Frontier of the Science of Dusty Plasmas

Osamu Ishihara[1]

[1] Engineering, Yokohama National Univ.

Recent advances in the study of dusty plasmas are reviewed. Dusty plasmas, in which fine particles of micron sizes are present in the plasma, are called complex plasmas because of a complex nature of two collective modes involving plasma particles and much heavier fine particles[1]. Dust particles were studied earlier in 1940s and 50s in the context of interstellar matter and planet formation [2,3]. Space exploration in 1980s rekindled the interest of charged dust particles in the universe [4]. In 1990s dust particles found in the industrial plasma processing were identified as a result of particle coagulation in the plasma [5]. It is rather remarkable to notice the common ground between interstellar dusts and laboratory dusts on the earth. They are both charged either negatively or positively and are subject to the electric and magnetic fields. Dust particles in the laboratory are large enough to be visible by naked eyes through scattering of a laser light. Extensive research in laboratories revealed the nature of coagulation, self-organization and collective behavior of dust particles [6, 7, 8, 9]. Dust particles are found in a restricted region in ground experiments balanced dominantly by the gravitational force and the electric force, while dust particles in the gravitation-free environment form three dimensional structures subject mainly to forces of ion/neutral drag and the electric field. Dynamic motion of fine particles in a complex (dust) plasma is reviewed with the emphasis of collective nature of plasmas.

The ordered state of dust particles forms a Coulomb cluster and is subject to the transition to a disordered state under the change of background plasma conditions, known as a melting transition. The transition is observable by naked eyes in the particle or kinetic level. The attractive force between dust particles along the ion stream in the sheath is discussed in association with the wake potential [10]. The force released as a result of thermodynamic free energy is also discussed [11]. A complex plasma is under intensive investigation toward the understanding of the critical phenomena in the equation of state [12]. The effect of magnetic field on the complex plasma is still to be investigated. Some rotational motion of Coulomb clusters were reported and spinning motion of a single dust particle is also discussed [13,14,15].

[1] O. Ishihara, Physics of a complex plasma, Butsuri 57 (2002) 476.

[2] L. Spitzer Jr., Physical Processes in the Interstellar Medium (Wiley, New York, 1978).

[3] H. Alfvén, On the origin of the solar system (Oxford University Press, 1954).

[4] B.A. Smith et al., Science 215 (1982) 504.

[5] A. Bouchoule, Dusty Plasmas, Physics, Chemistry and Technological Impacts in Plasma Processing, (John Wiley, New York, 1999).

[6] Y. Watanabe, T. Yokota, Y. Hayashi, Y. Nakamura, M. Shiratani, T. Nakano, N. Sato, R. Hatakeyama, T. Hirata, Current Status of a dust plasma, JSPF 73 (1997) 1220.

[7] O. Ishihara, S. Takamura, S. Vladimirov, M. Nambu, S. Hamaguchi, Y. Hayashi, A. Mendis, N. Sato, Advances in dusty plasmas, JSPF 78 (2002) 293.

[8] O. Ishihara, Parity 20 (2005) 7. (translation); R. L. Merlino and J.A. Goree, Physics Today 57 (2004) 32.

[9] O. Ishihara, T. Mukai, H. Kamaya, C. Kaito, T. Yokota, M. Horanyi and C. Mitchell, Dust plasmas in space, JSPF 82 (2006) No.2.

[10] O. Ishihara and S. V. Vladimirov, Physics of Plasmas 4 (1997) 69.

[11] O. Ishihara and N. Sato, Physics of Plasmas, 12 (2005) 070705.

[12] S.A. Khrapak, G.E. Morfill, A.V. Ivlev, H. M. Thomas, D.A. Beysens, B.Zappoli, V.E. Fortov, A.M. 96Lipaev, and V.I. Molotkov, Phys. Rev. Lett. 96 (2006) 015001.

[13] N. Sato, G. Uchida, T. Kaneko S. Shimizu, and S. Iizuka: Phys. Plasmas 8 (2001) 1786.

[14] O. Ishihara and N. Sato: IEEE Trans. Plasma Sci. 29 (2001) 179; I.H. Hutchinson, New J. Phys. 6 (2004) 43.

[15] O. Ishihara, T. Kamimura, K. Hirose, and N. Sato, Phys. Rev. E 66 (2002) 046406.