NUCLEAR-INDUCED DUSTY PLASMA: SIMULATION OF THE FORMATION OF LIQUID LIKE DUST STRUCTURES AND THE GRAINS CHARGING

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The objective of this paper is to produce dynamic ordered dust structures in a nuclear-track plasma created by nuclear-reaction products in inert gases and to carry out computer modeling of the processes that lead to their formation.

Investigations of the behavior of dust grains in a plasma created by nuclear-reaction products provide new information on the self-organizing abilities of the dust in the plasma. The dusty plasma differs considerably in properties from other plasmas [1-9], the primary difference being that it is strongly inhomogeneous in space and highly unsteady in time. In a nuclear-track plasma, a dust grain is affected by the flows of drifting electrons and ions that are cylindrically symmetric in structure (the symmetry axis being parallel to the propagation direction of an ionizing particle). Because of diffusion, the electron and ion flows spread out in the radial direction; simultaneously, because of a difference in the electron and ion diffusion coefficients, the radii of the electron and ion cylindrical flows increase to a far greater extent. As a rule, the dust grains acquire a negative electric charge, because the electrons are much more mobile than the ions. The ion flows efficiently discharge the grains. The external electric fields of both the dielectric walls of an experimental device and its electrodes can substantially redirect the drift flows of plasma particles.

The experimental device in which we observed the formation of levitated dust structures consists of an ionization chamber with horizontally oriented parallel electrodes. The chamber was filled with neon at a certain pressure. Dust grains were injected through a hole in the upper electrode into the interelectrode space, in which the external electric field was created. The role of the radioactive source was played by a 7-mm-diameter plane layer of $^{252}$Cf at the lower electrode. The numerical results presented below were obtained for the experiments condition under which we observed vortex structures (Fig.1).

We apply the Monte Carlo (MC) method to calculate the time dependence of the charge of dust grains in a nuclear-track plasma that decays under the action of an external electric field into the flows of electrons and ions drifting toward the oppositely charged electrodes. We show that, since the grain
charge is alternately affected by electron and ion flows, it fluctuates strongly about a value smaller than that typical of a quasineutral plasma. The mean values of the grain charge agree with those measured experimentally.

**Fig. 1.** Evolution of a cloud of Zn dust grains. The photographs were taken (a) 2 min, (b) 4 min, (c) 4 min 30 s, and (d) 4 min 45 s after the injection of the dust. The upper electrode was held at a potential of 152 V, the distance between the upper and lower electrodes was 3.5 cm, and the neon gas pressure was 570 torr. Each photograph corresponds to an observational area of 4.2x3.1 cm². The main directions of the dusty grains local motions in the regions I, II, III, IV are shown by related arrows.

Dynamic vortex dust structures in a nuclear-track plasma were simulated using the standard method of molecular dynamics (MD). This method usually assumes calculations for a finite number $N$ of particles in a cell of size $L$. In order for the computations to take a reasonable amount of time on available computers, we restricted our simulations to $N = 200–1000$. Accordingly, in order for an MD cell to capture the characteristic dust structure, the linear cell size was chosen to be equal to $L = 100r_D \approx 3$ cm, which approximately corresponds to our experimental conditions. Note that such a small cell size, as well as a smaller number of dust grains in comparison with that in the experiments, substantially relaxed the requirements on computational resources and made it possible to reduce the run time of the code to about ten hours. Let us note that general behavior of the dynamic vortex dust structures does not
depend on the number of particles in MD cell for large enough particle number (200 -1000). We modeled levitated dust grains in an electrostatic trap with the potential derived in [2]. The characteristic potential at the chamber wall was varied in the range from 0.5 to 3 V. The z-axis was directed downward, i.e., along the direction of the gravity force. The initial spatial distribution of dust grains and their initial velocities were specified with the help of computer-generated random numbers, distributed uniformly within the interval from zero to unity.

**Fig. 2.** Schematic representation of a thin layer of the vortex dynamic structure obtained using the method of molecular dynamics under the assumption that the forces acting upon the grains are potential. Each part of the grain trajectories calculated at three successive times is shown by three successive arrows. The black and gray arrows refer to the grains moving downward and upward, respectively. The radioactive source is at the center of the bottom of the frame.

Figure 2 shows parts of the grain trajectories inside a planar vertical axial layer of small radial thickness. The trajectories were calculated at three successive times. The arrows indicate the direction of the grain motion. The physical cause of the onset of dynamic vortex structures is the dependence of the charges of both dust grains and the device walls on the distance from the source. In fact, let us consider a grain located near the upper electrode, in which case the grain’s negative charge is small because its distance from the source is large. Under the action of the gravity force, which exceeds the electrostatic force of attraction toward the upper electrode, the grain starts falling
downward, i.e., toward the lower electrode. In such motion, the grain charge, first, decreases and, then, begins to increase. A downward moving grain experiences increasingly strong radial fields of the dielectric walls, whose charge, in turn, increases near the radioactive source. The radial forces bend the grain trajectory and cause the grain to move toward the device axis and toward the radioactive source at the axis. On the other hand, as the charge of the grain increases, it is affected by the increasingly strong upward-directed electrostatic force of the positively charged upper electrode. Because of inertia, the grain passes the equilibrium position and its charge continues to increase until the electrostatic force becomes larger than the gravity force. The grain begins to move upward, keeping its radial velocity component unchanged, until the gravity force becomes larger than the electrostatic force. Then, this cycle of the grain’s motion repeats itself. As a consequence, most of the grain trajectories are very similar in shape to the infinity symbol. In the axial region of the device, the grains move predominantly upward, while, in the peripheral region near the walls, the grains fall downward. As a result, a dynamic vortex structure forms that consists of dust grains rotating in the same direction as the vortex structures observed in our experiments.

References