Study of the effect of nonlocal hopping and resetting in asymmetric exclusion process

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by

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Abstract

The totally asymmetric simple exclusion process (TASEP) is a paradigmatic model of nonequilibrium statistical mechanics. It describes a system of particles interacting with each other via hard-core repulsions, undergoing driven diffusive dynamics. The one dimensional version of the model is simple to define and has been used to model various phenomena like mRNA translation, molecular motors and traffic flow. With periodic boundaries, it has been shown that the steady state has a solution with all microstates being equally probable. When the boundaries are open, the model shows interesting behaviour with the existence of three different phases determined by the input and output rates of the particles. Due to its simplicity of definition and non-trivial but well understood phase behaviour, the TASEP has been adapted to model various physical phenomena by varying the particle and boundary dynamics. In this thesis, our motivation is to study the effect of two different kinds of dynamics on driven diffusive systems and we have chosen TASEP as the basic system to study these effects.

In the first part of the thesis, we will describe our results on the effect of nonlocal hopping dynamics on the phase behaviour of driven diffusive systems. Here we considered a model where in addition to the normal TASEP dynamics of moving to the nearest neighbour site, the particle is also allowed to make a long hop all the way to the next unoccupied site before an occupied site. The non-local hopping dynamics is characterized by a parameter p with $p = 0$ corresponding to the usual TASEP. The introduction of finite p in a model with open boundaries leads to the possibility of a new phase called empty road (ER) phase, where the particles clear out of the lattice soon after entry, leading to a zero bulk density. We have studied the full phase diagram in the three dimensional phase space of entry rate α, exit rate β and the nonlocal hopping parameter p. Using numerical simulations and mean field arguments, we studied the transitions between four possible phases; the three usual TASEP phases: low density (LD), high density (HD) and maximal current (MC), as well as the new ER phase. We mapped out the full phase diagram and showed that the ER and HD phases come to dominate the phase space at large values of p. In addition to the open boundary system, we also studied the effect of nonlocal hopping in a system with periodic boundaries and defects. When the defect is static, we see that the long hop dynamics introduces a phase transition into the system between two different kinds of shock

phases, which we have named LD-HD and ER-HD. While the defect always produces a shock between a high and a low density region, the long hop dynamics opens up the possibility of the density becoming zero on the low density side. When the impurity considered is dynamic (one slow particle), we see a transition between a homogeneous density phase and a shock phase. Increasing the value of p increases the tendency of shock formation and we have mapped out the complete phase diagram of the system in the $\mu - p$ space, where the parameter μ is the hopping probability of the slower particle. The mean field approximation works well qualitatively and correctly identifies the possible phases, while the quantitative agreement with numerics varies depending on parameter values.

In the second part of the thesis, we have studied the effect of stochastic resetting to the initial empty state on a TASEP with open boundaries. The problem of resetting in dynamical systems has invited much recent attention. Resetting involves a sudden large change in the state of the system, in addition to the usual continuous dynamics. TASEP being a paradigmatic model is an obvious choice for the study of such dynamical effects on nonequilibrium driven diffusive systems. In addition to this, we are also motivated by mRNA translation where the resetting dynamics models the observed stochastic decay of mRNA-ribosome machinery. Using numerics and approximate expressions of the time evolution of density in TASEP, we studied the effect of stochastic resetting to an initial, empty lattice state on all the phases of the system. We considered two possibilities for the distribution of the time intervals (τ) between successive resets - a power law $\tau^{-(1+\gamma)}$ where $\gamma > 0$, and an exponential distribution $\lambda e^{-\lambda\tau}$. We find that the system achieves a steady-state in the large time limit for $\gamma > 1$ while for $\gamma < 1$ we see a time dependant scaling function. The large time behaviour of density function shows a power-law decay at the boundaries in all the phases except at the HD phase, where it shows a non-monotonic behaviour. For the exponential resetting case, the monotonic behaviour persists and the system always attains a steady state in the long time limit. The results from numerics show good agreement with the theory.