# Influence of a charge-gradient force on dust acoustic waves.

Alexey G. Khrapak[1], Sergey A. Khrapak[1, 2]

[1]*Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, RUSSIA*
[2]*Institut für Materialphysik im Weltraum, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Weßling, Germany*

In complex plasmas charged dust particles not only change the electron–ion composition and thus affect conventional wave modes (e.g., ion–acoustic waves), but also introduce new low-frequency modes associated with the microparticle motion, alter dissipation rates, give rise to instabilities, etc. Moreover, the particle charges vary in time and space, which results in important qualitative differences between complex plasmas and usual multicomponent plasmas. The focus of this work is on the influence of the plasma background and grain charge variability on linear waves in weakly coupled unmagnetized complex plasmas. In the long-wavelength limit these waves exhibit acoustic-like dispersion and are called "dust acoustic waves" (DAWs). The dispersion relation of DAWs for ideal isotropic complex plasmas was originally derived by Rao, Shukla, and Yu [1]. In complex plasma, different forces affect particle dynamics. One of these forces is the so-called "polarization" force, which was introduced by Hamaguchi and Farouki [2] and comes from the nonuniformity of the plasma background. The grain charge variability may result in the appearance of an additional component of this polarization force. Actually, the energy of an individual test charge $Q$ immersed in an ideal plasma is $U=-Q^2/2\lambda_D$. The total force acting on a small charged grain in a nonuniform plasma with external electric field $\mathbf{E}$ is $\mathbf{F}=Q\mathbf{E}-\boldsymbol{\nabla}U$. The "gradient" force can be written as

$$F_g=-\boldsymbol{\nabla}U=F_{pol}+F_Q=-\frac{Q^2}{2}\frac{\nabla\lambda_D}{\lambda_D^2}+\frac{Q\nabla Q}{\lambda_D}.$$

$F_{pol}$ corresponds to the conventional polarization force [2], influence of which on the dust acoustic waves was investigated earlier [3]. To determine the dispersion relation of the longitudinal DAWs, the system of forth differential equations (continuity, momentum, charging, and Boltzmann equations) has been solved. After linearization, we have obtained the long-wavelength dispersion relation of low-frequency DAWs of the form

$$\omega^2\left(1+\frac{n_{d0}}{n_{i0}}\frac{J_0}{\Omega_{ch}}\right)=\omega_d^2\lambda_D^2k^2\left(1+\mathcal{R}_{pol}+\mathcal{R}_Q\right),\;\; \mathcal{R}_{pol}=\frac{Qe}{4\lambda_D T_i},\;\; \mathcal{R}_Q=\frac{J_0e^2}{\lambda_D\Omega_{ch}T_i},$$

where $J_0$ is the flux of electrons/ions that the particle collects, $\Omega_{ch}$ is the charging frequency, and other parameters are conventional. The effect of the charge-gradient force is expressed by the term $\mathcal{R}_Q$. This term is positive (unlike $\mathcal{R}_{pol}$) and thus, it reduces the effect associated with the polarization force. For typical gas discharge conditions the relation between $\Omega_{ch}$ and $J_0$ (within the collisionless OML theory and under the assumption $T_e\gg T_i$) is

$$\Omega_{ch}\cong J_0\frac{1+z}{z}\frac{e^2}{aT_e},\quad z=\frac{|Q|e}{aT_e}.$$

The relative importance of polarization and charge gradient force is $\left|\mathcal{R}_{pol}/\mathcal{R}_Q\right|\cong(1+z)/4$. As typical values of $z$ according to the OML are $\cong(2\div4)$, these two components of the gradient force are of comparable magnitude and needs to be taken into account simultaneously.

## REFERENCES

[1] N. N. Rao, P. K. Shukla, and M. Y. Yu, Planet. Space Sci. **38**, 543 (1990).
[2] S. Hamaguchi and R. T. Farouki, Phys. Rev. E **49**, 4430 (1994).
[3] S. A. Khrapak, *et al.*, Phys. Rev. Lett. **102**, 245004 (2009).