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Dynamical Phenomena in Dusty Plasmas Under Microgravity Conditions

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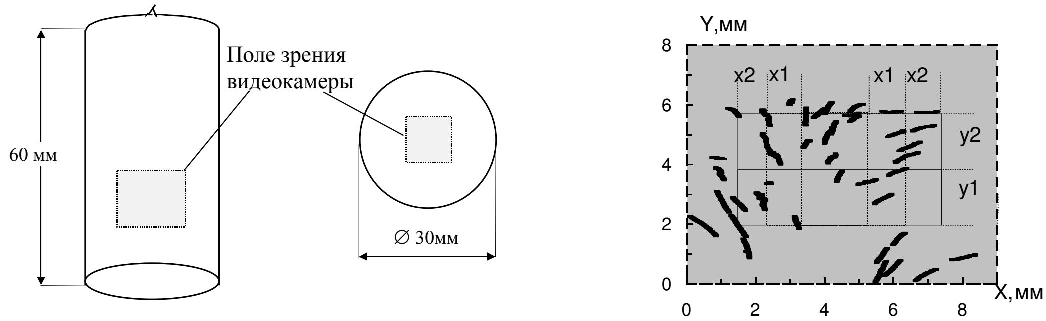
One of basic transport phenomena is diffusion. Diffusion occurs in varios regimes, for example, the Brownian diffusion of macroparticles suspended in a background gas, or the self-diffusion of particles. In this work, results of an experimental study of diffusion of dust particles, charged by photoemission under microgravity conditions are presented. The data were obtained during complex investigations of dusty plasma induced by solar radiation on MIR space station, which have shown that under the action of intensive solar radiation the micron-size particles can acquire considerable positive electric charges [1]. The experimental study of dust diffusion was performed for bronze particles with the mean radii $a \cong 37.5$ μm in background gas (neon) at the pressure $P \cong 40$ Tor. The particles were contained in a cylindrical glass tube, the bottom of which was the uviol window intended for the solar irradiating of dust cloud. Extra irradiating of particles by a laser beam was used for improved diagnostics. The image was registered by a videocamera with the field of view ~ 8x9 mm (see Fig. 1).

The experiments were carried out under the following plan: (1) dynamic action (jolt) on the system with the closed window; (2) exposure in darkness ~ 4 s >> ν_+^{-1} (ν_+ is the frequency of collision of dust with the gas molecules) to reduce of initial dust velocities; (3) irradiating of the tube by solar radiation; (4) relaxation of the particles to the initial state for the time ~ 3-5 min.

The initial dust concentration n_o was varied from 195 to 300 cm^{-3}. The dependencies the relative dust concentration $n_p(t)/n_o$ on the time t are shown in Fig. 2. The photoemission charge of particles was obtained from the approximations of the curves $n_p(t)/n_p(t{=}40\text{s})$ at $t >$ 40 s by the method detailed in [1] and was close to $Z \approx 4\ 10^4$ (±15%). Illustrations of simulation of dust transport due to the mutual Coulomb repulsion of particles by the molecular Brownian dynamic method (curve 1) and its analytical approximation (curve 2), which was used for determining dust charge [1], are presented in Fig. 2 for conditions close to experimental ones. Under the solar action, the dust motion acquired a directed motion forward the tube walls. For a time ~ 3 s after the beginning of solar irradiation, the dust



a) b)

FIGURE 1. The geometry of the glass tube **(a)** and trajectories of dust motion **(b)** after the action of solar radiation.

stochastic kinetic energy is increased, and the interparticle correlation changed. The pair correlation functions of particles obtained by the exclusion of interparticle distances less then $l_p/2$ are shown in Fig. 3. These functions may not be suitable for quantitative analyses of the phase state of dust structure but they are reflected the qualitative changes in the system.

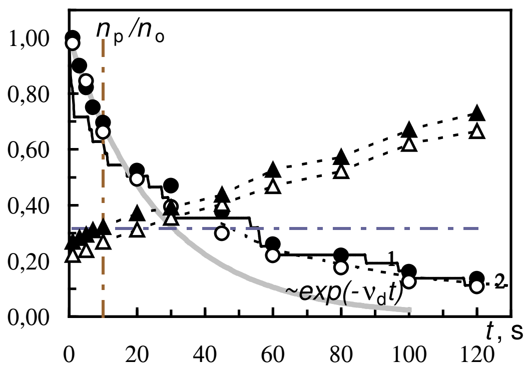


FIGURE 2. Dependencies of relative concentration n_p/n_o (○; ●) and ratio of λ/R (Δ; ▲) versus time t for the different initial concentration n_o: (●; ▲) - 195 cm^{-3}; (○; Δ) - 300 cm^{-3}.

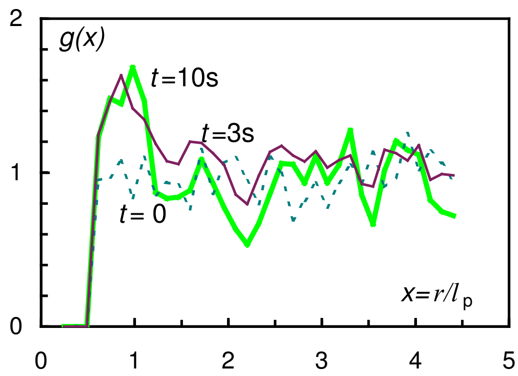


FIGURE 3. Pair correlation function $g(x)$ versus $x = r/l_p$ for several observation time t.

