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Kinetics of flowing plasma around rodlike particles

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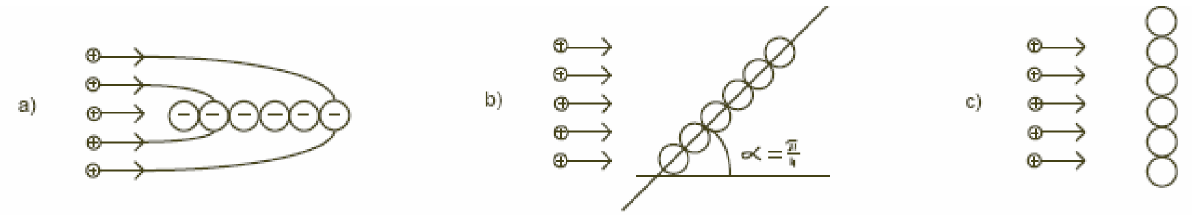
In the present paper, the charging of elongated grains is studied numerically for the first time using the particle method. At present, such grains are extensively studied experimentally, whereas theoretical studies of their properties are rather scanty (see recent papers [1, 2]; some results of the present paper were also published in [3]).

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 [4]. An example is the influence of ion focusing on the charging of a grain located in the wake generated by another grain [5]. 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.

The formation of a space charge around an elongated grain in a plasma flow is studied. In this case, ion focusing substantially influences the space charge distribution around the grain and, accordingly, the density of the current of charged plasma particles onto the different parts of the elongated grain varies. The charging of a chain of micron-size grains that are in contact with one another and are immersed in a plasma flow is investigated numerically using the particle method. Such a chain of grains simulates an elongated grain. The cases of highly conducting and nonconducting grains are considered.

Here, we study the characteristics of plasma particle kinetics in the presence of flowing ions around rodlike stationary dust grain aligned in the direction of the ions flow and with angle $\pi/4$ or $\pi/2$ (orthogonal to flow direction). The problem was studied by using a three-dimensional molecular dynamics simulation method. The dynamics of plasma electrons and ions as well as the charging process of the rodlike dust grain are simulated self-consistently. Distributions of electron and ion number densities, and the electrostatic plasma potential are obtained for various position of rodlike dust grain in ion flow, including parallel, orthogonal, and sharp angle. The cases of dielectric and metallic rodlike dust grains are analyzed.

The method for studying the properties of dusty plasma by numerically integrating the dynamic equations for many particles is described in detail in [4, 5]. This method is here adapted to solve the problem of the interaction of plasma with an elongated grain. The simplest method (from the standpoint of its implementation) is to represent a grain as a chain of spherical particles. Assuming the charge of each spherical particle to be uniformly distributed over the particle surface, we reduce the problem to a usual scheme of solving the set of equations of molecular dynamics. The inaccuracy of this model lead to the loss of information about the charge density distribution over a length nearly equal to the grain radius. Because of the charge averaging over the particle surface, the ion and electron trajectories near the surface cannot be determined exactly. In addition, the effect related to a geometrical factor arising when an elongated cylindrical (rodlike) grain is replaced with a chain of spherical grains also can be of importance. When calculating the parameters of charging, it seems reasonable to choose the sizes of spheres such that the cylinder volume would coincide with the total volume of the spheres. However, at this stage of our study, we are interested in a qualitative character of the charge distribution over an elongated dust grain, rather than in the exact determination of the charging parameters of a rodlike grain in plasma. Therefore, this model seems to be quite applicable to our problem.



We consider a system of Coulomb particles consisting of mobile point particles (ions and electrons) and immobile spheres with 1 μm diameter. The ions have a mass *M* and positive charge e. The electrons have a mass m and a negative charge *-e*. We consider the case where the positions of all spheres are fixed; the spheres have the same radius *R*, and absorb all the electrons and ions arriving at their surfaces. Accordingly, the charge of a sphere is determined by the number of the absorbed electrons and ions and depends on time.

