7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Diffusive transport of magnetized dusty plasma

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Dusty plasma is a complex plasma system involving electrons, ions, and charged dust particles. In such a plasma system, the size of the dust particles varies from nanometers to microns. The plasma electrons get attached to these dust particles making them highly negative third charge species of the plasma. The charge of these dust particles typically varies from 100e to 10000e, where 'e' is the electronic charge.

The dusty plasma medium turns out to be an ideal system to study strongly coupled behavior of matter. The high charge of the dust species enables them to be pushed into strongly coupled regime (where the coupling parameter is defined as the ratio of inter dust Coulomb interaction potential to their average thermal energy) even at room temperature and with reasonable density of the dust particles. A host of studies on this medium have been conducted to identify the effect of strong coupling on a variety of physical phenomena (e.g. typical electrostatic modes [1] instabilities [2, 3] etc.) have been conducted.

The main focus of this work here is to understand the transport characteristics of the dusty plasma medium in the presence of external magnetic field. These studies have been carried out with the help of an open-source Molecular Dynamics code LAMMPS [4], which involves charge particles dynamics in the presence of external magnetic field. The electrostatic repulsion causes the dust particles to expand. The magnetic field on the other hand confines their motion. It is observed that in the absence of any collisions the dust particles show radial pulsations but remains confined within a certain radius. It is observed that in the presence of dust neutral collisions, diffusive transport gets triggered. A detailed parametric study has been conducted to understand the behavior of the diffusion coefficient as a function of magnetic field B and collision frequency $\nu_{d\text{-}n}$. The diffusion coefficient is found to scale as 1/B when the dust cyclotron frequency is greater than or equal to the dust neutral collision frequency ($\omega_{cd} \geq \nu_{d\text{-}n}$). With respect to the dust neutral collision frequency, the diffusion coefficient scales as $1/\nu_{d\text{-}n}$ for $\omega_{cd} \geq \nu_{d\text{-}n}$, whereas, a $\sqrt{\nu_{d\text{-}n}}$ scaling is observed when $\omega_{cd} < \nu_{d\text{-}n}$. For neutral plasmas a theoretical understanding of the scaling of diffusion coefficient has been provided by Taylor and McNamara [5]. Here on the other hand the simulations have been carried out for the one component dusty plasma, for which a theoretical analysis has been carried out.

The theoretical work has a connection with the deposition of thin films using magnetized plasma device like magnetron sputtering (MS). Particularly, the growth of crystalline microstructure or nanostructure is a critical requirement for numerous applications in nanoscience. In this sense, one can have a similar analogy of nanoparticle deposition using MS. The nanoparticles or crystalline films in plasma creates a dusty plasma environment where they pass through the plasmas in presence of magnetic field. This scenario can be realized as diffusion of nanoparticles across the magnetic field, and it will be studied in a MS device later.

References

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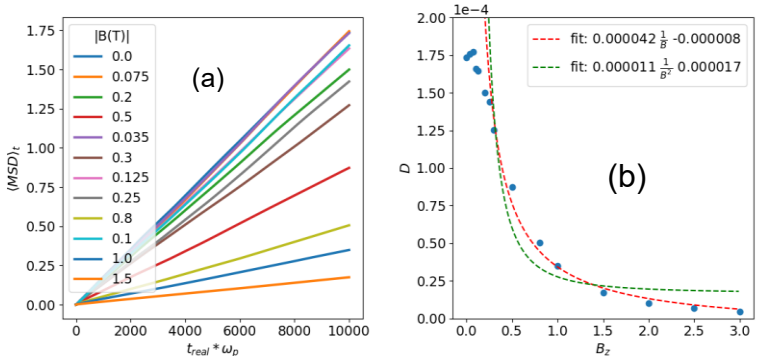

Figure 1. The "Mean Square Displacement (MSD)" of dust particles as a function of time has been shown in subplot(a) for various values of the magnetic field B. The straight lines indicate that the transport is diffusive. In subplot (b) the diffusion coefficient D as a function of magnetic field has been plotted which shows 1/B scaling, The coupling parameters for this case corresponds to a value of 10.