Abstract

The central focus of this thesis is understanding small fluctuating active systems, particularly through a thermodynamic perspective. Our approach includes a dual strategy: first, we explore the theoretical and numerical approaches to studying the dynamics of stochastic systems, exploring both Gaussian and non-Gaussian noises. Secondly, we explore the realm of stochastic heat engines to investigate various thermodynamic properties and explore the factors contributing to the enhancement of their performance.

First, we examine the dynamics of a confined overdamped Brownian particle immersed in a thermal bath and subjected to a non-equilibrium bath containing a dilute solution of active particles. Due to confinement, the Brownian particle encounters a harmonic potential. Additionally, it undergoes Poisson shot-noise impulses with a defined amplitude distribution resulting from collisions with active particles within the bath. We derive the stationary solution for the displacement distribution by analyzing the Fokker-Planck equation. We also calculate the moments, including mean, variance, skewness, and kurtosis. Additionally, we calculate an effective temperature using the fluctuation-dissipation theorem and demonstrate the validity of the equipartition theorem for all zero-mean kick distributions, even those resulting in non-Gaussian stationary statistics. In the scenario of Gaussian-distributed active kicks, we observe a transition from Gaussian to non-Gaussian and again re-entry to the Gaussian stationary states with a heavy-tailed leptokurtic distribution across various parameters, consistent with recent experimental findings. Further, we analyze the system's irreversibility by calculating the time asymmetry of cross-correlation functions. In our investigation, we conducted a comprehensive study of the system to lay the groundwork for building a heat engine in the future. We aim to identify the regions where non-Gaussian behavior can be attained and subsequently analyze its impact on engine performance.

Later, we perform an extensive analysis of passive as well as active micro-heat engines with different single-particle stochastic models. Using stochastic thermodynamics, we calculate thermodynamic work, heat, entropy production, and efficiency of passive and active Brownian heat engines through analytical calculation and simulation

techniques and compare both results. We discuss a group of protocols for which exact non-quasistatic calculations can be done, entirely in the passive engine case and partially in the active engines. Then, we summarize our results for a particular protocol. We study the position distributions of the Brownian particle in both passive and active engines. We compare their characteristics in terms of the parameter that measures the competition between the active persistence in the particle position and the harmonic confinement. Our goal is to uncover the correlation between non-Gaussian attributes and efficiency through the computation of excess kurtosis. Our findings indicate that the efficiency of thermal machines can enhanced or reduced based on the activity within the model, and determining the exact cause solely from the excess kurtosis is not straightforward.

Therefore, we further investigate the model of an active heat engine involving Brownian particles in an active bath, resulting in active Poissonian noise. The positional distribution displays a non-Gaussian leptokurtic fat-tailed shape, and we assess its non-Gaussianity through the calculation of excess kurtosis. Our objective is to directly measure a parameter that correlates with the non-Gaussian behavior of the system, establishing a direct link with the excess kurtosis. For this model, we study two different protocols. We calculate exact analytical expressions for work, heat, and efficiency, which further helps to understand many physical insights about the system. Our research reveals that while there is a general trend of increasing efficiency with increasing excess kurtosis initially, but no particular correlation can be established between these two quantities. This indicates that other factors influenced by activity, besides non-Gaussianity and excess kurtosis, contribute to the observed enhanced efficiency.