Here, we present the results of numerical simulations of a two-temperature argon plasma flow with $z = 1$, an ion temperature of $T_i = 0.025\ eV$, electron temperature of $T_e = 1$

eV, and ion density of N_i = 2 x 10^{12} cm^{-3}. The plasma flow velocity on *x* direction corresponds to an ion kinetic energy of $K_i = 1\ eV$.

The table summarizes the integral characteristics of a chain of spherical grains made different materials and angle with flow α: the time-averaged total charge of the chain of grains in units of the electron charge, the time-averaged total ion flux to the grains normalized to the flux of the unperturbed plasma flow $J_0 = \pi R^2 N_i (2K_i / M)^{1/2}$, the time-averaged surface potential of the chain. φ_s normalized to the electron temperature, dipole moment along flow $P_x = \sum xq$, normalized on $P_0 = eN_i^{-1/3}$ and orthogonal to flow direction $P_y = \sum yq$. The surface potential averaged over six grains is taken at a surface potential of the chain of dielectric grains. For comparison, the charging characteristics of an isolated grain of the same size under similar conditions are also presented (run No 7).

No	σ_s	α	*-Q/e*	J/J_0	$-e\varphi_s/T_e$	$\langle P_x/P_0 \rangle$	$\langle P_y/P_0 \rangle$
1	0	0	3157	125	3.08	9084	-118
2	0	π/4	3242	251	2.80	11090	1485
3	0	π/2	3199	187	2.80	11580	330
4	∞	0	3087	51	2.61	7301	3
5	∞	π/4	3159	246	2.74	10410	1165
6	∞	π/2	3220	192	2.83	11980	255
7	Single sphere		1214	9	3.02	239	-10

The results of calculations have demonstrated two new interesting effects for α=0 (run No 1, 4): the influence of ion focusing on the character of charging of elongated grains and the dependence of the charging process on the conductivity of the grain surface. Strictly speaking, for the surface to be equipotential, it is not necessary that the grain be highly conducting (metal). A finite (even rather low) conductivity can be quite sufficient to ensure the equipotentiality of the grain surface.

The total grain charge for metal and dielectric grains differs only slightly (it is higher by 2% for dielectric grains); however, the character of the charge-density distribution over the grain changes radically. Nearly one-half of the charge of a dielectric grain is concentrated at its forward end; downstream from this region, the charge density substantially decreases in magnitude and can even change its sign. This is explained by the fact that the ion flow is focused onto this part of the grain and the electron flow is reduced there because of the geometrical factor. As a result, a dielectric grain possesses a considerable dipole moment, which can substantially influence its stability and can lead to the onset of oscillations [2, 6].

Another interesting feature is that the plasma flux onto a dielectric grain is higher than that onto a metal grain by a factor of about 2.5 at approximately the same total grain charge (see table), because the accumulation of charge at the forward end of a dielectric grain results in a stronger ion focusing onto its tail.

The results of calculations for $\alpha= \pi/2$ (run No 3, 6) have demonstrated no effects the influence of ion focusing on the character of charging of orthogonal to flow rodlike grain and the independence of the charging process on the conductivity of the grain surface.

The similar situation is for the results of calculations for $\alpha= \pi/4$ (run No 2, 5). It also have demonstrated no effects the influence of ion focusing on the character of charging of orthogonal to flow rodlike grain and the independence of the charging process on the conductivity of the grain surface. Interesting feature of this configuration is that significant dipole moment orthogonal to flow direction $P_y = \sum yq$ arises. As result, interesting interplay of interactions of the rodlike grain with plasma and themselves and these interaction affects on the equilibrium positions and orientations of the rodlike grains [6].

Simulations by the model developed in this paper are the first numerical experiment on studying the electric characteristics of elongated dust grains in the ion flow of an electrode sheath. In spite of the simplifying assumptions adopted here, the simulation results make it possible to clarify the character of charging of elongated grains.

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