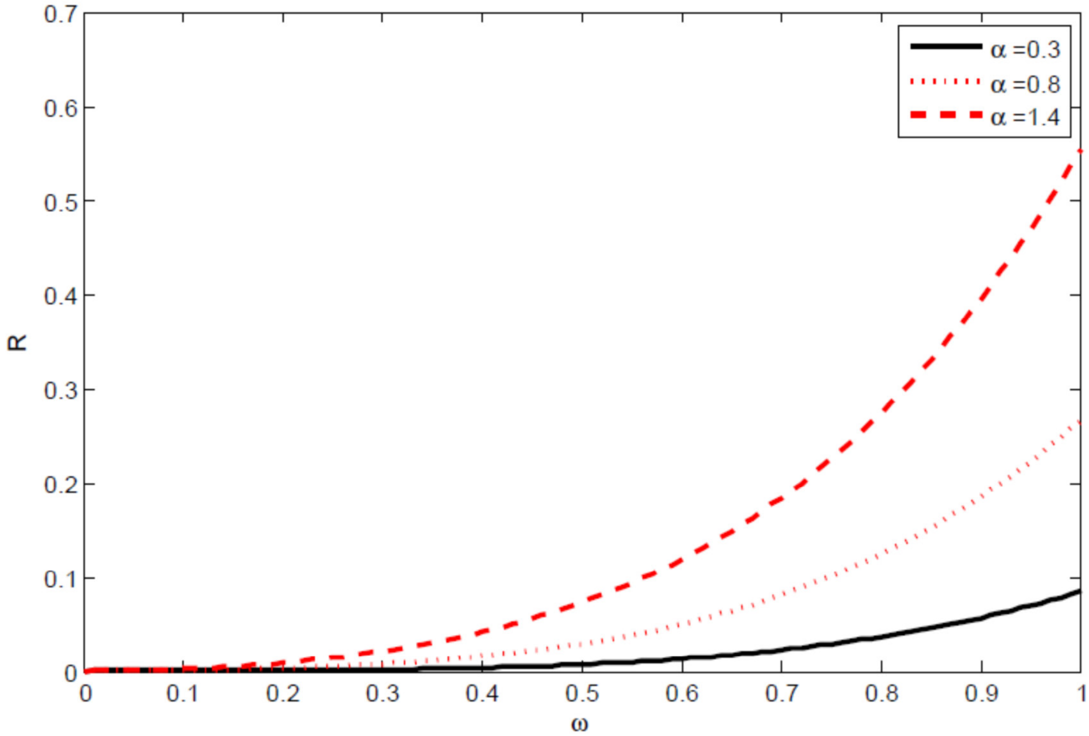


Figure 1.2: plots of the decay rate from the upper physical level to the bright state versus the transition frequency with the detuning frequency ($\Delta = 0.2$), dephasing in the system is considerable as zero ($\alpha'' = 0$), for different spontaneous decay rate [$\alpha = 0.3$ (See the solid black curve), $\alpha = 0.8$ (see the dotted red curve) and $\alpha = 1.4$ (see the dashed red curve)].

For the ground state ($\sigma = 0.4$), the numerical results for electromagnetically induced transparency with the above values would be satisfied for R>0.4. And thus assertions have been made for this quantum phenomenon which observed in lambda type atomic structure with the induced two orthogonal states (bright and dark states).

**3. Conclusion**

This paper gives an assertion for the dynamics of electromagnetically induced transparency in lambda atomic state. In this area of science, this paper contributes the underline points that are an indicator of EIT existence in the selected atomic system. Such phenomena in a microscopic scale cannot be analyzed by the classical point of view because quantum interference is non-classical nature for any atomic system. The system obeys the quantum nature under certain conditions that are needed to lead such features to happen. Not in all case these non-classicality have been affirmed. So that is why we set a boundary for the region of quantum nature and classical annals. In this paper is therefore; for the rate $R > \sigma$ the system retain with transparent but if $R < \sigma$ the system loses its transparency and then its entire dynamics would be predominantly leads by classical nature.

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