Active systems: Contribution of interfaces to the bulk stationary states

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Active particles belong to a class of non-equilibrium systems that constantly convert energy into motion, resulting in a continuous dynamic reorganization of the constituents. A fascinating variety of non-equilibrium phenomena like swarming, lane formation, giant density fluctuations, clustering, vortices, etc. has been revealed by a number of synthetic and biological systems. Theoretical models of these systems, apart from the aforementioned novelties, have also been known to show equilibrium-like phenomena such as condensation, phase transition, crystallization etc. Recent research in the field has been towards explaining such behavior in terms of equivalent thermodynamic quantities. We explore properties such as the states of phase coexistence and mechanical pressure[1], interfacial tension[2], chemical potential[3], entropy generation and power dissipation in these out-of-equilibrium systems. Our results show that the coexisting bulk states not only depend on bulk properties but also on the interfacial properties even though the coexisting states are in mechanical and diffusive equilibrium[3]. Our findings relate to conclusions of previous studies which associate the stationary state with strong entropy production at the interfaces[4].

In this study we further explore the effect of an external potential that is localized at the interface of a phase-separated system of Active Brownian Particles (ABPs). In particular, we apply a sawtooth-shaped potential (also known as a Ratchet potential) which is asymmetric. It has been observed in earlier studies that these kinds of setups can induce rectification of the particles[5]. In the case of arbitrarily large bulk regions enclosed by walls, the steady-state densities are dependent on the ratchet potential[6].

We perform numerical calculations for a system of non-interacting as well as interacting ABPs either by directly solving the Smoluchowski equation or performing explicit particle based Brownian dynamics simulations. Our observations indicate that the difference in densities of the bulk regions depends on the parameters of the ratchet potential. For the Active ideal-gas, we establish a power-law dependence with respect to the degree of activity, height of the ratchet potential and the asymmetry. For the interacting system the preliminary results also indicate such a trend with respect to 'effective height' of the ratchet where the effective temperature of the particles is enhanced due to the presence of activity.

These results suggest that unlike equilibrium systems, the interfacial contributions play a major role in active systems to the extent that bulk properties such as the density depends on the arbitrarily far interface.

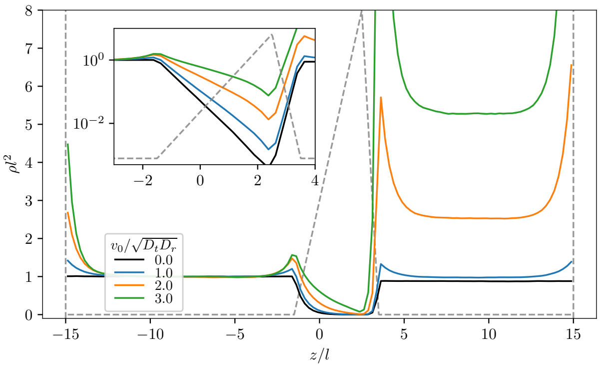

FIG. 1. Density profiles for an Active ideal gas confined in the z-direction by hard-walls. A ratchet potential of height $\beta V = 8$ is applied (shown as grey dashed lines. The resultant stationary state for the passive case (black line) is of equal densities in the two bulk regions to the left and right of the ratchet. Whereas, the active cases ($v_0 \neq 0$) attain different bulk densities depending upon the degree of activity. The inset shows magnified version of the Ratchet region with classical exponential density profiles for a linear external potential.

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