Dynamics of dust motion in tokamak edge plasmas

S. I. Krasheninnikov[1], Y. Tomita[2], R. D. Smirnov[3], R. K. Janev[2,4], and T. K. Soboleva[5]

[1]*University of California at San Diego, La Jolla, CA 92093, USA*
[2]*National Institute for Fusion Science, Toki, Gifu 509-5292, Japan*
[3]*The Graduate University for Advanced Studies, Toki, Gifu 509-5292, Japan*
[4]*Macedonian Academy of Sciences and Arts,1000 Skopje, Macedonia*
[5]*UNAM, Mexico D.F., Mexico and Kurchatov Institute, Moscow, Russia*

It has been suggested long time ago [1] that dust particles might be a source of plasma impurities in the early stages of a tokamak discharge. Later on the presence of significant amounts of dust has been observed in the chambers of fusion devices (see for example the review paper [2], and the references therein). The dust particle impact on the performance of current fusion devices has still not been adequately understood [3, 4]. The existence of dust particles in next-step fusion devices, however, may potentially pose a significant safety threat due to the accumulation of hardly containable toxic and radioactive materials retaining tritium [2].

Here we consider some aspects of the dust dynamics in tokamak, and show that transport of dust particles can be an important mechanism of core plasma contamination with impurities. We assume that dust density in a tokamak plasma is rather small so that our consideration is based on a single dust particle motion. Therefore, we ignore the collective phenomena associated with the dust [5]. Similarly as in the studies of dust behavior on the devices with weakly ionized plasmas, a dust particle in a tokamak edge plasma can be confined in an effective potential well formed in the sheath region by the perpendicular components of plasma friction and electrostatic forces. However, unlike those studies, dust particles in a tokamak edge plasma are subject of acceleration by unbalanced large parallel components of the plasma friction force, which appear due to: a) the plasma flow along the shallow magnetic field lines and b) diamagnetic and $\mathbf{E}\times\mathbf{B}$ flows within the magnetized sheath. Therefore, dust particles in tokamak divertor region can be quickly (for ~1 ms) accelerated to the speed $\sim 3\times 10^3$ cm/s, which can explain some of the puzzles in Ref. [4]. We demonstrate that the motion of a dust particle along the wall surface, having micro-inhomogeneities, is subject to resonance interactions with particle oscillations in the potential well. As a result, the oscillation amplitude can grow drastically and dust particle can leave the sheath region and fly outside it and, being pushed back by the plasma flow to the wall, bouncing time to time off the surface and further gaining speed by plasma flow acceleration. Finally, the amplitude of particle excursions becomes too large to be pushed back so that dust particle moves to another location at the wall, or flies toward the core plasma. We also report the results of numerical modeling of fast moving dust particles with micro-inhomogeneities of the surface. We consider the limit of strong departures of dust particle from the sheath and compare numerical results with our analytic predictions. Assessment of dust impact on core plasma contamination by impurities shows that: It is unlikely that dust formation on the main chamber wall due to first wall recycling processes can strongly contribute to core contamination. It is, however, quite likely that dust formation in the divertor region, with further dust transport into main chamber, can play significant role in core contamination.

[1] T. Ohkawa, Kaku Yugo Kenkyu **37** (1977) 117
[2] G. Federici, C. H. Skinner, J. N. Brooks, et al., Nucl. Fusion **41** (2001) 1967
[3] D. H. J. Godall, J. Nucl. Materials **111-112** (1982) 11
[4] K. Narihara, K. Toi, Y. Hamada, et al., Nucl. Fusion **37** (1997) 1177
[5] P. K. Shukla, Phys. Plasma **8** (2001) 1791; V. N. Tsytovich, Physics-Uspekhi **40** (1997) 53