論文内容の要旨

Measurement of the Energy Dissipation Rate in Fluctuating Small Systems

[揺らぐ小さな系におけるエネルギー散逸率の測定]

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In macroscopic systems, thermal fluctuation does rarely appear explicitly except several situations such as opalescence of light through colloidal solution and the color of blue sky or sea. However, as the system size becomes sufficiently small, we can no longer be evitable from thermal fluctuations. The behaviour of the system deviates largely from its averaged one and is no longer predictable. If this is the case, we know the system's behaviour for the first time after some appropriate averaging operations. Recent developments in experimental techniques reveals that a fruitful nature is embedded in such small systems, especially in biological systems. Stimulated by these experimental achievements, several relations such as Jarzynski equality and fluctuation theorems are discovered. They extend the formalism of the conventional macroscopic thermodynamics to fluctuating systems far from equilibrium. These relations are experimentally verified using optical tweezers in colloid suspensions and macromolecules. The equality derived by Harada and Sasa[Phys. Rev. Lett. 95, 130602(2005)] is the recent prominent achievement in nonequilibrium thermodynamics. This equality relates the energy dissipation rate and experimentally accessible quantities such as the correlation and response functions of the velocity in nonequilibrium steady states described by Langevin equations. Although the energy dissipation rate is a principal quantity to characterize nonequilibrium steady states, it is usually hard to measure it in experiments. This equality enables us to calculate it from readily obtainable quantities in experiments. Moreover, this equality implies the direct relation between the energy dissipation rate and the violation of the fluctuation dissipation theorem(FDT), which holds in equilibrium states and is generally violated in nonequilibrium states. Recently, this equality is generalized to non-Markovnian systems described by generalized Langevin equation by Deutsch and Narayan [Phys. Rev. E 74, 026112(2006)]. Interesting and practically important systems often have a retarded friction. For example, molecular machines are working in extremely crowded environment in cells. In such a situation, the non-Markovnian behaviour is expected. Thus, this generalization provides us extensive applications of the equality. In this thesis, we evaluate the energy dissipation rates for an optically driven colloidal particle in nonequilibrium steady states in a viscous fluid and viscoelastic fluid using optical tweezers. Also, we evaluate the energy dissipation rates in an electric circuit consisting of a resistor and capacitor in parallel with an external current. Electric circuits provide us standard test grounds for the study of thermal fluctuations. In these experiments, although we do not observe the explicit FDT violation, we evaluate the energy dissipation rates from experimentally accessible quantities such as the correlation and response functions of the velocity to a fairly good precision for the first time. These results imply the validity of the descriptions by the Langevin equation and generalized Langevin equation of our systems. Moreover, we propose possible candidates for the experimental setups to check the equality in the case that the FDT is explicitly violated. We also demonstrate multiple optical tweezers and one dimensional flashing periodic potential by a spatial phase modulation.