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Floquet Control of Coulomb Drag and Dispersion Forces in Nonequilibrium Quantum Systems

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Understanding interaction-driven phenomena in nanoscale quantum systems far from equilibrium is essential for describing how spatially separated quantum systems entangle and exchange energy, momentum, and information. In this work, we investigate Coulomb drag and nonequilibrium dispersion forces between two interacting quantum dots, each connected in parallel to its own macroscopic leads. Coulomb drag occurs when carrier flow in one subsystem induces a current in the other purely through long-range Coulomb interactions, while nonequilibrium dispersion forces originate from correlated quantum fluctuations under bias.

We develop a theoretical framework based on the nonequilibrium Green's function (NEGF) formalism, treating electron-electron correlations within the self-consistent second-order Born approximation. The resulting correlation self-energy contains both Hartree and exchange-correlation contributions, enabling us to capture static mean-field effects alongside dynamic nonequilibrium many-body processes.

Our study begins in the static regime, where we compute drag currents and interaction energies as functions of bias, temperature, and intersystem coupling strength. We then introduce periodic driving via an external time-dependent field and employ the Floquet-NEGF theory developed by our group to handle the explicit time dependence. This Floquet representation maps the continuous time domain into a discrete harmonic index, transforming the Keldysh-Kadanoff-Baym equations into a coupled algebraic form in Floquet space.

The resulting Floquet-NEGF method allows us to explore how coherent periodic driving modifies Coulomb drag and reshapes nonequilibrium dispersion interactions. We find that the driving field provides tuneable enhancement or suppression of drag currents and alters the effective interaction profile between the quantum subsystems. Our results demonstrate that Floquet control offers a powerful route for engineering long-range interaction effects in nonequilibrium quantum systems, opening possibilities for dynamically controlled quantum transport, long-range entanglement, and force manipulation at the nanoscale.

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