The Demkov-Kunike model in the coherent magneto- and photoassociation of ultracold atoms

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The Landau-Zener (LZ) model [1] long ago became a standard notion in quantum physics. It describes a situation when two quantum states are coupled by an external field of constant amplitude and a variable frequency which is linearly changed in time. But this situation has some drawbacks; it is unrealistic to have a constant coupling that never turns off or infinite energies at $t \to \pm\infty$. However, there exists a model that has all the virtues of the LZ model and is free from its shortcomings. Such model is the first Demkov-Kunike (DK**)** quasi-linear level-crossing model of a bell-shaped pulse (vanishing at $t \to \pm\infty$) and finite detuning [2]. The DK model can be considered as a a *physical generalization* of the LZ model.

We consider the basic *nonlinear* version of the DK problem relevant to one-colour two-mode photoassociation of cold atoms [3], to sweep across a Feshbach resonance [4] and, generally, to all the bosonic and classical field theories involving a generic cubic Hamiltonian. We investigate the case when the system is initially in all-atomic state. We discuss two limiting cases of the nonlinear DK problem– weak interaction limit corresponding to small peak Rabi frequency, $U_0 << 1$, and strong interaction limit occurring at high values of the maximal field intensities, $U_0 >> 1$. The strong interaction limit is subdivided into two distinct regimes, the large and small detuning regimes [5]. The main peculiarity of the photoassociation process in the large detuning regime is its almost non-oscillatory behavior, i.e., only weak oscillations between the atomic and molecular populations occur. On the contrary, in the small detuning regime the evolution of the system is essentially oscillatory; high-amplitude large-frequency oscillations are observed. In this case the evolution of the molecular state probability can be approximated by the oscillatory Jacobi *sn*-function [5]. It is important to note that in the case of the LZ model the described two different regimes do not reveal themselves, and the dynamics of the molecule formation, under the initial conditions discussed here, always follows the non-oscillatory scenario.

Using an exact third-order nonlinear differential equation for the molecular state probability, we develop a nontrivial version of the strained parameter method which enables us to construct *highly accurate and simple analytic approximations describing time dynamics* of the coupled atom-molecular system in each of the interaction regimes. We show that the approximation describing time evolution of the molecular state probability both in the weak interaction limit and in the large detuning regime of the strong interaction limit can be written as a sum of two distinct terms; the first one, being a solution to a limit first-order *nonlinear* equation, effectively describes the process of the molecule formation while the second one, being the scaled solution to the well-known *linear* DK problem [2] (but now with *modified* parameters), models the remaining oscillations which come up when the process of molecule formation is over. The graphs of the approximate and numerical solutions are practically indistinguishable for almost all the time range.

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