Nonequilibrium Hydrodynamic Fluctuations Driven by Concentration and Temperature Gradients Across a Transpiration Membrane

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An out-of-equilibrium fluid in the presence of concentration or temperature gradients exhibits long-ranged correlations of its hydrodynamic fluctuations that extend through the bulk of the fluid. It was previously shown that the presence of a transpiration membrane in a quasi-one-dimensional dilute gas suppresses and distorts these correlations [1]. In this talk we extend the previous results to the case of a three-dimensional gas containing multiple species that is driven out of equilibrium by temperature and concentration gradients in the presence of a transpiration membrane. In particular, we focus on the correlations of hydrodynamic fluctuations perpendicular to the applied gradients, and where the transpiration membrane is differently selective to the various species of the gas. A fluctuating hydrodynamics framework, which extends the deterministic compressible Navier-Stokes equations by incorporating stochastic fluxes, is utilized for simulating the fluctuations in these multispecies systems. A numerical scheme is developed for the solving the resulting stochastic partial differential equations on a grid with staggered momenta, where the stochastic, diffusive and advective fluxes are discretized in a second-order accurate manner that satisfies the fluctuation-dissipation balance. The temporal integration of the differential equations is performed using an explicit third-order Runge-Kutta scheme. These numerical methods are initially validated against theory for the simple cases of nonequilibrium single species and binary species gases without a membrane. Thereafter, the transpiration membrane is modeled using a Langevin equation implementation of the fluxes crossing the interface with a given effusion probability.

References

[1] Ladiges et al., Phys. Fluids 31, 052002 (2019)