Lane dynamics in a two-dimensional Pair-ion Plasmas: effect of external magnetic field

Swati Baruah[1] and Rajaraman Ganesh[2]
[1] Department of Physics, School of Basic Sciences, Kaziranga University
[2] Institute for Plasma Research
e-mail (speaker): baruah.s1@gmail.com

When driven out of equilibrium, many physical systems may spontaneously exhibit many different kinds of pattern formation which are much richer than traditional phase transitions in equilibrium systems. The detailed behavior of non-equilibrium system that forms patterns may be extremely challenging to predict, and as such is therefore a very interesting field of research. Pattern formation is found on many different length scales and time scales, for example, in molecular systems, geology, the animal kingdom, granular systems, colloids, migrating macro ions, in binary plasmas, in systems of self-propelling particles, pedestrian dynamics, and in army ants. Lane formation [1] is an important representative of non-equilibrium phase transition. Over the last decade, a series of research papers focusing on the effect of the externally applied magnetic field over the particle dynamics has been reported [2]. The pair-ion (PI) plasmas [1, 3] in a magnetic field is unique in that the behavior of such a kind of plasma system in the presence of the external magnetic field in two dimensions (2-D) is largely unexplored.

We focus on a 2-D PI plasma system and explore the lane formation dynamics using Langevin Dynamics (LD) simulation [3], specifically, the influence of an external magnetic field is studied. Our study is based on a plasma model where the ion-ion interaction is described with a screened electrostatic potential characterized by a screening parameter, and the ion-neutral background interaction is described using an overall friction force characterized by a damping factor and a zero-average stochastic collisional term that enables describing the diffusion effect. This model is used to describe the dynamic of a set of N ions subjected to stationary or time varying electric field in a 2-D domain. More specifically, the authors focused on a self-organization effect where the ‘plasma’ is structured as a set of lanes that alternatively contain positive and negative ions in presence of external magnetic field. The phase diagram obtained distinguishing a peculiar lane formation-disintegration parameter space from a study of various Coulomb coupling parameter values. The different phases are identified by calculating the order parameter. This and the critical parameters are calculated directly from LD simulation. The critical electric field strength value above which the lanes are formed distinctly is obtained, a higher value of the electric field strength is required to enter into the lane formation state in presence of magnetic field is observed. The critical value of electric field frequency is found as an increasing function of the electric field strength. Our study also reveals the existence of the electric field drift. Additionally, with the application of an oblique force field the orientation of the lane structures is observed (see, Figure 1). Further, the role of geometric aspect ratio on the stability of lanes is systematically determined, which reveals that the system aspect ratio plays a major role on the lane formation dynamics. This work may be relevant for the understanding of non-equilibrium lane formation phenomena in the naturally occurring PI plasma systems and for their relevance to technological applications that exploit or mitigate self-organization such as in e-ink [4] and microfluidics [4].

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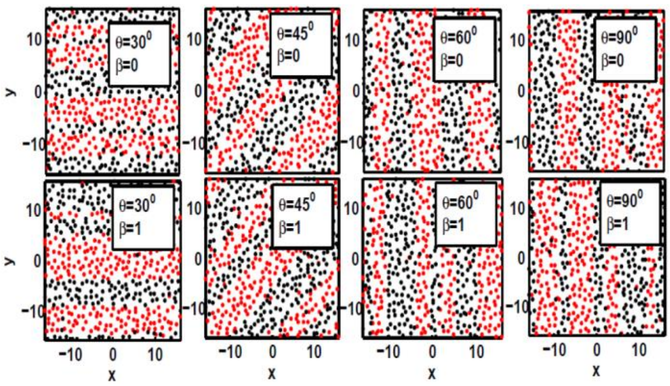

Figure 1: Instantaneous position of particles in the application of constant ($\omega = 0$) oblique electric field taking $\theta = 30^0, 45^0, 60^0, 90^0$ (θ is the angle made by the electric field with the x-direction), external electric force acting on the particles pointing in the Y-direction. This study is performed both in the presence ($\beta = 1$) and absence ($\beta = 0$) of the external magnetic field [2].