Response of dusty plasma system on confinement field alteration

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Complex (dusty) plasma is gas plasma consisting of electrons, ions and neutral atoms; it also contains microscopic particles having sizes in the range from 10 nm to 10 μm. Complex plasma has a greater variety of properties by comparison with classical plasma, which consists of electrons and ions. Of significant interest is the investigation of different states of complex plasma and of physical phenomena involved since in-depth information can be derived about the state of classical, macro- and microscopic disperse systems [1]. Complex plasma occurs widely in nature; besides, it has distinct linear properties, which opens up broad perspectives for fruitful research into complex plasma behavior, in particular, on exposure to external action. Excitation in dusty plasma can be generated by a number of methods, i.e. the action of laser on dusty plasma particles [2]; electric field generation in dusty plasma [3]; the action of magnetic field [4]; gas-dynamic loading [5] etc.

The goal of the given study is an investigation of dusty plasma in which particles form so-called "Coulomb balls", in particular, the response of such systems to pulsed change in the holding field pattern of the trap. The distinctive features of system oscillation were simulated for two variants of external action: (i) spherically symmetric external action and (ii) anisotropic pulsed change of the confining field.

Formalism

The investigation was performed by molecular dynamics method. Dusty plasma systems studied contained 180-720 particles, which formed Coulomb balls due to the symmetric confining field. In the neighborhood of ground (crystalline) state Coulomb balls are characterized by shell structure.

The interaction between particles is determined by the Debye-Hückel potential

$$\phi = \frac{Q}{4\pi\varepsilon_0 r} e^{\left(-\frac{r}{\lambda_d}\right)} \quad (1)$$

where λ_d – plasma screening length (Debye radius) and Q – particle charge. The particles were acted upon by the force from the trap, which had electrostatic nature and held them together, thus preventing from bouncing apart. The given force is described by the following expression

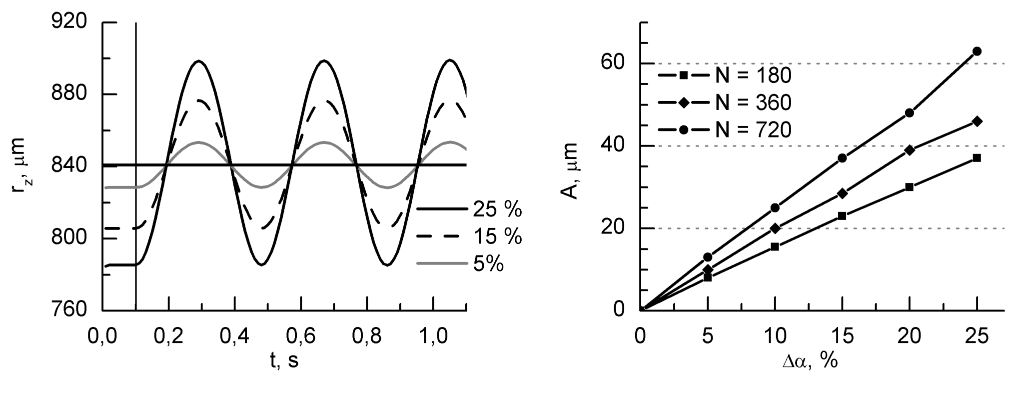
$$F = \alpha_z Q z + \alpha_\rho Q \rho \quad (2)$$

where$\rho = (x^2 + y^2)^{1/2}$. The coefficients α_z and α_ρ determine the force of the confining field in the vertical and horizontal directions, respectively. In the studied state (after a jump-wise change of the confining force) $\alpha_z = \alpha_\rho = 3.6 * 10^{-13}$. The dusty-plasma particles had spherical shape; particle radius was 2.4 μm and their charge 2013 e. The particle density is comparable to that of melamine formaldehyde.

The spherically symmetric action exerted on a Coulomb ball in the ground state was simulated by decreasing in a jump-wise manner the parameters α_z and α_ρ until they reached one and the same value. For the case of anisotropic stressing, only the parameter α_ρ was changed.

Results of Simulation

A spherically symmetric change of the confining field would generate shell oscillations of the confining field; a concurrent change in the volume of the Coulomb ball would occur, with its shape remaining the same. It should be noted that at first the shells would oscillate synchronously enough; however, the ordered motion of the shells gradually transforms into thermal motion. The oscillation frequency of the shells is determined by the dimension of the confining field, which prevents the particles from bouncing apart (Fig. 1a). The oscillation amplitude of the simulated system of particles increases linearly with growing magnitude of the confining field jump (Fig. 1b).



(a) (b)

Figure 1: Oscillation of the outer shell of the Coulomb ball comprising 720 dusty plasma particles due to an avalanche-like increase in the confining force (A) The oscillation amplitude of the outer shells of the Coulomb balls containing a different number of dusty plasma particles (N) as a function of the change in the coefficients α_z and α_ρ (B)

The oscillation period of the outer shell as a function of the number of particles can be interpolated as $T \approx A + B * e^{-C*N}$ where A, B and C are parameters which are determined by the confining field strength as well as by the properties of dusty plasma particles. The latter expression agrees satisfactorily with the results reported in [6].

