Polariton Chemistry: Quantum Control with Cavity Photons

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Seminar Room, Centre Européen de Sciences Quantiques,
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'Polariton Chemistry' opens new possibilities of quantum control, but also presents new challenges. Inspired by recent experiments in optical civities, this talk discusses theoretical work on (i) cavity-modified chemical reactions and (ii) cavity-enhanced exciton transport.

In the first part of the talk, I will introduce the emerging topic of 'polariton chemistry' and discuss recent progress on vibrational strong coupling (VSC). Our transition state theory calculation [1] attributes the modification of reaction rates in the VSC regime to the vibrational frequency shifts, thus explaining the thermodynamic origin of cavity-catalyzed reactions. To go beyond the rate theory, new and complementary mechanisms [2] are proposed to explain the intriguing experimental features in the VSC regime: (1) cooperative quantum tunneling; (2) collective vibrational energy relaxation; (3) cavity-modified intermolecular interactions and emergent molecular order.

In the second part of the talk, I will discuss the effects of various dissipative channels on the wave-packet dynamics of exciton-polaritons: (1) In optical cavities, disordered molecules are coupled to cavity photons collectively to overcome the Anderson disorder and yield a turnover in physical properties at an optimal level of static disorder.[3] (2) Cavity photons can enhance the ballistic time-scale of wave-packet motion by 2 orders of magnitude in the presence of dephasing and lead to noise-enhanced ballistic spreading. [4] (3) Photon leakage induces the coherent-incoherent transition characterized by a turnover in relaxation rate, sign change of group velocity, collapse of wave-packet. [5]

(1) Yang and Cao, JPC Lett 11, 7204 (2021), Quantum effects in chemical reactions under Polaritonic vibrational strong coupling
(2) Cao, JPC Lett 13, 10963 (2022), Generalized resonance energy transfer theory: Applications to vibrational energy flow in optical cavities; Cao and Pollak, JPC Lett. 16, 5466 (2025); Cavity-induced van-der-Waals interactions; Pollak and Cao, JCP 163, 234111 (2025); The effect of an optical cavity on diabatic tunneling in an ensemble of symmetric double-well systems.
(3) Engelhardt and Cao, Phys. Rev. Lett. 130, 213602 (2023), Polariton localization and dispersion properties of disordered quantum emitters in multi-mode microcavities; PRB 105(6), 064205 (2022), Unusual dynamical properties of disordered polaritons in microcavities
(4) Tutunnikov, Qutubuddin, Sadeghpour, and Cao, Commun. Phys. (2026), Noise-enhanced ballistic transport in an optical cavity
(5) Qutubuddin, Tutunnikov, and Cao, arXiv:2507.19671 (2025), Coherent-incoherent transition driven by cavity photon loss.