Report on long-term overseas dispatch

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Abstract

I stayed the laboratory of Dr. Massimiliano Esposito at Université du Luxembourg from July 10th to October 5th, 2015, and researched formulation of small heat engines and efficiency of them. Here, I report my research and life during the dispatch.

Research Background

The hosting researcher, Dr. Massimiliano Esposito, is an expert on foundations of statistical mechanics and complex systems. Especially, he is the world's leading authority on stochastic thermodynamics. Stochastic thermodynamics is the field that extends the notions of thermodynamics, which are originally defined only at the level of ensemble of events, to individual events. The notions newly defined in stochastic thermodynamics enable us to discuss thermodynamic properties of small heat engines subjected to relatively large thermal fluctuations. Around the same time, the community of statistical physics discovered a group of theorems, now known as the fluctuation theorems. The fluctuation theorems quantitatively characterize the asymmetry of the entropy production of systems under time reversal, and are innovative in that they hold as exact equalities in strongly nonequilibrium systems beyond the linear-response regime. Later on, the community formulated fluctuation theorems based on stochastic thermodynamics. In this trend, Dr. Esposito took a crucial role especially in the formulation of fluctuation theorems based on the master equations. In 2014, his group gives rather general results on the asymptotic behavior of the probability distribution of the efficiency of small heat engines based on fluctuation theorems.

Research Contents

I decided my theme during the dispatch by the correspondence with Dr. Esposito via e-mail. The results of his group's on the probability distribution of the efficiency of small heat engines ignore the state change of the engines themselves because it seems to be small. This observation is true when the phase space of the engines is bounded, but not necessarily true when the phase space is unbounded. In fact, van Zon and Cohen analytically demonstrated that effects of unbounded phase space destroy the fluctuation theorem of heat. Since the analysis of the efficiency of heat engines is based on the fluctuation theorem of heat, it is expected that the unbounded phase space gives a qualitatively different probability distribution of the efficiency than the previous results. Therefore, we decided to study effects of unbounded phase space analytically in a concrete model of a heat engine.

We analyze a heat engine of a Brownian particle simultaneously coupled to two heat reservoirs in a translated harmonic potential. A widespread method to analyze thermodynamic of a Brownian particle is to take a so-called overdamped limit, in which the momentum degrees of freedom are assumed to relax to the steady state instantaneously. However, in a system coupled to two heat reservoirs, the ordinary overdamped limit fails to evaluate the heat currents between the system and the reservoirs since it ignore the heat transport due to the momentum degrees of freedom. This is because the momentum degrees of freedom relax to a nonequilibrium steady state in the case of two reservoirs, whereas they relax to an equilibrium state in the case of a single reservoir. Therefore, we sought to systematically construct a novel overdamped limit, which precisely evaluates the heat transfers via momentum degrees of freedom in the case of two hat reservoirs. Our method is based on perturbation theory with respect to the generating function of heat. Our method enables us to calculate the heat transfers much easier than the method without overdamped limit. By our method, we succeeded to obtain the probability distribution of the efficiency of a simple heat engines. However, up to now, we cannot observe any difference of the probability distribution of the efficiency than the previous results.

We plan to write an article about our novel method to take the overdamped limit when a system is coupled to multiple reservoirs by taking into account the heat transfers by momentum degrees of freedom. The title can be “Overdamped thermodynamics with multiple reservoirs: Towards analysis of small heat engines.”

Life during the dispatch

Luxembourg has a land as large as Kanagawa prefecture and a population of 500,000. It shares its boundary with France, Germany and Belgium. The citizens mainly speak French and German. In the capital city, also called Luxembourg, French is spoken more. The hosting laboratory is in Limpertsberg campus of Université du Luxembourg. To walk from the city center of Luxembourg to the campus, it takes about twenty minutes. During the stay, I lived in a dormitory of the university, which is three-minute-walk distant from the laboratory. During the stay, the temperature was lower and the humidity was also lower than Tokyo, and therefore it was better to live in summer. Because Luxembourg has the highest GDP per person, I had a concern about the price of living. Eating out is in fact extremely more expensive than Japan, but food and dairy necessities are not much more expensive but a little more on average. Meats, cheeses and fruits are cheaper, and I really appreciated it when I cooked. The forty percent of the population of Luxembourg are foreigners, and there are people from a lot of different countries. Therefore, the research institute also has researchers and students from variety of countries. It was precious experience for me to have opportunities to speak with them and learn national characters and cultures of a lot of countries.

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