

EDITORIAL

Coherent Control

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Guest Editors

Quantum mechanics, though a probabilistic theory, gives a ‘deterministic’ answer to the question of how the present determines the future. In essence, in order to predict future probabilities, we need to (numerically) propagate the time-dependent Schrödinger equation from the present to the future. It is interesting to note that classical mechanics of macroscopic bodies, though reputed to be a deterministic theory, does not allow, due to chaos (which unfortunately is more prevalent than integrability), such clear insights into the future. In contrast, small (e.g., atomic, molecular and photonic) systems which are best understood using the tools of quantum mechanics, do not suffer from chaos, rendering the prediction of the probability-distributions of future events possible.

The field of quantum control deals with an important modification of this task, namely, it asks: given a wave function in the present, what dynamics, i.e. what Hamiltonian, guarantees a desired outcome or ‘objective’ in the future? In practice one may achieve this goal of modifying and finding the desired Hamiltonian by introducing external fields, e.g. laser light. It is then possible to reach the objective in a ‘trial-and-error’ fashion, performed either numerically or in the laboratory. We can guess or build a Hamiltonian, do an experiment, or propagate the initial wave function to the future, compare the result with the desirable objective, and correct the guess for the Hamiltonian until satisfactory agreement with the objective is reached. A systematic way of executing this procedure is the sub-field called ‘optimal control’.

The trial-and-error method is often very time consuming and rarely provides mechanistic insight. There are situations where analytical solutions exist, rendering the control strategies more transparent. This is especially so when one can identify quantum interferences as the heart of quantum control, the essence of the field called ‘coherent control’.

The experience accumulated so far by many groups is that quantum interferences are the mechanism underlying most successful control scenarios and control experiments. The identification of the control mechanism is especially facile when the time-dependence of the Hamiltonian merely serves to prepare a state which then evolves in the absence of external fields. Analytical theories also exist when the explicit time dependence of the Hamiltonian can be treated adiabatically.

Under these circumstances one can identify the quantum interfering pathways that lead to control, allowing for the simultaneous exploration of entire ‘landscapes’ (and not just a single ‘desirable’ objective) resulting from varying all the experimental ‘knobs’ at our disposal, e.g., relative- and envelope-phases, intensities, polarizations, and pulse-sequencing. Such ‘pulse-shaping’ knobs are now available down to the sub-femtosecond regime in broad spectral regions ranging from the UV to the IR.

We expect that comprehensive investigations of the quantum interference required to control dynamical processes will result in a more detailed understanding of the dynamics themselves. Together with experimental progress—the stage is now set for many exciting applications in fundamental and applied sciences by ‘tailoring’ light–matter interactions essentially at will.