A new idea “nugget” from FOCUS:
Control of decoherence in quantum dynamics
Eitan Geva and FOCUS collaborators

Eitan Geva heads a collaboration studying active control of decoherent quantum dynamics. His overall research objectives are the development of general quantum dynamics simulation methodologies, with emphasis on laser drive condensed phase systems; the exploration of general strategies of controlling decoherence via pulse shaping; and understanding the prospects and underlying mechanisms of coherently controlling chemical reactions, and related processes, in solution.


The figure provides a schematic overview of the two systems studied. The upper panel shows a hydrogen (blue) switching reaction between an O-H (red) and a S-H (green) binding sites on a molecule. The switching occurs via tunneling through the barrier separating the two binding sites. The tunneling rate is maximized by turning on a DC field for a prescribed period. The field shifts the levels on both side of the barrier, brings them closer, and thereby resonantly enhances the tunneling rate. Turning it off after the transition is complete locks the hydrogen at the product state. They performed an optimization of the pulse length and amplitude in the presence of dephasing, in order to understand how the latter affects the optimization scheme and whether or not it is possible to perform this process in solution. The answers to both questions are positive, at least under some circumstances.

The lower panel shows the popular STIRAP method for coherently transferring population from one level (1) to another (3). The population transfer is brought about by shifting the energy levels in an adiabatic manner via two subsequent light pulses. They examined this process in the presence of dephasing, and discovered that high-intensity pulses can be used to minimize the destructive attributes of dephasing (see plot on right hand side that shows how the performance with dephasing approached that without dephasing as the field intensifies).

Methodology

The reduced quantum dynamics was modeled by quantum master equations, which were derived from first principles in the presence of a driving field of arbitrary intensity. Unlike standard quantum master equations, the relaxation coefficients in these equations are explicitly dependent on temporal and spectral characteristics of the driving field.

Here is a short list of the main observations:
- Decoherence can be controlled via pulse shaping, by taking advantage of the
field-dependence of the relaxation coefficients.

- Dephasing doesn’t have to be destructive.
- The optimal pulse in the presence of decoherence will be different than in its absence.
- Coherent control in the condensed-phase represents a compromise between steering the coherent dynamics and minimizing the destructive attributes of decoherence.
- The optimal pulse shape can be used as a very sensitive probe of decoherence mechanisms.

In the future, Geva and his colleagues plan to push towards the development of a general quantum dynamics simulation methodology for the analysis of ultrafast coherent control experiments in solution.