Electromagnetically induced transparency with a strong chaotic field

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Electromagnetically induced transparency (EIT) is a reduction of absorption when the upper level of a material transition is coupled to another excited level by a strong resonant field. The EIT is a nonlinear optical phenomenon generally involving quantum interference. The EIT has many potentially important applications. Powerful lasers, required to produce the EIT, often undergo random fluctuations. Whereas the model of a field with a random Markovian phase, which is applicable to single-mode lasers, is rather simple and well understood, the case of powerful multi-mode lasers, the sources of an amplitude-phase fluctuating field, is rather difficult. Recently we developed a theory of the EIT produced by a Gaussian-Markovian amplitude-phase fluctuating (chaotic) field for the cases of strong destructive [1] and constructive [2] interference, i.e., when the material or excited transition is broad and the coupling field is not too strong.

Here we present a comprehensive solution for the EIT with a resonant chaotic field of an arbitrary intensity. We consider also the Fourier transform of the EIT spectrum, $\bar{U}_{aa}(t)$, which determines absorption of a probe field with a time-dependent intensity. The quantity $\bar{U}_{aa}(t)$ has the meaning of a diagonal element of the average evolution operator of an effective two-level system (TLS), closely related to the coupled transition. The problem reduces to the solution of a partially averaged stochastic Schrödinger equation, which has the form of a boundary problem for a system of second-order differential equations. We obtain both the exact numerical solution and approximate analytical results for all important regimes.

We consider first the case when the field is so strong that one can neglect the material relaxation. Paradoxically, this case, though being conceptually the simplest one, is the most difficult one for solving, whereas for nonzero relaxation constants the problem may be significantly simplified [1, 2]. The limits of broad and narrow bandwidths, as well as the transition between them, are studied. In the most interesting limit, when the rms Rabi frequency V_0 is much greater than the field bandwidth ν, we obtain scaling relations for the EIT lineshape and the TLS evolution. In particular, the EIT lineshape is independent on the parameters, its width scaling as $(V_0^2\nu)^{1/3}$. The normalized probe absorption coefficient at the minimum $\bar{A}_{\rm m} = 1.73\nu^{1/3}V_0^{-4/3}$. The function $\bar{U}_{aa}(t)$ performs damped oscillations with the decay rate on the order of $(V_0^2\nu)^{1/3}$. The above results can be extended to a more general case, when, for sufficiently short time intervals, the complex amplitude of the field is approximately a diffusion

(Wiener) process.

Next, the case of nonvanishing relaxation constants is considered. This, in particular, allows one to extend the results of Ref. [1, 2] to arbitrarily strong fields.

[1] A. G. Kofman, *Phys. Rev. A* **56**, 2280 (1997).
[2] A. G. Kofman, *Europhys. Lett.* **46**, 164 (1999).