Fast directed transport via energy recuperation in non-Markovian media

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Recent experimental studies show that driven overdamped Brownian particles can recover energy stored in non-Markovian environments [1]. Using the Generalized Langevin Equation formalism, we demonstrate that energy recuperation is, in fact, an inherent feature of systems exhibiting memory and occurs even in the simplest models, such as a free Brownian particle driven by thermal noise. Moreover, we show that inertial particles can recover energy from their environments even when thermal noise vanishes and without any external forcing. Next, we investigate the influence of energy recuperation on the directed transport of Brownian particles in the presence of energetic barriers. In particular, we demonstrate that the delayed response of the non-Markovian medium to the particle's motion results in the emergence of running solutions, which are absent in analogous Markovian media. The running solutions are qualitatively different from those encountered in viscous fluids in that the particle repetitively reverses the direction of its motion to recover energy from the non-Markovian medium, which enables it to overcome potential barriers. Notably, in our system, the transport in a non-Markovian medium can almost reach the free-particle limit, in contrast to the locked behaviour of particles in a Markovian case. Our findings shed new light on the role of energy exchange between Brownian particles and their environments in transport at the micro-scale, with direct applications to the dynamics of colloids in viscoelastic fluids and intracellular transport.

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[1] F. Ginot and C. Bechinger, Nat. Commun. 16, 10114 (2025)