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Transport and Hydrodynamics Phenomena in Non-Ideal Dusty Plasmas

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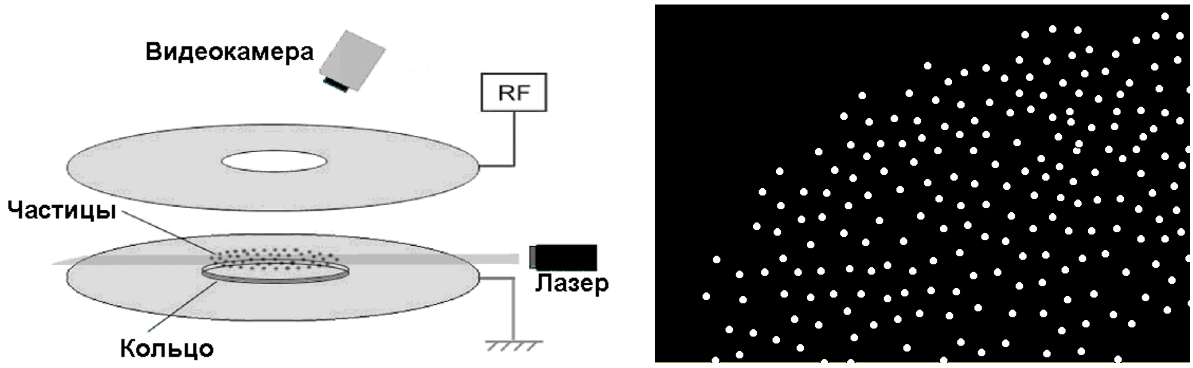
Dusty plasmas consist of neutral gas, ions, electrons, and micron-sized particles (dust grains), typically in the micrometer range. The particles are usually charged negatively in gas-discharge plasmas by collecting electrons and ions. The combined effect of interaction between the particles and the ambient plasma as well as between the particles themselves leads to the formation of various complex plasma states ranging from “gaseous plasma” to “liquid plasma” (or plasma fluid) and “plasma crystals” [1-5]. Since the particles can be visualized and analyzed at the kinetic level, complex plasmas are recognized as valuable model system for the study of phase transitions and other collective processes including transport properties.

In this paper the results of investigation of transport processes such as diffusion of dust particles and formation of dust vortices in the strongly non-ideal dusty plasma of dc and rf discharges are considered. Pair correlation functions, velocity spectra, and diffusion coefficients of dust particles were measured. On the basis of the results of measurements, the concentrations and temperature (kinetic energy of random motion of dust structures) of dust particles were obtained for the regions of dust structures, in which there was no regular motion of dust.

The particles kinetic temperature, number density and the diffusion constant D_L can be measured simultaneously in the dust cloud without any additional external perturbation of the system (just by analyzing video records of particle motions) (for details see [6]). Measurement of these characteristics allows determination of effective dust parameter Γ^* [6,7] from comparison with the results of numerical simulations. Here we assume the Debye-type interaction between particles and estimate the effective coupling parameter Γ^*, using dust diffusion measurements in weakly ionized plasma of gas discharges. The accuracy of this method increases with increasing Γ^*. According to Ref. [7] the error is ~30% at $\Gamma^*\sim 30$ and considerably smaller at $\Gamma^*>50$.

Experiments in an rf capacitive discharge. Figure 1a shows a schematic of the experimental setup for studying the transport characteristics of grains in a dust monolayer formed in an rf discharge. A fragment of the video recording of the dust layer (top view) is shown in Fig. 1b. To prevent the grains from expanding beyond the electrode edges, a ring 2 mm high and 4 cm in diameter was set at the lower electrode. The experiments were performed in argon at a pressure of P = 10–40 Pa. The discharge power was $W \approx 0.5$ W. The dust component consisted of aluminum oxide (Al_2O_3) grains with the mass density ρ=2.4 g/cm^3 and radii a_d = 1-2.5 μm (the average radius was a_d = 1.5 μm, which corresponded to m_d=3.4 10^{-11} g).



(a) (b)

Fig. 1. (a) Schematic of an experiment with rf discharge and (b) the video recording of dust grains in the electrode sheath.

The pair correlation function $g(l/l_d)$ and the time evolution of the diffusion coefficient $D(t)/D_o$ for two different pressures P are shown in Fig. 2. The effective coupling parameter Γ^* deduced from the measurements of the diffusion coefficient varied from 35 to 60. We note that applying the results of three-dimensional numerical simulations to analyzing the effective parameters of a dusty system is not well justified under conditions of this experiment because the observed dusty structures are two-dimensional. At present, no simulation data are available that can be used for the non-intrusive diagnostics of the grain transport characteristics in two-dimensional fluid dusty systems.

Vortex measurements in a dc-glow discharge. The experiment was carried out in a standard dc-discharge tube. A detailed description of the experimental procedure can be found in [4]. Video image of self-excited dust motion (vortex) in the striations of dc discharges is shown in figure 3a. Experiments were carried out in neon (Ne) at pressures in the range P =0.1-1

Torr and discharge currents I ~0.4 mA, with MF particles of diameter a_d=2.02 μm. A digital image of convection in a dust cloud is shown in figure 3b.

