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Structure and Dynamics of Fine Particles in Plasmas with Cylindrical Symmetry: Charge Separation and Formation of "*Screw*"

円筒対称プラズマ中微粒子の構造形成とダイナミックス:電荷分離と「スクリュー」の形成

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Low temperature structures and dynamics of fine (dust) particles in the ambient plasma with the cylindrical symmetry are analyzed by simulations and theory. Fine particles are regarded as Yukawa particles and the one- and two-component cases are considered. In the one-component case, we have well-defined thin concentric cylindrical shells and the structures are expressed by simple interpolation formulas. When we modify the charges on a shell into larger and smaller ones, particles are separated into a smaller shell of larger charges and a larger shell of smaller charges. In the two-component Yukawa system, we usually have structures composed of charge-separated shells which appear alternately in the order of radius. When some charge-dependent force along the axis is applied, shells of different charges can move relative to each other keeping their own structures and the mobility for the relative motion can be defined. Under appropriate conditions, a kind of `*fine-particle (dust) screw*' is formed and the mobility is increased.

1. Introduction

Fine particles in fine particle (dusty, complex) plasmas, mixtures of fine (dust) particles and the ambient plasma, provide us with a possibility to observe strongly coupled charge systems at the kinetic level. A typical example is the formation of dust (Coulomb) crystals. In such observations, those with high symmetry are helpful.

Next to the homogeneous and isotropic systems which are difficult to realize, we have those with spherical or cylindrical symmetry. In experiments on the ground, however, the electric field in the sheath levitates fine particles against gravitation and fine particles form horizontal layers[1]. It is therefore difficult to have spherically or cylindrically symmetric systems.

Long straight discharge chambers under microgravity seem to be one of candidates for such observations with ideal cylindrical symmetry. Recently, systematic analyses of fine particle plasmas in such a chamber are in progress[2]. This apparatus is planned to succeed the highly successful parallel-plate type one in the International Space Station (ISS)[3] and the structure formation has been observed on the ground[4].

We here analyze Yukawa particles in a system with the cylindrical symmetry by numerical simulations and theory. As a model we consider fine particles interacting via the Yukawa repulsion embedded in the ambient plasma (electrons and ions). We assume that the plasma is uniformly distributed in a cylinder of radius R_0 and the overall charge neutrality is satisfied. For Yukawa particles with the negative charge $-Qe$, the background (ambient) plasma works as a source of the confining potential as shown in Fig.1.

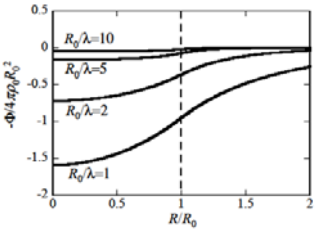

Fig.1. Confining potential

2. Structures of one-component Yukawa systems

We denote the *linear* density of Yukawa particles by n. Regarding Yukawa particles distributed within uniformly, we define the mean distance a and express the strength of screening by $\xi=a/\lambda$, λ being the screening length.

Our system at low temperatures is characterized by two independent dimensionless parameters and we take the set (na, ξ), the degrees of packing and screening. It will be shown that the structure is almost insensitive to the latter when scaled by the mean distance a.

Some examples of the structures are shown in Fig.2 where particles are projected onto the *xy*-plane. Particles are organized into well-defined thin concentric shells. On each shell, particles form a triangular lattice with defects.

With the increase of *na*, the number of concentric shells increases and radii of shells linearly increase with $(na)^{1/2}$, while the spacing between them is almost constant. The surface density σ is almost common except for the innermost shell of radius smaller than a and given by sigma σa^2 ~ 0.352. Structures are expressed by simple interpolation formulas[5].

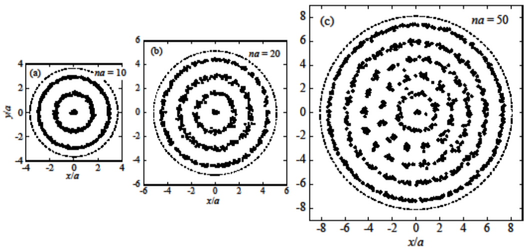

Fig.2. Structure in one-component case (*xy*-plane)

3. Structures of two-component Yukawa systems

The results of our simulations of two-component systems on static structures are summarized as follows. (A) Each shell in the one-component case is separated into the one of smaller radius with larger charges and the one of larger radius with smaller charges. (B) We have shells of one-by-one alternating charges in the order of increasing radius. Some examples are shown in Fig.3.

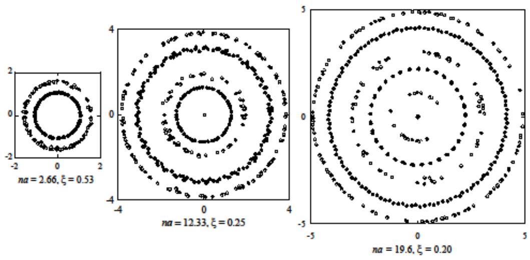

Fig.3. Structure in two-component case: Black (gray) points have larger (smaller) charges.

4. Dynamics of two-component systems: Formation of 'screw'

Among many interesting dynamical aspects of strongly coupled charge systems, we here focus on the relative motion of different species of charges. In strongly coupled systems, there exists a possibility that different components of charges keep their own structures and, at the same time, move relative to other components. This kind of motion may be characterized by the mobility.

The system with the cylindrical symmetry seems to fit particularly the observation of this phenomenon. Examples of relative motions in two-layer system under the axial electric field are shown in Fig.4: Inner shell of larger charges translates relative to the outer shell of smaller charges. The relative velocity increases linearly with the field and described in terms of mobility.

Under appropriate conditions, we observe an increase of the mobility by about a factor 2. At the same time, the structures of shells undergo the change and screw-like structure is formed by two layers as shown in Fig.5. We also observe that two shells rotate around the symmetry axis oppositely to each other seemingly facilitating the relative motion just as usual screws as in Fig.6.

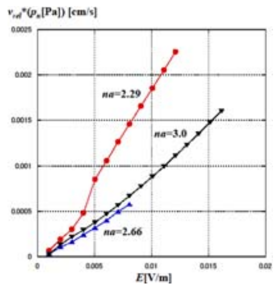

Fig.4. Relative velocity vs. axial electric field

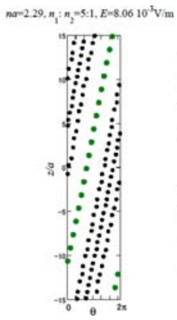

Fig.5. Screw formation

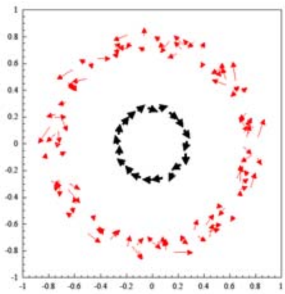

Fig.6. Rotation of screw

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References

[1] H. Totsuji, T. Kishimoto, and C. Totsuji: Phys. Rev. Lett. **78**(1997)3113.

[2] For example, V. Fortov, G. Morfill, O. Petrov, M. Thoma *et al.*: Plasma Phys. Control. Fusion **47**(2005) B537.

[3] H. M. Thomas, G. E. Morfill, V. E. Fortov, A. V. Ivlev *et al.*: New J. Phys. **10**(2008) 033036.

[4] S. Mitic, B. A. Klumov, U. Konopka, M. H. Thoma, and G. E. Morfill: Phys. Rev. Lett. **101** (2008) 125002.

[5] H. Totsuji and C. Totsuji: Phys. Rev. E **84** (2011) 015401(R).