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Modulated optical tweezers as a dynamical tool for stochastic thermodynamics

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Since the development of the first thermal engines, the study of thermodynamics has been extremely important, describing numerous processes on a macroscopic scale involving energy, work, heat, and their exchanges and relationships. Nevertheless, many conceptual open questions existed throughout history and still do today, especially when decreasing a system's size. (1) Despite that, the interest in the field has resurged just in the last decades due to new theoretical ideas and technological developments. One such technology is optical tweezers, as they have become one of the leading and most versatile tools for manipulating micro and nanoscale systems. (2) Our homebuilt setup is simple, consisting mostly of an infrared laser, a high numerical aperture objective, responsible for focusing the laser beam, and an acousto-optic modulator (AOM) to shape the light distribution and control it dynamically. When a microscopic dielectric particle approximates to the focus, it feels an approximately harmonic potential whose parameters (trap stiffness and equilibrium position) can be dynamically controlled over time. Thus, instead of driving a system from one state to another using macroscopic quantities like pressure, volume, or chemical potential, we can control the shape of the optical trapping potential locally and dynamically. Combining high-speed modulation and detection, we can readily explore many interesting features of Brownian particles, using several methods as low and high-frequency modulation, feedback trapping, etc. (3) Currently, we are developing different experimental tests, with colloidal particles, ranging from the verification of Fluctuation Theorems to optimization of protocols for minimal energy dissipation. Using dynamic modulation of the optical potential, we can apply micro and nanoscale tasks, with the possibility of quickly driving the system out of the equilibrium regime.

Palavras-chave: Stochastic thermodynamics. Optical tweezers. Dynamic optical potentials. Acousto-optic modulation.

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