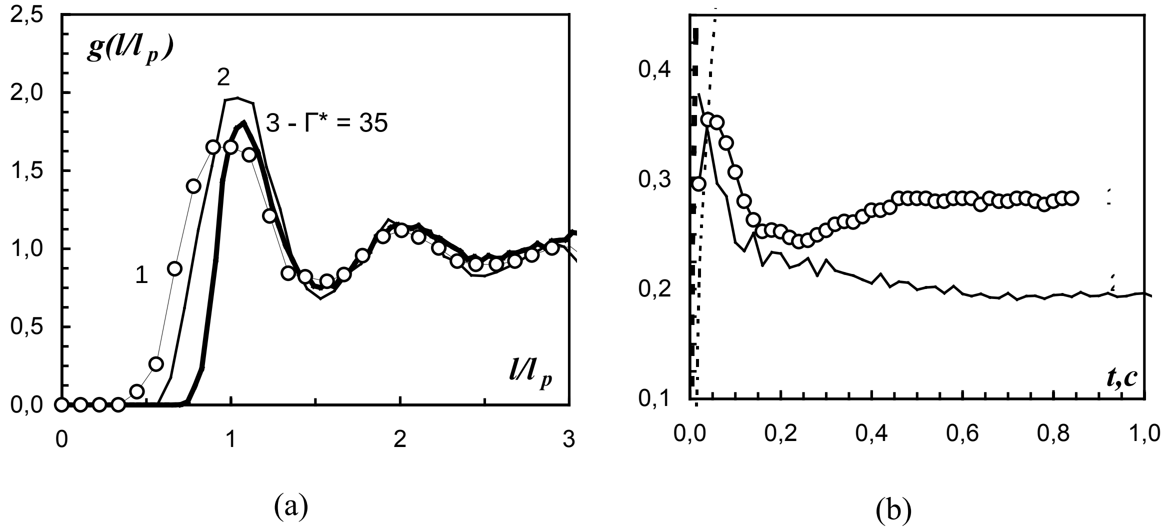


Fig. 2. (a) Pair correlation function $g(l/l_p)$ and (b) the time evolution of the diffusion coefficient $D(t)/D_o$ of grains in a dust mono-layer at pressures P = 40 (*1*) and 10 Pa (*2*). Curve *3* in plot (a) shows the function $g(l/l_p)$ obtained from numerical simulations at Γ*≈35.

The direction of dust rotation shows that radial gradient of the particle charges $\beta_r > 0$ and $\Omega = g\beta_r/(Z\nu_{fr}) > 0$, in accordance with the theoretical analysis [8]. In such a case the particles will move downwards in the center of the dust cloud.

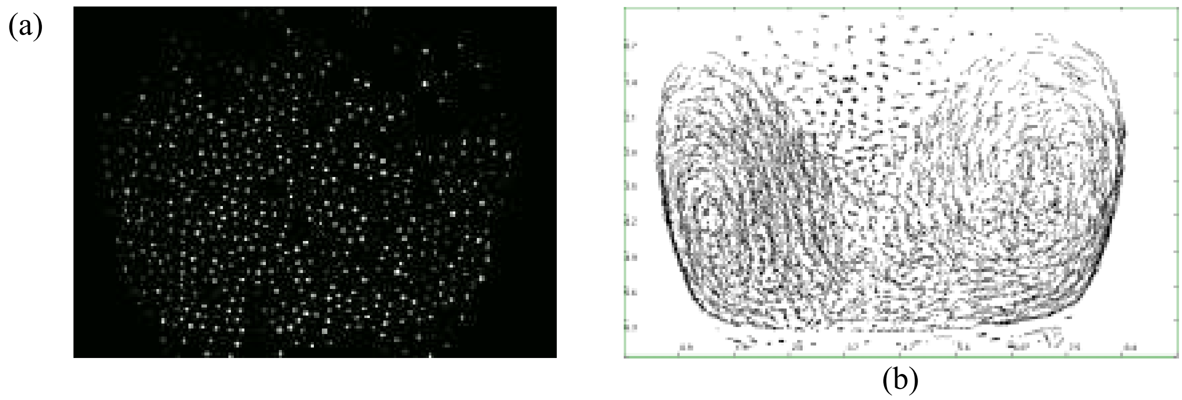


Fig. 3. Self-excited motions of dust particles in the striations of a dc-glow discharge: video image of dust vortex (a) and trajectories of dust particles (b).

An experimental estimate of β_r can be made from the measurement of velocities V=AΩ/2 and the diameter A of dust rotation. Thus we obtain ($\beta_r/Z = 2V\nu_{fr}/Ag \approx 0.01$ cm^{-1} (ν_{fr} (s^{-1}) ≅ 30P (Torr) ≅ 24 s^{-1}, P =0.8 Torr), in accordance with the theoretical predictions (see [9]). The calculated mean kinetic energy of the dust particles (K~4.5·10^{-18} J) agrees with the experimentally measured value. The rotation of dust particles in the upper part of a dust cloud is typical for a dc-glow discharge [5]. These complicated motions can be easily explained on the base only on the assumption of different charge gradients in the various regions of a discharge striation.

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