BACKGROUND ELECTRONS AND IONS IN RELAXING DUSTY PLASMAS

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1. Introduction

Dusty plasmas are statistical systems with variable numbers of particles due to a collection of background electrons and ions by dust particles which can be considered as some specific boundary distributed over the entire dusty plasma. In the general case, such non-stationary systems have to be non-equilibrium because the probabilities of all processes providing a change of particle numbers in systems depend on particle energies. In particular, a selective collection of electrons and ions by dust particles depending on electron and ion energy can provide a non-equilibrium dusty plasma [1-3].

Of course, there are processes balancing a non-equilibrium of these systems but the selective probabilities indicated above exist always and therefore some relaxation phenomena have to appear also always in non-stationary systems with variable numbers of particles, in particular in dusty plasmas. These relaxation phenomena are especially of interest in dusty plasmas in the case of a strong mutual influence of dust particles which takes place in plasma crystals investigated intensively during recent times.

Computer modeling allows to investigate non-equilibrium dusty plasmas. This paper consists of results of detailed numerical investigations of relaxation phenomena in dusty plasmas in the case of a strong mutual influence of dust particles. These investigations were carried out taking into account the charge dynamics of dust particles without the assumption of equilibrium electrons and ions. Some results of these investigations were published in [3].

2. Model

Some 2D square crystals initially consisting of motionless neutral dust particles of radius R_d and background equilibrium electrons and ions with initial densities n_o and temperatures T_{eo} and T_{eo} are considered. Dust particles with a density n_d are separated by some distance d between the centers of these particles. Relaxation phenomena start after the start of an interaction of electrons and ions with dust particles (collection and collisions). Collisions between electrons and ions are not taken into account, because the relaxation time is less than the electron-ion collision time, owing to the choice of plasma parameters.

Of course, there is some square crystal cell around each dust particle. A periodic structure of the crystal gives on boundaries of this cell some periodic boundary conditions which provide an equality of all parameters in corresponding points of these boundaries.

The modified 2D PIC method [13] is used for the modeling of relaxation phenomena. A crystal cell around some dust particle is divided into square simulation cells where electrons and ions are presented by large macroelectrons and macroions of a corresponding square cross-section. These macroparticles are collected by a dust particle if trajectories of their centers cross a surface of this dust particle. Macroparticles can cross opposite cell boundaries simultaneously as a result of the influence of neighboring crystal cells. Poisson's equation is solved using the Fourier transform method with periodic boundary conditions.

3. Results

Typical obtained results are shown in Fig. 1-6 for a dust crystal with $d = 1 - 10$, $R_d = 0.2$, $(T_{eo} / T_{io}) = 10$ where spatial coordinates and all line sizes are normalized by an initial Debye length $\lambda_d = \left(kT_{eo} / 4\pi n_o e^2\right)^{1/2}$, and time t is multiplied by a initial ion plasma frequency $\omega_{io} = \left(4\pi n_o / M\right)^{1/2}$.

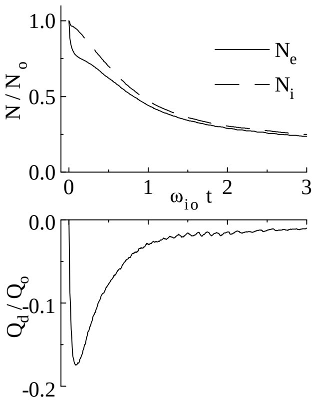

Fig. 1.

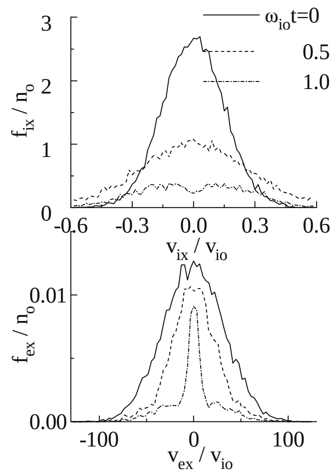

Fig. 2 .

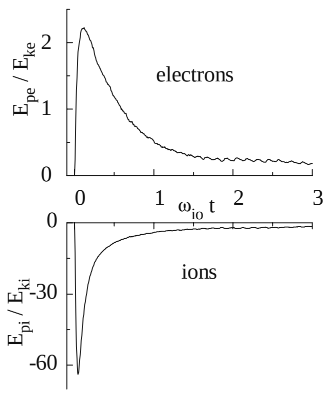

Fig. 3.

As can be seen from the top part of Fig. 1 obtained for a crystal with $d = 1$, the total number of electrons N_e and ions N_i in a crystal cell decreases monotoneously due to their collection by the corresponding dust particle, i.e. a dusty plasma relaxation takes place. This decrease is stronger for electrons at first due to a more intensive electron flux which charges the dust particle negatively. The temporal evolution of a dust particle charge Q_d is shown in the bottom part of Fig. 1 where $Q_o = en_o / n_d$ is an initial ion charge in the crystal cell. This charge increases sharply at first and therefore the electron flux decreases then, so that the ion flux exceeds it, and the charge Q_d decreases after having reached some maximum value.

