MAS20-2020-000034

Abstract for an Invited Paper
for the MAS20 Meeting of
the American Physical Society

Nonequilibrium energy transduction in stochastic strongly coupled rotary motors

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Living systems at the molecular scale are composed of many constituents with strong and heterogeneous interactions, operating far from equilibrium, and subject to strong fluctuations. These conditions pose significant challenges to efficient, precise, and rapid free energy transduction, yet nature has evolved numerous biomolecular machines that do just this. What are the physical limits on such nonequilibrium performance, and what machine designs actually achieve these limits? In this talk, I discuss a simple model of the ingenious rotary machine that makes ATP (the predominant portable energy currency of the cell), where one can investigate the interplay between nonequilibrium driving forces, thermal fluctuations, and the strength of interactions between strongly coupled subsystems. This model reveals nontrivial yet intuitive design principles for effective molecular-scale free energy transduction. Most notably, while tight coupling between machine components is intuitively appealing, output power is in fact maximized at intermediate-strength coupling, which permits lubrication by stochastic fluctuations with only minimal slippage.