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Reentrant condensation transition in a two species driven diffusive system

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HIGHLIGHTS

- Non-equilibrium steady state of a two species driven diffusive system is studied.
- The two species interact via a coupling parameter between their dynamics.
- System shows reentrant condensation transition as the coupling parameter is varied.

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ABSTRACT

We study an interacting box-particle system on a one-dimensional periodic ring involving two species of particles A and B. In this model, from a randomly chosen site, a particle of species A can hop to its right neighbor with a rate that depends on the number of particles of the species B at that site. On the other hand, particles of species B can be transferred between two neighboring sites with rates that depends on the number of particles of species B at the two adjacent sites–this process however can occur only when the two sites are devoid of particles of the species A. We study condensation transition for a specific choice of rates and find that the system shows a reentrant phase transition of species A – the species A passes successively through fluid–condensate–fluid phases as the coupling parameter between the dynamics of the two species is varied. On the other hand, the transition of species B is from condensate to fluid phase and hence does not show reentrant feature.

1. Introduction

The study of systems driven far from thermal equilibrium, also known as driven diffusive systems (DDS), has been at the forefront in statistical mechanics in the last few decades [1]. These systems have found applications in understanding transport in superionic conductors [2,3], protein synthesis in prokaryotic cells [4,5], traffic flow [6], biophysical transport [7,8], etc. These systems evolve under local stochastic dynamics and in the long time limit reach a non-equilibrium current carrying stationary state. Certain surprising features of these non-equilibrium steady states have generated an overwhelming interest among researchers. For example, these systems may exhibit spontaneous symmetry breaking [9], boundary induced phase transition [10,11], phase separation transition [12], condensation transition [13,14] even in one dimension.

In this work, we discuss reentrant condensation transition in a DDS involving two species of interacting particles on a one dimensional periodic ring. A reentrant phase transition is said to occur if by varying a certain parameter, the system undergoes transition from one phase to another phase and finally reenters the initial phase. Such transitions have been reported in a variety of equilibrium systems, for example in models of spin glasses [15] and multicomponent liquid

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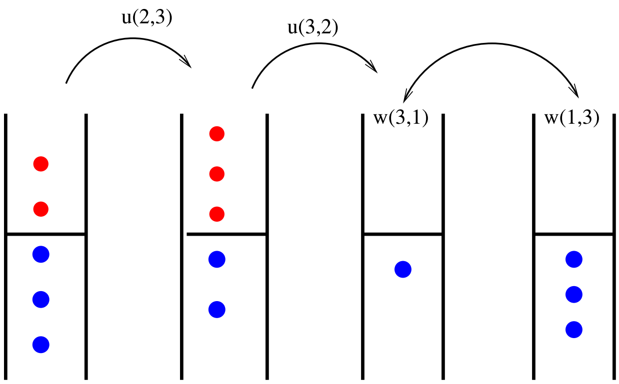

Fig. 1. Dynamics of the two-species box-particle model: The diffusion rate, $u(m, n)$ of species A (red-circles) in general can depend on the number of particles of both the species at that site. Exchange process of species B (blue-circles) can occur only if both the sites are devoid of the species A. The rate of this process depends on the number of particles of the species B at the two participating sites. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

mixtures [16]. Reentrant transition have also been reported in some non-equilibrium systems. For example, Antal and Schütz studied a system of a driven non-equilibrium lattice gas of hard-core particles with next-nearest neighbor interaction in one dimension [17], where for attractive interactions, a reentrant transition between high density (HD) phase and maximal current (MC) phase was observed. A few reaction–diffusion systems [18,19] having a competing dynamics between diffusion and particle interaction have been observed to show a similar reentrant phase behavior –where the transition is from absorbing-to-active-to-absorbing phases. In biological systems, reentrant transitions have been reported experimentally in protein and DNA solutions in presence of multivalent metal ions [20]. Such physical phenomena are vital for understanding biological processes like protein crystallization and DNA condensation. Reentrant phase behavior has also been observed in driven colloidal systems [21] and force induced DNA unzipping transitions [22].

The two species driven diffusive model discussed here was first introduced in [23], where the phase separation transition in a model of reconstituting k-mers can be studied by mapping the model to the two species box particle system. Here we report that this model can show a reentrant condensation transition where one of the species undergoes fluid–condensate–fluid transition when the interaction parameter between the two species is varied.

The article is organized in the following way: In Section 2 we define the model and write down its product measure steady state. In the next section we study the system in the grand canonical ensemble for a specific choice of diffusion rates and show that condensation transition in one of the species show a reentrant behavior. In Section 4 we compare the reentrant behavior of this model with that in some single species models and finally we summarize the results in Section 5 and conclude with some discussions.

2. The model

We study condensation transition in a box-particle model on a one dimensional periodic lattice of L sites or boxes labeled as $i = 1, 2, \ldots, L$ and containing two species of particles, say A and B. At a given site i, let m_i and n_i be the number of particles of species A and B respectively. A typical configuration of the model is represented as $C = \{m_1, n_1; m_2, n_2 \cdots m_i, n_i \cdots m_L, n_L\} = \{m_i, n_i\}$. The dynamics of the model is the following: from a randomly chosen site i, a particle of species A can hop to site $i + 1$ with rate $u(m_i, n_i)$ that in general depends on the number of particles of both A and B. On the other hand, particles of species B can be transferred between two neighboring boxes i and $i + 1$ with rates that depend on the number of particles at both arrival and departure sites. However, in this case there is an additional restriction that the boxes exchanging particles of species B are devoid of particles of the species A. This condition is crucial for explicit factorization of the steady state [23]. Depending on whether a B-type particle is transferred from site i to $i + 1$ or vice-versa, we define $w(n_i, n_{i+1})$ or $w(n_{i+1}, n_i)$ to be the corresponding rates for the dynamics of species B. The above dynamics, also shown in Fig. 1 can be represented in the following way:

$$\{\cdots m_i, n_i;\ m_{i+1}, n_{i+1} \cdots\} \xrightarrow{u(m_i,n_i)} \{\cdots m_i - 1, n_i;\ m_{i+1} + 1, n_{i+1} \cdots\}, \tag{1}$$

$$\{\cdots 0, n_i;\ 0, n_{i+1} \cdots\} \xrightarrow{w(n_i,n_{i+1})} \{\cdots 0, n_i - 1;\ 0, n_{i+1} + 1 \cdots\} \tag{2}$$

and

$$\{\cdots 0, n_i;\ 0, n_{i+1} \cdots\} \xrightarrow{w(n_{i+1},n_i)} \{\cdots 0, n_i + 1;\ 0, n_{i+1} - 1 \cdots\}. \tag{3}$$

Note that the dynamics conserves the total number of particles of each species. In this article we would limit to the situation where $u(m, n) \equiv u(n)$, thus the rate of diffusion of species A depends on the number of particles of species B. Such