Trajectories of 40 particles (for 5 sec after the beginning of solar irradiation) are shown in Fig. 1b. Irregular fluctuations of velocity (V_x, V_y) of the separate particles on a background of their total drift motion reflect the dust temperature T, which for Maxwellian distribution can be obtained from:

$$T_{x(y)} = m_{+}\{<V_{x(y)}^2> - <V_{x(y)}>^2\}, \quad (1)$$

Here < > is the averaging of velocities on the time, and $<V_{x(y)}> = V_d^{x(y)}$ is the regular drift velocity. Determining of the dust temperature from Eq.(1) for the various experiments gives $T_x \cong 51$ eV, $T_y \cong 22$ eV, within 5%. Similar non-uniform distributions of stochastic kinetic energy ($T_x \neq T_y$) and "abnormal heating" were observed in a number of other dusty plasma experiments and can be related to the temporally-spatial fluctuations of dust charge, for example, due to the random nature of charging currents, or the spatial inhomogeneity of system [2-7].

As the considered system consists of the positively charged macroparticles and the photoelectrons with the density $n_e \sim Zn_p$ emitted by them, it is possible to assume, that the transport properties of this system will depend on ambipolar diffusion of the particles. Because of the large difference of mobility of electrons μ_e and dust μ_+, a negative surface charge appears on the tube walls. The incipient polarization electric field blocks further partitioning of the charged components. Therefore, the electrons and the heavy dust particles can diffuse "together" with some effective coefficient D_a of ambipolar diffusion [8]:

$$D_a = \{D_e\, \mu_+ + D_+\, \mu_e\}/\{\mu_+ + \mu_e\}. \quad (2)$$

Here D_e, D_+ are the free diffusion constants for electrons and particles:

$$D_{e(+)} = T_{e(+)}/\nu_{e(+)}\, m_{e(+)}, \quad (3)$$

where $T_{e(+)}$, $m_{e(+)}$ and $\nu_{e(+)}$ are the temperature, the mass and the frequency of collisions with the neutral gas molecules for electrons and dust, respectively. Then, in the case of $\mu_e >> \mu_+$, the ratio of diffusion constants can be represented in the form:

$$D_a/D_+ \approx 1 + ZT_e/T_+ \quad (4)$$

With the measured temperatures (T_x , T_y), the ratios of diffusion constants can be estimated as $D_a/D_+^{x} \approx 0.8\text{-}1.6\ 10^3$, and $D_a/D_+^{x} \approx 1.8\text{-}3.6\ 10^3$ for $T_e = 1\text{-}2$ eV.

In a plasma with the density n, the diffusion have a ambipolar character when $\delta n = |n_e - n_+| << n \approx n_e \approx n_+$. For cylinder with the radius R, it is valid for $\delta n/n \approx (\lambda/R)^2 << 1$, where $\lambda^2 = T_e / 4\pi e^2 n_e$ [8]. Taking into account that $n_e \approx Zn_p$ we have $\delta n/n \approx 2.1\text{-}6.4\ 10^{-2}$ for the considered initial conditions $n_p = n_o$ under the assumption of $T_e \cong 1\text{-}2$ eV. The dependencies of λ/R on time are shown in Fig. 2 for $T_e = 2$ eV.

Assuming that for $\delta n/n < 0.1$ the losses of charges in our experiments are connected with their ambipolar diffusion to the ampoule walls, the area of ambipolar diffusion can be determined from the mean velocity of diffusion losses of macroparticles

$$dn_p/dt = -\, n_p\, \nu_d, \quad (5)$$

where $\nu_d = D_a/\Lambda^2$ is the frequency of diffusion losses, and Λ is some diffusion length [8]. For cylinder with the radius R and the height ~ $4R$, the value of $\Lambda \approx R/2$. The value of ν_d can be obtained from the experimental curve $n_p(t)/n_o$ at $t < 10$ s, where the $n_p(t)/n_o$ function agrees well with the solution $n_p = n_o\exp(-\nu_d t)$ of Eq.(5) for $\nu_d \approx 0.0135$ s^{-1} (Fig. 2). Then, an estimate of ambipolar diffusion gives $D_a \approx 2\ 10^{-2}$ cm^2/s.

The free diffusion constants $D_+^{x(y)}$ can be retrieved from the measurements of dust temperature, and drift velocity $V_d^{x(y)}$:

$$D_+^{x(y)}(t) = \{<\Delta r(t)^2> - (V_d^{x(y)}t)^2\}/2t, \tag{6}$$

where $<\Delta r(t)^2>$ is the mean-square displacement of separate particles in the direction of axis OX (or OY). Thus, the values of free diffusion constants can be estimated as $D_+^x \approx 1.3\ 10^{-5}$ cm^2/s and $D_+^y \approx 5.7\ 10^{-6}$ cm^2/s. The value of ratio $D_+^x/D_+^y \approx 2.28$ agrees very well with the measured dust temperature, and both the measured ratios $D_a/D_+^x \approx 1538$, and $D_a/D_+^x \approx 3509$ are in agreement with the theoretical prediction (4).

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REFERENCES

1. V.E. Fortov, A.P. Nefedov, O.S. Vaulina *et al*, JETP **87,** 1087 (1998).
2. O.S. Vaulina, A.P. Nefedov, O.F. Petrov, ad V.E. Fortov, JETP **91,** 1063 (2000).
3. O.S. Vaulina, S.A. Khrapak, A.P. Nefedov *et al*, Phys. Rev. E **60**, 5959 (1999).
4. R.A. Quinn and J. Goree, Phys. Rev. E **61**, 3033 (2000).
5. V.V. Zhakovskii, V.I. Molotkov, A.P. Nefedov *et al*, JETP Lett. **66,** 392 (1997).
6. H. Thomas and G. Morfill, Nature **379**, 806 (1996).
7. A. Melzer, A. Homann, and A. Piel, Phys. Rev. E 53, 2757 (1996).
8. Y.P. Raizer, *The Physics of Gas Discharge* (Berlin: Springer Verlag, 1991).