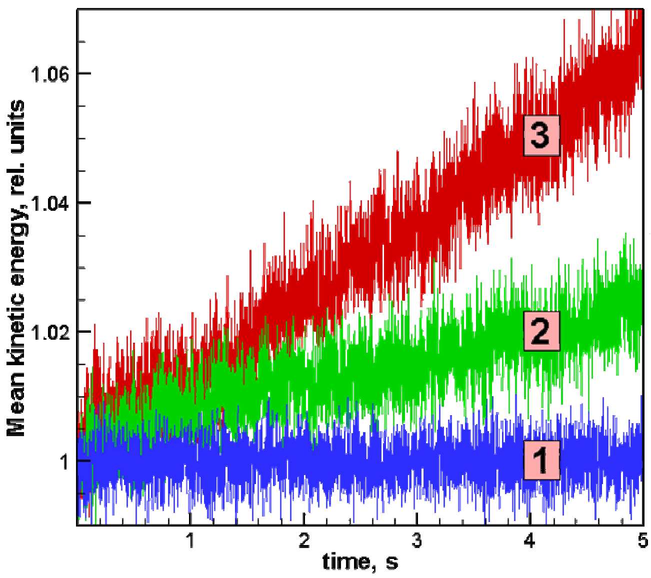
Kinetics of non-Hamiltonian ensembles

Kinetics of particle ensembles with variable charges is investigated. It is shown that the energy of such non-Hamiltonian systems is not conserved in the interparticle collisions. The case when the equilibrium charge depends on the particle coordinate is studied, and the collision integral describing the momentum and energy transfer in collisions is derived. The mean thermal energy exhibits explosion-like growth, diverging at a finite time.

One of the remarkable features distinguishing complex (dusty) plasmas from usual plasmas is that charges on the grains are not constant, but fluctuate in time around some equilibrium value which, in turn, is some function of spatial coordinates[1]. Ensembles of particles with variable charges are non-Hamiltonian systems, because the mutual collisions do no conserve the energy. Therefore, the use of thermodynamic potentials to describe such systems is not really valid. An appropriate way to investigate their evolution is to use the kinetic approach. We studied the case when the equilibrium charge depends on the particle coordinate and derived the collision integral describing the momentum and energy transfer in collisions[2]. From the solution of the corresponding kinetic equation we obtain that the mean particle energy grows in time.



Collisions of particles with neutral gas cause the dissipation which may inhibit the instability. For the particles interacting via the Yukawa potential with the screening length, λ, and weakly inhomogeneous charges, Q (the inhomogeneity spatial scale is $L_Q=|Q/Q'|\gg\lambda$), the condition for the energy growth is that the product of the neutral friction rate $\gamma_{\rm fr}$ and the interparticle collision time $\tau_{\rm coll}$ obeys the inequality:

$$\gamma_{\rm fr}\tau_{\rm coll} \leq (\lambda/L_Q)^2.$$

When the inequality is satisfied, the energy changes as $\propto (t_{\rm cr}- t)^{-2}$, with $t_{\rm cr} \sim (L_Q/\lambda)^2\tau_{\rm coll}$, exhibiting the explosion-like growth. The figure shows the initial stage of the mean energy grows, as obtained from the molecular dynamics simulations. The particle energy (normalized to the initial temperature) is plotted as function of time for different values of the charge gradient: $\lambda/L_Q = 0$ (1), 10^{-2} (2), and 1.5×10^{-2} (3). Of course, the mean energy remains constant without the gradient. For finite L_Q, the energy scales initially as $\propto (\lambda/L_Q)^2 t$, in agreement with the theory. The drift part of the kinetic energy rapidly decreases in the simulations after a few interparticle collisions (at $t < 10^{-1}$ s for this example) and is negligible at later stages. Therefore, the plotted curves actually show the thermal part of the mean energy.

The obtained solutions can be of significant importance for laboratory dusty plasmas as well as for space plasma environments, where inhomogeneous charge distributions are often present. For instance, the instability can cause the dust heating in low-pressure complex plasma experiments and be responsible, e.g., for the melting of plasma crystals, or might operate in protoplanetary disks and, thus, affect kinetics of the planet formation, etc.

References:

[1] V. N. Tsytovich, Phys. Usp. **40**, 53 (1997).

[2] A. V. Ivlev *et al*., Phys. Rev. E (2004, to be published in November issue)

A. V. Ivlev, S. K. Zhdanov, B. A. Klumov, V. N. Tsytovich, and G. E. Morfill