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Modelling of kinetic energy of grain in dusty plasmas

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Here, we study the characteristics of plasma particle kinetics in the presence of moving dust grain (Brownian motion). The estimation of the kinetic energy of grains is one of the most interesting problems in dusty plasmas with different electron, ion and atom temperatures.The results of *ab initio* simulations of dusty plasmas are reported. We use molecular dynamics (MD) and particle in cell (PIC) simulation methods to calculate the mean kinetic energy (temperature) of a dust grain in two temperature plasma. The research of classical Coulomb plasmas by computer simulation showed that the kinetic energy of grains is greater then that corresponding to the ion temperature. The PIC simulation results agree well with MD runs. In the recent papers it was shown that the velocity grain distribution is described by an effective temperature different from those of the plasma subsystem. Computer simulation results confirm this statement. The time scale for the change of the grain kinetic energy is of the same order as that of the change mass. Some results of the present paper were also published in [1-6]).

The next topic is connected with the ion flow. The complete problem of plasma dynamics around a macroscopic body in the presence of plasma flows is highly nonlinear and therefore its numerical analysis is of major importance. Among various numerical methods, direct integration of the equations of motions of plasma particles represents a numerical experiment whose significance approaches experiments in the laboratory. We study by using the MD method the characteristics of grain particle kinetics in the presence of flowing ions around single spherical dust grain [7], two dust grains [8, 9] and rodlike grain [10].

When a supersonic ion flow passes around a negatively charged spherical grain (such a situation can occur when a grain levitates in an electrode plasma sheath), a region with an enhanced ion density (a so-called ion focus) is formed downstream from the grain. The formation, structure, and characteristics of the ion focus were considered in [7]. The grains in the electrode sheath can form ordered structures, and ion focusing can substantially affect the interaction of grains. In this case, the grain interaction cannot be adequately described using potential interaction models (the screened Debye-Huckel potential is most commonly used for this purpose). An example is the influence of ion focusing on the charging of a grain located in the wake generated by another grain [8, 9]. Calculations show that ion focusing produced by the upstream grain can substantially reduce the negative charge of the downstream grain because of the increase in the ion current density. This raises the question as to how ion focusing influences the charging of elongated grains [10].

The next topic is the rotational-translational kinetics of dust grains absorbing ambient gas [11-13]). Although the simple model of the atom-grain inelastic collisions accepted, it demonstrates many interesting features. We confirmed that the translational temperature of the dust component differs from the temperature of the ambient gas. However, we demonstrated that the ‘‘equilibrium’’ temperature is highly sensitive to the details of the inelastic collision. In particular, taking into account the grain mass growth results in appreciable reduction of the dust temperature. It should be noted that the difference between various collisions laws discussed above numerically is very small. The discrepancies in energy balance of the order of a fraction of a tiny mass ratio are accumulated and eventually result in a considerable effect. It is also worth pointing out that the rotational temperature is sensitive even to details of inner structure of a grain.

The simulations of the Brownian kinetics of a single grain were performed in a following way. The computational area was a three-dimensional cube of unit length on edge in contact with the unbounded equilibrium gas. This contact was simulated by point atoms, which were randomly injected inside the cube from all of its faces and could freely leave the computational cell. For each atom leaving the cube, another atom with the random velocity was injected from the random point of the random cube face. The distribution function of the injected atoms was semi-Maxwellian. Since there were no forces acting upon atoms, their trajectories were straight lines.

Various laws of interaction between atoms and dust grains have been used. According to theoretical predictions [1, 12] both translational and rotational temperatures are sensitive to the type of the atom-surface interaction and rotational temperature also depends on the mass distribution inside the grain. The results of numeric simulations are in good agreement with the analytical theory (Fig.1, 2). We confirmed that the translational temperature of the dust component differs from the temperature of the ambient gas. The ‘‘equilibrium’’ temperature is highly sensitive to the details of the inelastic collision. In particular, taking into account the grain mass growth results in appreciable reduction of the dust temperature.

