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Enhanced fluctuations in driven lattice gases

G. Szabó, A. Szolnoki, Z. Juhász and G. Ódor
KFKI-Research Institute for Materials Science, POB 49, H-1525 Budapest, Hungary

Monte Carlo simulations are performed to study the enhanced density fluctuations in a square lattice gas with repulsive first and second neighbour interactions which is driven far from equilibrium by an external field. Regions with excess particles (and holes) travel (in opposite directions) with a velocity dependent on the concentration. In this steady state the power spectra of current–current correlation functions are proportional to $\omega^{-1/3}$ at low frequencies. This behaviour may be considered as a consequence of the peculiar concentration dependence of conductivity which has a sharp minimum related to the short range ordering.

Phase transitions far from equilibrium are extensively studied in different lattice gas models. The driven lattice gas was first suggested by Katz, Lebowitz and Spohn [1] to study nonequilibrium behaviour in the steady state produced by a homogeneous external field. In these systems the particle hopping is biased by an electric field causing a persistent material transport. In these non-equilibrium systems the observables cannot be determined as averages over suitable chosen Gibbs ensembles although the steady state may be considered as the simplest generalization of thermal equilibrium.

Different lattice gases are investigated by using a large variety of analytical and simulation techniques (for a review see the paper by Schmittmann [2]). In this work we concentrate on a square lattice gas characterized by repulsive first and second neighbour interactions with equal strength. In the fourfold degenerate ground state of this half-filled system the particles form parallel chains, i.e. the rows (or columns) are alternately occupied and empty. In this system the order–disorder phase transition was first studied by Sadiq and Binder [3]. The dynamics of domain growth is also investigated by several authors [4,5]. In the presence of a horizontal driving field the equivalence between the horizontal and vertical directions vanishes and the chains prefer the orientation parallel to the field [6]. In other words, the states with perpendicular chains become unstable or metastable in the driven system below the ordering temperature. Our previous work is limited to weak fields. Here the analysis is extended to strong fields. For this purpose Monte Carlo simulations are carried out on a half-filled 60×60 lattice as described in ref. [6]. We have found a significant increase in the fluctuations of internal energy around the transition when increasing the electric field. Similar anomaly is already observed in other driven systems [7,2].

To visualize the system behaviour we have displayed the time evolution of particle distribution. In the low field limit we have observed a "homogeneous" distribution similar to the equilibrium one. Increasing the electric field the density fluctuations have become conspicuous. In this case one can recognize regions with low and high concentrations travelling in opposite directions. This behaviour may be explained by the concentration dependence of drift velocity, whose role becomes significant at strong fields.

Using computer simulations we have determined the dependence of conductivity on concentration. Fig. 1 shows the conductivity vs. concentration for different reduced temperatures. In the ordered phase (T/T_c $(c=1/2)=0.8$) the conductivity σ has a sharp local minimum at concentration $c=1/2$. Since the conductivity is related to the short range correlation rather than long range order therefore this feature appears above the transition temperature until $T \leqslant 1.75\ T_c$ $(c=1/2)$. According to this figure the drift velocity strongly depends on the concentration. The regions having excess particles travel faster than those with average concentration. The larger the increase of concentration the faster the drift. Due to the particle–hole symmetry the regions of excess holes travel opposite to the field. Consequently, the concentration patterns generated by thermal noise are driven with different velocities. The peaks and valleys can meet and unite before they are spreaded by diffusion. From the above picture one can conclude that this process is responsible for the enhanced fluctuations in the driven systems whose transitions are strongly

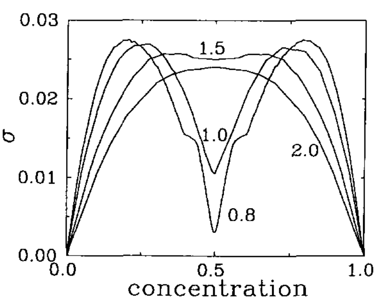

Fig. 1.

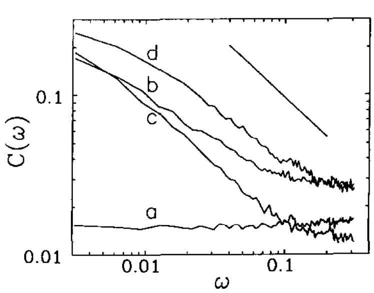

Fig. 2.

Fig. 1. Conductivity vs. concentration for different reduced temperatures as indicated by figures.

Fig. 2. Power spectra of current fluctuations for different driving fields: (a) $E=0$; (b) 0.5; (c) 1.0; (d) 5.0. The straight line indicates the slope of the $\omega^{-1/3}$ behaviour suggested by van Beijeren et al. [8] for a one-dimensional system.

affected by the driving field. The significant modification of the fluctuations may be studied by the traditional noise analysis.

During simulations we have measured the current $J(t)$ summarizing the single jumps over the whole lattice. The sampling time is chosen to be a Monte Carlo step/particle (MCS). Following the notation introduced by van Beijeren et al. [8] we have determined the current–current correlation as a function of time by averaging over 10^6 MCS. In the absence of electric field the current fluctuation is white, i.e. $C(t) \approx \langle \delta J(t)\, \delta J(0) \rangle \propto \delta(t)$ and its power spectrum is constant as represented in fig. 2. In the driven system, however, $C(t)$ does not vanish for finite t. The log–log plots of the power spectra show $\omega^{-1/3}$ character in the low frequency range as demonstrated in fig. 2 for different driving fields. In these power spectra the white noise becomes dominant for sufficiently high frequencies.

The occurrence of $1/f$ noise is not surprising because the Burgers equation [9] of the present problem is similar to those introduced to study the self-organized criticality [10,11]. In our best knowledge the Burgers equation is not yet studied assuming a $\sigma(c)$ described above.

Using a lattice-gas formalism a similar power spectrum was suggested theoretically by van Beijeren et al. [8] in a one-dimensional system with hard-core interaction. In this system the conductivity ($\sigma(c) \propto c(1-c)$) has a local maximum at $c = 1/2$ and the concentration dependence of the drift velocity can lead to a congestion of concentration peaks and valleys. This process results in a current–current correlation similar to the presented one. This qualitative agreement suggests that similar behaviour is expected in those driven systems in which $\sigma(c)$ has either a maximum or a minimum around the average concentration.

The spatiotemporal fluctuations have been studied in other driven lattice gases by several authors [8,12,13]. In the present model the interaction results in an ordering causing a sharp minimum in $\sigma(c)$. The sharp minimum is exhibited by all the lattice gases with repulsive first-neighbour interaction. Unfortunately, in these simpler models the strong electric field can suppress the ordering [14–16]. In the present model, however, the transition is not suppressed because the jumps are blocked along the oriented chains and the electric field cannot affect the ordered structure. This is the property which makes the present model attractive for future study when analysing the effect of strong fields on fluctuations of current or density.

In this paper we have reported that the strong electric field increases the density fluctuations in a lattice gas exhibiting a sharp minimum in the conductivity vs. concentration. In the resulting steady state the current fluctuations are correlated and their power spectra behave like ω^{α} ($\alpha \approx -1/3$) in the low frequency limit.

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