Non-adiabatic transitions in nonlinear quantum systems

A.M. Ishkhanyan, M.V. Hakobyan

Institute for Physical Research, Armenian Academy of Sciences, Ashtarak, Armenia,

e-mail: aishkhanyan@gmail.com

The theory of time-dependent non-adiabatic transitions in nonlinear few-state atom-molecular quantum systems for arbitrary time dependencies of the external laser field variation will be reviewed on the basis of a recently proposed original approach. The approach allows one to eliminate the divergence of the familiar adiabatic and super-adiabatic approximations thus generating a valid approximation accurately description of the behavior of the system in the whole time domain. The approach is straightforward in application and is highly potent to generate compact analytic formulas for the probability of non-adiabatic transitions. Several physical situations will be reviewed. The first example is the Landau–Zener model which is a well appreciated key paradigm of quantum physics. In particular, it is the prototype of all term-crossing models applied in the theory of quantum non-adiabatic transitions, thus being a basic tool for understanding the physics underlying in such processes. For this reason, it serves as a standard reference to be compared with in discussing all other models. We present here a rigorous analysis of several nonlinear versions of the Landau–Zener problem that are currently a subject of considerable interest, both theoretical and experimental, in several occasions, in particular, in the context of cold molecule production in quantum degenerate gases. We start with a version which is the very basic semiclassical variant of a non-linear two-state problem arising in all the nonlinear field theories involving a generic cubic Hamiltonian. In the form considered here, it is faced in the theory of cold atom production in atomic Bose-Einstein condensates via laser Raman photoassociation or magnetic Feschbach resonance, in the second harmonic generation in non-linear optics, etc. For this reason, the variant we treat may pretend to play the same role in the theory of non-adiabatic transitions in non-linear systems as the original model by Landau and Zener plays in the linear quantum theory. Furthermore, several essential generalizations involving nonlinearities of higher order (e.g., the quartic nonlinear case describing the atom-atom, atom-molecule and molecule-molecule elastic scatterings in cold atom association or the Kerr-type nonlinear media in nonlinear optics, etc.). Some applications of developed models to relevant recent experiments will be presented. Finally, we go beyond the Landau-Zener dynamics and consider a different type of highly-oscillatory nonlinear time-dynamics that is not covered by the Landau-Zener model. This discussion involves the Demkov-Kunike model that incorporates the two distinct strong nonlinearity regimes in the theory of nonlinear non-adiabatic transitions. Applications to current experiments will close the discussion.