State Preparation and Measurement in Isolated Quantum Systems with Few Degrees of Freedom

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The preparation of specific nonstationary quantum states with large population transfer is a critical component of many quantum control scenarios. We discuss a simple Hamiltonian model for strong-field control of atomic Rydberg electronic wave packets and the vibrational mode of a diatomic molecule that yields analytic solutions for the electric field required to produce the target wave packet with high fidelity and with a programmable inversion. Not only do such solutions provide insight into the mechanisms of excitation via short optical pulses, including the suppression of Rabi oscillations and population trapping, but also provide an excellent starting point for the more sophisticated methods of optimal control theory.

A complementary aspect of quantum control is the ability to measure the prepared quantum states. Methods for achieving this goal include tomography, spectrography and interferometry. We discuss the application of these techniques to characterizing vibrational wave packets in a diatom, and to the center-of-mass motion of an optically trapped atom, concentrating in particular on the experimental issues that must be accounted for in reconstructing quantum states from realistic data.