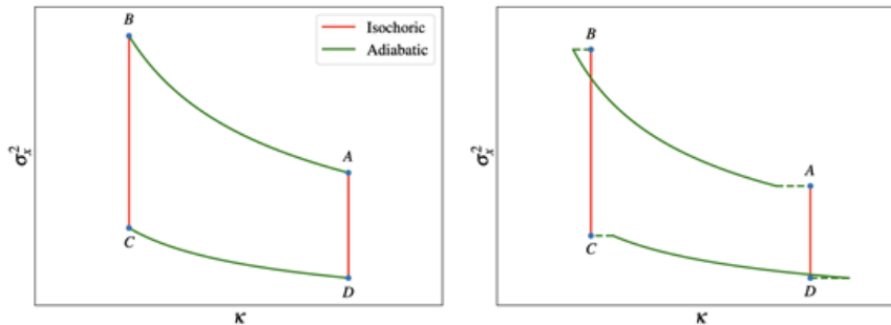


# Power maximization in an Otto engine for a harmonically confined colloidal particle

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The development of stochastic thermodynamics has significantly advanced our understanding of thermodynamic processes in small systems. When we consider mesoscopic systems—characterized by a small number of degrees of freedom in contact with a thermal bath and thus strongly influenced by thermal fluctuations—the traditional description of thermodynamics, which focuses exclusively on mean values, is no longer sufficient. As a result, thermodynamic quantities like work or heat must be defined along individual trajectories in order to properly account for these fluctuations within a stochastic framework. In this context, optically trapped particles constitute an excellent physical platform for designing and experimentally implementing stochastic thermodynamics. These systems allow for precise control over parameters like the trap stiffness. Together with the ability to control the temperature of the thermal bath, they allow the realization of paradigmatic thermodynamic cycles, such as Carnot or Stirling cycles [1,2], at the microscale. In this work, we investigate an Otto-like heat engine based on an overdamped particle confined in a harmonic potential and coupled to a thermal bath. The thermodynamic cycle consists of four branches: two isochoric processes and two adiabatic processes. During the isochoric branches, the stiffness of the trapping potential remains constant, while the adiabatic branches are designed such that the average heat exchange vanishes at all times [3]. We perform a detailed analysis of the finite-time performance of this engine, looking for the maximum power output and its corresponding efficiency. Our results reveal the trade-off between efficiency and power that naturally arises in such systems, and we identify the conditions under which the engine delivers optimal performance: the optimal branches correspond to minimum-time processes. Furthermore, we compare the performance of this cycle with that of an irreversible Stirling cycle implemented under similar conditions. We find that the Otto cycle delivers a higher maximum power than the Stirling cycle, at the expense of a lower efficiency, representing the trade-off between those quantities. Overall, our study provides deeper insight into the design and optimization of microscopic heat engines operating under stochastic dynamics, and contributes to the broader effort of extending Thermodynamics to the realm of small systems and non-equilibrium processes.



Projection of the movement of the state-point onto the  $(\kappa, \sigma_x^2)$  plane for (left) a reversible Otto engine, (right) an irreversible Otto engine. In both panels,  $\sigma_x^2$  is the variance of the position of the particle and  $\kappa$  is the stiffness of the trap; red lines correspond to isochorics and green lines to adiabatics. The dashed segments mark finite jumps in the stiffness at the initial and final points of each of the adiabatic branches of the cycle.

References:

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