§7. Modeling of Microscopic Self-Organization (III) — Super Ion Acoustic Double Layer —

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Most of the self-organization researchers have been studied from "macroscopic" point of view. The idea of "self-organization" which was shown in those previous works is the following: in local system where the interior of "open" system can be fed self-consistently by a free energy from the exterior of the system and a produced entropy can be swept out toward exterior of the system, there can occur a spontaneous transition from a disordered state to an ordered state. In order to generalize our idea of "self-organization" from macroscopic(MHD) point of view, it will be extended to the problem in "microscopic self-organization." As a suitable candidate, an ion-acoustic double layer is chosen. In this paper, we wish to reveal the long temporal evolution of ion acoustic double layers by using particle simulation under the realistic condition where fresh particles are supplied continuously from ambient source and nonlinearly disturbed, dirty particles leave the system spontaneously.

Toward the end of 1970's, the ion-acoustic double layer was discovered by a particle simulation[1]. In the conventional particle simulation, one usually employs a periodic or reflecting boundary condition for particles in order to avoid the dangerous numerical artifacts due to charge imbalance in the discrete space and time domain. In nature, however, it would hardly occur that same particles periodically circulate from one end to the other of a system, but it is more likely that fresh particles enter the system and disturbed particles leave from it. Previous simulation[1], where the particles leaving from one boundary enter into the system periodically from the other boundary, is far from reality.

In this study, we have developed a suitable numerical model for open system in which fresh ambient particles can continuously come in the system and disturbed particles can be swept out toward the ambient regime in a consistent manner without causing any numerical noise. The net incoming particle flux through the upstream boundary is taken to be the same as the net outgoing flux through the downstream boundary. More specifically, at each time step of simulation, we count the number of the particles (electrons and ions) which leave from the simulation box through the upstream and downstream boundaries during the unit time increment. Then, we emit fresh particles into simulation box through the upstream and downstream boundaries so as to balance the net particle flux of emitted particles and departed particles on the upstream boundary with the net particle flux on the downstream boundary. We also keep the total number of particles in the simulation box.

In the present study, we deal with one dimensional system that is in contact with the external plasma sources at the upstream and downstream boundaries The ambient plasma sources have such a property that net particle flux through a boundary, whether upstream or downstream, is kept constant. The electric fields on the upstream and downstream boundaries are assumed to be zero, the electric potential being zero at the upstream and floating at the downstream.

By applying our new numerical procedure, it is found that a "super" ion acoustic double layer is formed[2]. By changing the drift speed of the shifted Maxwellian in the range from $v_d = 0.3$ to $0.7v^e_{th}$, we have definitely confirmed so far that the self-breeding excitation of the "super" ion acoustic double layer is really a physical phenomenon. The results are summarized as follows:

1) First, in the early phase of evolution, week ion acoustic double layers are generated in a stairs-like form. The evolution is neither a monotone nor a single-shot. It is repetitive. Secondly and most importantly, during the repetitive evolution of week double layers, it happens that a two-stream like distribution of electrons and ions is met somewhere in the system. Then, self-feeding condition , or self-breeding condition, is satisfied there and a "super" ion acoustic double layer is created. The maximum potential difference reaches to a much higher level than the electron thermal energy, say, 15 times in the case of $v_d = 0.6v^e_{th}$. This super structure does not persist long but eventually subsides with leaving a highly disturbed structure behind.
2) ion acoustic double layers are generated when $v_d \gtrsim 0.4v^e_{th}$
3) a super ion acoustic double layer is self-excited when $v_d \gtrsim 0.5\ v^e_{th}$
4) the maximum amplitude of the super ion acoustic double layer is much, by order of magnitude or more, larger than the electron thermal energy or drifting electron energy and becomes larger as the drift speed becomes larger.

Reference

1) Sato,T. and Okuda,H., Phys.Rev.Lett. 44, 740 (1980); J.Geophys.Res 86, 3357(1981).
2) Takamaru,H. Sato,T., Horiuchi,R. and Watanabe,K. NIFS report No.282(1994)