The dusty plasma relaxation is accompanied by an essential change of electron and ion velocity distribution functions. The mean v_x depended functions are plotted for some times $\omega_{oi} t$ after a relaxation start in Fig. 2. Corresponding v_y depended functions were identical. As can be seen from Fig. 2, an electron velocity distribution function f_e is impoverished by fast electrons during a relaxation contrary to an ion velocity distribution function f_i which is impoverished by slow ions. This evolution is a result of a selective collection of electrons and ions by a dust particle with a negative charge Q_d, like [6,7].

Corresponding to the evolution of electron and ion velocity distribution functions, the plasma relaxation is accompanied by a change of mean potential (E_p) and kinetic (E_k) energies of electrons and ions. A time evolution of the ratio of these energies E_p / E_k is shown in Fig. 3 for electrons and ions. As can be seen from this figures, this ratio grows quickly after the relaxation start and is much larger than unity during some time. It means that electrons and ions are non-ideal components of relaxing dusty plasmas during this time although their initial number in the Debye cube is much larger than unity and these electrons and ions have to be an ideal gas without dust particles. The indicated non-ideality of electrons and ions is caused by a change of dust particle charging accompanying any change of plasma parameters for example in some oscillations or waves.

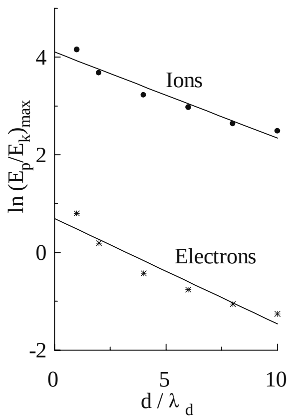

Fig. 4.

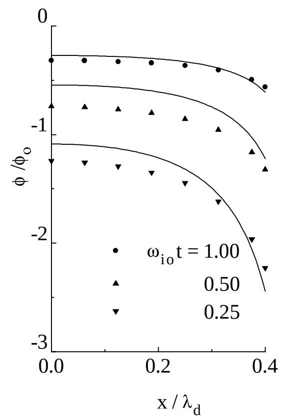

Fig. 5.

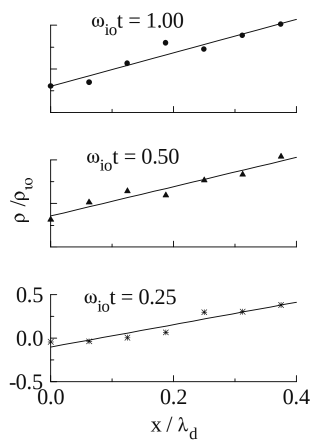

Fig. 6.

As can be seen from Fig. 4, where the dependencies are shown of the maximum rations of potential and kinetic energies for electrons (stars) and ions (circles) on the distance *d* between the dust particles in a dusty crystal, these dependencies are practically exponential and can be fitted by $y = y_o + Ae^{-(x - x_o)/L}$ (solid lines) where x_o= *1.13; A =1.7* and *45.8;* y_o =

0.35 and *13.6; L =1.44* and *1.86* for electrons and ions, respectively. Of course, all indicated values relate to lengths divided by the initial Debye length.

Spatial distributions of the potential ϕ divided by $\phi_0 = kT_{eo} / e$ are shown in Fig. 5 by various shapes (circles, up and down triangles) for some instants of time. This potential is negative in the entire crystal cell including its boundaries due to an influence of neighboring cells. Note that the potential is equal to zero in all points before relaxation due to a quasi-neutrality of a plasma with dust particles. Solid curves present here some Yukawa potential $\frac{\phi}{\phi_o} = \frac{A}{x - 0.5} \exp(-2(x - 0.5))$ with A=*0.05, 0.10* and *0.20* for $\omega_{oi} t$ = *1.0, 0.50* and *0.25*, respectively. As can be seen, these curves are like the obtained potential distributions but the shielding length is equal to only $0.5\lambda_d$ i.e. the potential shielding is non-equilibrium.

The spatial distributions of electron and ion densities are also non-equilibrium which is confirmed by Fig. 6 where the spatial distributions of an electric charge $\rho = \rho_i - \rho_e$ are shown as functions of a coordinate x of the crystal cell which (ρ is divided by an initial spatial ion charge ρ_{io}). These dependencies show a sandwich structure of the spatial electric charge around a dust particle in a crystal cell which is the result of a redistribution of electrons and ions. Slow electrons are concentrated close to the boundaries of a crystal cell according to spatial distributions of a self-consistent electric potential (Fig. 5). Of course, positive ions are concentrated close to a dust particle which is negatively charged due to selective collection of electrons and ions by dust particles. These spatial distributions show a non-trivial shielding of an electric potential in relaxing plasmas with dust particles.

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