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Molecular machinery: quantifying the energetic cost of controlling nanoscale biological systems

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At microscopic scales, biological systems must maintain a high degree of organization in order to properly function. Ultimately, this organization is achieved by the concerted efforts of a collection of nanoscale molecular machines, protein complexes that perform specific energy-transduction functions within the cell. Quantifying the flows of energy, information, and material through such systems is a central challenge in understanding their dynamics and *in vivo* operation. What fundamental physical limits are placed on these nonequilibrium systems? What design principles produce efficient machines? I will discuss our recent efforts, using tools from nonequilibrium thermodynamics, to quantify the energetic costs of driving strongly fluctuating systems. In particular, when the controller itself is stochastic (as is the case in molecular machines), dissipation is minimized at a finite speed, implying a thermodynamic benefit to rapid operation.

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