§24. Wakefield of a Charged Particulate Influenced by Emission Process of Secondary Electrons

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The realization of a “plasma crystal” in experimental plasma has made the ordered structure of dusty plasmas visible to naked eyes. Particulates immersed in a plasma acquire a charge from the surrounding plasma and interact with other particulates through an isotropic screened Coulomb potential if there is no external force. In actual experiments on plasma crystals, an anisotropic layered structure of particulates can be observed in the vicinity of the sheath region where ion flow exists. It has been pointed out that plasma flow disturbs the Coulomb potential of a charged particulate. In particular, when the velocity of ion flow exceeds the ion thermal velocity, a potential structure called a “wakefield” can be generated on the downstream side of a particulate. While it is said that the layered structure that appears in a plasma crystal results from the wakefield, there is no direct evidence to support this assertion.

Analysis shows that an oscillatory structure of the electric potential appears on the downstream side of a test particle, in which the particulate charge was fixed to be negative. Little attention has been given to the wakefield generated by a positively charged particulate until now. Our concern is to investigate the wakefield created by a charged particulate immersed in a streaming plasma and discuss some of the differences between the wakefields generated by a positively charged particulate and a negatively charged one. We perform a three-dimensional particle simulation dealing with both attachment of plasma particles and emission of secondary electrons from the surface of a particulate.

The distance d/λ_e from the particulate surface to the nearest position of $E_z = 0$ varies for various Mach numbers ($M = V/c_s$, where V is the velocity of the particulate relative to that of a streaming plasma). This relation is shown in Figure 1. The important point is that the difference between a negatively charged particulate and a positively charged one becomes remarkable as the Mach number increases. It is clear that the distance for a negatively charged particulate tends to be larger than that for a positively charged particulate.

Figure 2 shows the dependence of the distance d/λ_e on the particulate charge at $M = 5$. When the charge is positive, the distances are almost same, regardless of various values of the charge. On the other hand, when the charge is negative, the distances are changed slightly, depending on the absolute values of the charge. It is obvious that there exists a clear difference about the distances between negatively charged particulates and positively charged ones, irrelevant to the absolute values of the charge. It should be concluded, from Figs. 1

and 2, that the difference of wakefields emitted by a negatively charged particulate and a positively charged one can be characterized by the velocity of the particulate relative to that of the plasma, irrelevant to the absolute value of the particulate charge.

There is an assertion that the anisotropy of a plasma crystal is caused by the wakefield, namely the distance d/λ_e corresponds to the length between the layers observed in a plasma crystal. As our simulation results show, the length between layers will depend on both the Mach number and the sign of the dust charge if this assertion is true. Thus, an experiment in which the Mach number or the sign of the particulate charge is changed could answer the question as to whether the layered structure of a plasma crystal can be explained as being attributable to the wakefield.

Fig. 1. Dependence of the distance d/λ_e from a particulate surface to the closest zero point of the electric field on the Mach number M .

Fig. 2. Dependence of the distance d/λ_e on the particulate charge $Q/4\pi en_0 \lambda_e^3$ at $M = 5$.