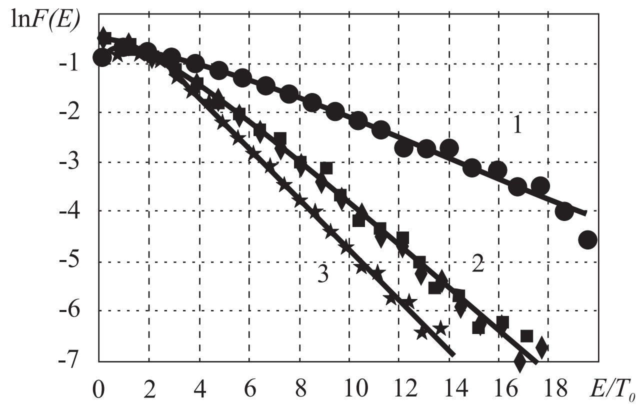

Fig.1. Energy distributions for various kinds of atom-grain interactions. The distributions over kinetic energy are plotted for the cold grain model (●), for the specular reflections (■) and for the absorbing grain (★). The distribution over rotational energy is shown for the case of the absorbing grain (♦). The solid curves correspond to Maxwellian distributions with $T/T_0 = 2$ (1), $T/T_0 = 1$ (2) and $T/T_0 = 4/5$ (3).

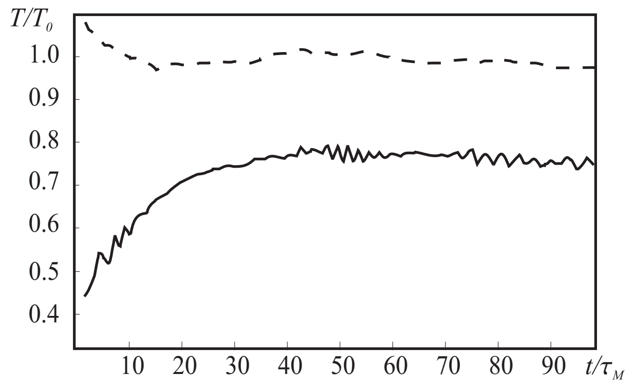

Fig2. Temporal dependence of translational (solid line) and rotational (dashed line) temperatures.

It should be noted that the difference between various collision laws numerically is very small. The discrepancies in energy balance of the order of a fraction of a tiny mass ratio are accumulated and eventually result in a considerable effect.

The important lesson, which may be drawn from our studies of this topic, is that there is no thermodynamic equilibrium between dust and ambient gas. The statement itself is fairly evident since a dusty plasma is an open system. However, this indicates the inapplicability of the fluctuation-dissipation theorem, which is the basement of the Langevin approach to the theory of Brownian motion. Therefore, the problem of deducing the Langevin equation applicable to dusty plasmas arises.

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REFERENCES

1. A.M. Ignatov, S.A. Trigger, W. Ebeling, and P. P. J. M. Schram, Phys. Lett A 293, 141 (2002).

2. S.A. Trigger, P.P.J.M. Schram, J. Phys. D 32 234(1999)

3. P.P.J.M. Schram, A.G. Sitenko, S.A. Trigger, A.G. Zagorodny Phys. Rev. E 63 016403 (2001).

4. A.M. Ignatov, S.A. Maiorov, P.P.J.M. Schram, S.A. Trigger, Bull. Lebedev Phys. Inst. No. 7, 7(2000); No. 6, 3(2001).

5. S.A. Maiorov, Bull. Lebedev Phys. Inst. No. 2, 17(2001).

6. S.A. Trigger, Contrib. Plasma Phys. 41 331(2001).

7. S. A. Maiorov, S. V. Vladimirov, and N. F. Cramer, Phys. Rev. E 63, 017 401 (2000).

8. S. V. Vladimirov, S. A. Maiorov, and N. F. Cramer, Phys. Rev. E 67, 016 407 (2003).

9. S. A. Maiorov, Plasma Phys. Rep., No. 8, 3(2004).

10. S. V. Vladimirov, S.A. Maiorov, O. Ishihara, Phys. of Plas. 10, No 10, p. 3867 (2003).

11. A.G. Zagorodny, P.P.J.M. Schram, and S.A. Trigger, Phys. Rev. Lett. 84, 3594 (2000).

12. A.M. Ignatov, S.A. Trigger, S.A. Maiorov, W. Ebeling, Phys. Rev. E 65, 046413 (2002)

13. S.A. Trigger, Contrib. Plasma Phys. 41, 331 (2001).