It should be noted that in spherically symmetric confining field conditions the Coulomb ball structure plotted in cylindrical coordinates is a set of concentric circles and in cylindrically confining field conditions, a set of concentric ellipses, with α_z differing slightly from α_ρ [7]. In the former case, only one parameter is required for description of the Coulomb ball position, i.e. the shell should be sufficiently far removed from the center of the Coulomb ball. In the latter case, one parameter is insufficient since the shell assumes an elliptical shape so that two parameters are required, i.e. semiminor and semimajor axes lengths.

By anisotropic stressing, the variation of the shape and volume of the Coulomb ball can be described using the following parameters, i.e. the distance (r_z) from the center of the Coulomb ball to the outer shell in the direction of the chosen axis and the distance (r_ρ) from the center of the Coulomb ball to the outer shell in the direction normal to the chosen axis. The lengths of the semiaxes r_z and r_ρ were determined by averaging the particle on the outer shell of the Coulomb ball. The Coulomb ball volume (V_{cb}) is given as $V_{cb} = \frac{4\pi}{3} * r_z * r_\rho^2$.

Analysis was made of the results of simulation. It has been found that the time dependence of the functions $r_z(t)$ and $r_\rho(t)$ obtained after stressing has a complex shape (see Fig. 2a). At the same time, the volume of the Coulomb ball changes with time in accordance with the harmonic law (Fig. 2). It is proposed to introduce two time functions, $W(t)$ and $B(t)$. The former function describes change of volume and the latter, change of shape without change of volume. This enables one to describe change of volume with time as $V_{cb} = V_{cb}(0) * W(t)^3$

The time dependence of the Coulomb ball semiaxis length $r_z(t)$ and $r_\rho(t)$ is written as

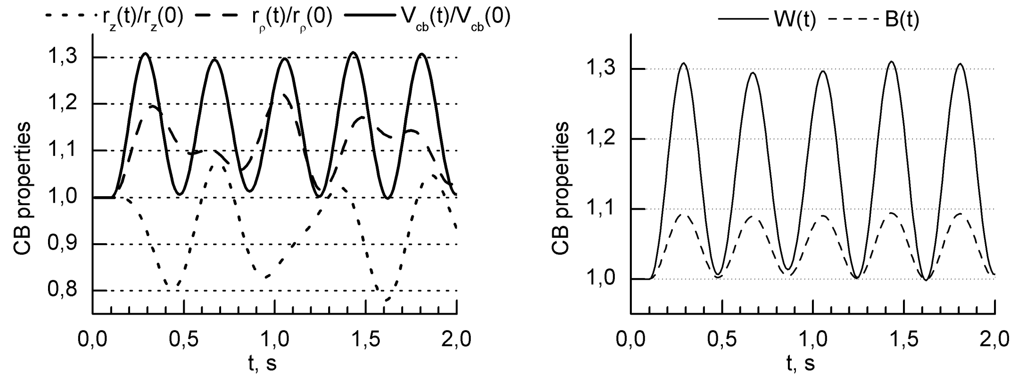
$$r_z(t) = r_z(0) * W(t) * B(t)^{-2} \tag{3}$$

$$r_\rho(t) = r_\rho(0) * W(t) * B(t) \tag{4}$$

The results of calculations suggest that variation of the functions $W(t)$ and $B(t)$ with time has a clearly pronounced periodicity (Fig. 2b).

Conclusion

Thus, the results of calculations suggest that a jump-wise variation of the confining field would cause oscillations of the Coulomb ball composed of dusty-plasma particles. In the case of spherically symmetrical loading, the shape of simulated system remains unchanged, while its volume varies in accordance with the harmonic law. The oscillation amplitude of the simulated system depends on the magnitude of the confining field jump and the oscillation frequency,



(a) (b)

Figure 2: Variation of the Coulomb ball characteristics with time by anisotropic stressing: (a) variation in the semiaxis lengths $\frac{r_z(t)}{r_z(0)}$ and $\frac{r_\rho(t)}{r_\rho(0)}$ and of the volume $\frac{V_{cb}(t)}{V_{cb}(0)}$; (b) variation in the harmonic modes $W(t)$ and $B(t)$

on the magnitude of the confining field which had bee assigned after stressing. In the case of anisotropic variation of the confining field, the oscillations of the Coulomb ball shell have an intricate character. Such behavior is largely due to the superposition of two harmonic oscillation modes; one of these modes describes variation of shape and the other, variation of the simulated system volume. The results obtained are consistent with the previous findings.

The investigation was performed in accordance with the Program of Fundamental Research of RAS Presidium No. 2 “Matter at high energy densities”.

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