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Influence of the plasma friction on the velocity autocorrelation functions of dusty particles

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Dusty plasma can be widely found on the Earth and in the space. It is available in planetary rings, comet tails, in interplanetary and interstellar clouds [1]; it was found in vicinity of artificial satellites and space apparatuses, in fusion reactors with magnetic confinement. Finally, such plasma is intensively investigated in laboratories. Dusty plasma is represented by ionized gas with charged particles of condensed matter. Dust particles (microparticles) can be deliberately introduced into plasma or be formed spontaneously in various processes [1]- [4]. It is noticeable that at investigations of dusty plasma properties the main challenge is imposed by the impossibility to use conventional methods of theoretical physics due to strong interparticle interactions in the plasma. That is why considerable attention is paid to numerical simulations; also, the method of the Langevin dynamics found its recent wide application in studies of dusty plasma properties [2],[5]-[7].

In the present work we consider a cubic cell of side L with periodical boundary conditions imposed on it and on the replicas; number of particles in a cell was taken to be 1024. Simulations of the dusty particle dynamics was made within the Langevin dynamics that describes motion of particles by the following equations:

$$m_d \frac{d^2\vec{r}_i}{dt^2} = \sum_j F_{int}(r_{ij}) \frac{\vec{r}_i - \vec{r}_j}{\left|\vec{r}_i - \vec{r}_j\right|} - m_d \nu_{fr} \frac{d\vec{r}_i}{dt} + \vec{F}_{br}(t), \quad (1)$$

where $F_{int}(r_{ij}) = -\partial\Phi/\partial r$ is a force imposed on a selected i-th particle due to interaction with other particles, $r_{ij} = \left|\vec{r}_i - \vec{r}_j\right|$ is the distance between two macroparticles, $\vec{F}_{br}(t)$ - stochastic force due to interactions with neutrals, ν_{fr} is the friction coefficient dependent on buffer plasma pressure, m_d is mass of a dust particle. The Yukawa potential was chosen as interaction potential; in the dimensionless form it looks as:

$$\Phi(R) = \frac{\Gamma}{R} e^{-\kappa R} \quad , \quad (2)$$

where $\Gamma = (Z_d e)^2/ak_B T$ is the coupling parameter, $\kappa = a/r_D$ is the screening parameter, $a = \left(\frac{3}{4\pi n_d}\right)^{1/3}$ is average distance between dust particles**.**

Time is taken in the units of reverse dusty plasma frequency $\omega_d = \left(\frac{4\pi n_d (Z_d e)^2}{m_d}\right)^{1/2}$. Stochastic force is taken in the form:

$$F_{br}(t) = A\sqrt{2\theta}\xi(t) \quad , \tag{3}$$

where A is a factor that depends on the time interval [6], $\xi(t)$ is the stochastic number with normal distribution within the range $0 \div 1$, $\theta = \frac{v_{fr}}{\omega_d}$ is the dimensionless friction parameter. Initial distribution of the coordinate and velocity components for the particles is taken at random with velocity component distribution according to the Gauss law at a given temperature. At the first stage of simulation the system achieves equilibrium state and this takes little time. Since simulation is done for the canonical ensemble, we used a thermostat for keeping temperature constant. We start collection of data on velocities and coordinates of the particles required for further calculation after the system achieved equilibrium.

One should note that these method of calculations provides us with reliable results only when the size of the system exceeds certain characteristic interaction length (for momentum exchange) between the particles. This situation can be quantitatively assessed with autocorrelation functions of macroparticle velocities described as:

$$A_{vv}(t) = \langle \vec{v}(t)\vec{v}(0) \rangle, \tag{4}$$

where the brackets denote averaging over the ensemble and over various initial times. As one can see from figure 1, velocity autocorrelation function demonstrates damping characterized by the attenuation time τ [8, 9]. This parameter can be evaluated using the following expression:

$$A_{vv}(\tau)/A_{vv}(0) = 1/e, \tag{5}$$

where $e = 2.718$. At higher values of the coupling parameter τ decreases. Time it takes for a particle to cover the distance L is equal to $\Delta t = L/\bar{v}$, where $\bar{V} = \sqrt{3k_B T/m_d}$ is average velocity of particles. Therefore, considering again the reliability of numerical simulation of the system of the scale L, it would be necessary to state one of the required conditions:

$$\tau < \Delta t \tag{6}$$

Autocorrelation functions for velocities were obtained at various coupling, screening and friction parameters; at that, the constant values were: $m_d = 5.4 \cdot 10^{-12}$, $a = 0.06$. From figure 1 one can see that attenuation time decreases with higher coupling parameter what can be explained as follows: at high coupling the collisions with other dust particles are more frequent and therefore a particle “forgets” about its initial velocity quite fast. For each autocorrelation

