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Charging of nanoparticles in complex plasmas: the role of quantum tunnelling

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Complex plasmas – plasmas with dust particles (grains) – owe most of their complexity to the process of charging of a dust grain in plasma which is sensitive to plasma parameters and proximity of other grains. As a result, the grain charges are variable in space and time, adding a whole new degree of complexity to the system. Understanding the physics of grain charging is thus most important for understanding behaviour and manipulation of complex plasmas, which in recent years attracted a great deal of attention from both theoretical and applied points of view [1]. Complex plasmas, for example, provide a test bed for fundamental research in phase transitions, allowing observations of the phase transitions in dust crystals at kinetic level and in real time. Understanding physics of complex plasmas is important in such areas as plasma processing, thin film deposition, combustion, complex materials, plasma fusion reactors, and environmental research. Research in complex plasmas with nanoparticles is also paving the way towards certain nanotechnologies (such as manufacture of mesoporous silicates). Nanoparticles in complex plasmas can also be the "building blocks" in the process of plasma-enhanced assembly of carbon-based nanostructures [2].

The most commonly used model for finding the equilibrium charge of a grain immersed in plasma is the Orbital Motion Limited (OML) model, in which the electron and ion currents from plasma onto the grain are found from analysing particle orbits using classical mechanics, and the equilibrium grain charge is found from the condition that these 'classical' currents cancel each other. However, for nanoparticles quantum mechanical effects become important, and may lead to significant additional currents from the grain to plasma, e.g., electron photoemission and electron thermoemission currents, which can significantly modify the grain charge, and thus affect interaction of grains in complex plasma.

Here, we first discuss these quantum contributions to charging currents of nano-sized grains, and then proceed to discussion of a new quantum mechanical process: the process of quantum tunnelling of plasma electrons through the repulsive potential barrier from plasma onto a negatively charged grain (i.e., the process inverse to the thermoemission of electrons from the grain to plasma). We show that the contribution of this process to the total current onto the grain, and hence to its charge, becomes significant for small (less than 100 nm) dust grains, and/or for rather low electron temperatures (10-100 K). This study is therefore applicable to plasmas with nanoparticles, to cryogenic complex plasmas, and to dark molecular clouds in astrophysics.

References

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[2] S.V. Vladimirov, K.N. Ostrikov, 2004 Physics Reports 393, 175-380