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Nonequilibrium Langevin equation for a particle interacting with spatially extended environment

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The Langevin equation has been a powerful tool for investigating the stochastic dynamics of a particle interacting with a large system, such as Brownian motion in aqueous solvent. However, there is no consensus how the Langevin description is modified for systems driven by an external force. Especially, the fluctuation-dissipation relation (FDR) that connects the friction kernel with the correlation of Gaussian colored noise is not guaranteed in such situation.

In this presentation, we investigate nonequilibrium dynamics of a particle interacting with an environment by introducing a microscopic model in which the dynamics of the environment is explicitly considered. The system under study consists of a particle and an elastic medium that corresponds to spatially extended environment. The elastic medium couples with an external heat bath of temperature T. Keeping a classical particle interacting with the lattice oscillation of a crystalline solid in mind, we propose the simplest model for describing the motion of the particle. For this model, we derive an effective Langevin equation by eliminating the degrees of freedom of the environment. We also calculate the kinetic temperature in nonequilibrium steady states driven by a constant external force.

As a result, it is shown that the FDR recovers in nonequilibrium steady states by replacing the bath temperature T with the kinetic temperature T_{K} if the timescale of dynamics of the environment is much faster than that of the particle. Moreover, we find that the kinetic temperature exhibits qualitatively different behavior as a function of the mean velocity of the particle depending on the relaxation time of the environment (Fig. 1).

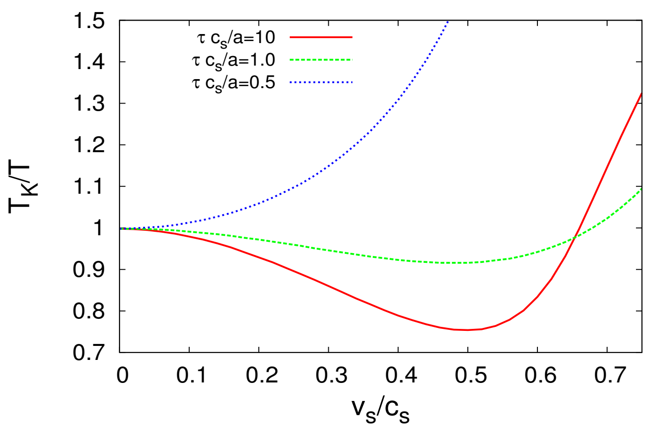

Figure 1: The kinetic temperature as a function of the mean velocity of the particle. τ denotes the relaxation time of the environment. c_{s} and a are the sound velocity of the elastic medium and the size of the particle, respectively.