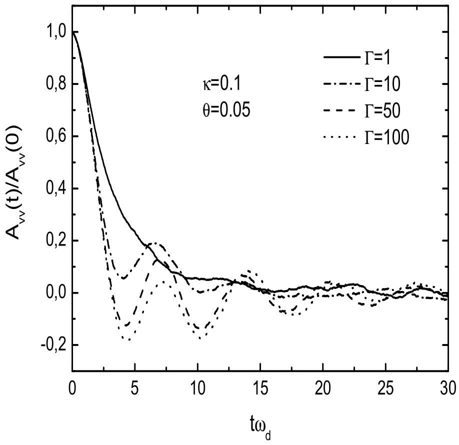

Figure 1: Autocorrelation functions for velocities obtained for different Γ at $\kappa = 0.1$ and $\theta = 0.05$

function it is possible to calculate τ and Δt. The last value depends on Γ only. Since the condition (6) is the most critical for small coupling parameters, we analyzed it for $\Gamma = 1$; for this coupling parameter $\Delta t \omega_d = 10.06$.

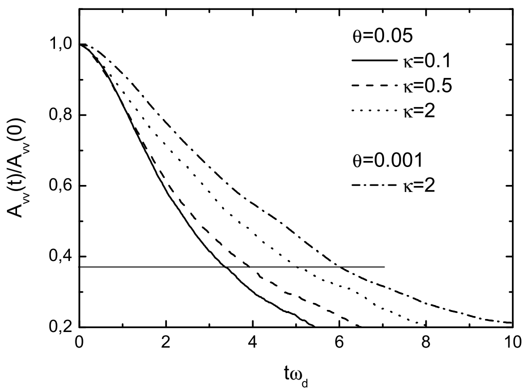

Figure 2: Autocorrelation functions for velocities obtained for different κ and θ at $\Gamma = 1$

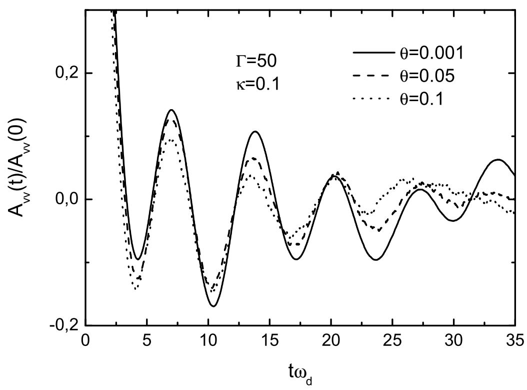

Figure 3: Autocorrelation functions for velocities obtained for different θ at $\kappa = 0.1$ and $\Gamma = 50$

Figure 2 presents autocorrelation functions obtained for various values of κ and θ. It also represents the line (5). Time that corresponds to the intersection of the autocorrelation function and the line (5) is $\tau\omega_d$. As one can see from the figure, the condition (6) can be violated at quite high κ or small θ. Figure 1 shows that there are oscillations at higher coupling parameter in the curves of the autocorrelation functions; the oscillations are more pronounced and remain for longer at higher Γ. From figure 3 one can see that at the same Γ and κ but different θ the oscillations decay more rapidly at higher friction parameters.

Based on the performed investigation we can make the following conclusions:

Since the coupling parameter achieves high values in dusty plasma and the method of the Langevin dynamics takes into account the final friction force, then the condition (6) is easily satisfied in the wide range of the parameters. Collisions with plasma particles result in more sharp attenuation in collective motion of dust particles.

References

[1] V.Ye. Fortov, A.G. Khrapak, S.A. Khrapak, V.I. Molotkov, O.F. Petrov, Uspehi fisicheskikh nauk **174** (2004) [in Russian]

[2] O.S. Vaulina, O.F. Petrov, V..Ye. Fortov, A.V. Chernishev, A.V. Gavrikov et.al., Fizika Plazmi.**29**, 698 (2003) [in Russian]

[3] V.N. Tcytovich, Uspehi fisicheskikh nauk **167**, 57(1997) [in Russian]

[4] V.N. Tcytovich, J. Winter, Uspehi fisicheskikh nauk **168**, 899(1999) [in Russian]

[5] O.S. Vaulina, S.A. Khrapak , JETF **119**, 264(2001)

[6] K.N. Dzhumagulova, Bulletin of National Academy of Sciences RK. Phyz.-Math. Series **2**, 55 (2005)

[7] F.B.Baimbetov, T.S.Ramazanov, K.N.Dzhumagulova, E.R.Kadyrsizov, O.F.Petrov and A.V. Gavrikov, J.Phys.A: Math. And Gen. **39**, 4521 (2006)

[8] Z.Donkó, Phys. Plasmas **7**, 45 (2000)

[9] Z.Donkó, P.Hartmann, Phys.Rev.E.**69**, 016405 (2004)