Anomalous transport and domain instability of plasma

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It is assumed that Rayleigh-Taylor hydrodynamic instability significantly affects the anomalous plasma transport onto the chamber wall. However, in experiments on magnetic plasma confinement under anomalous diffusion across the longitudinal magnetic field were found plasma clots, strong fields and streams of fast particles. These data give reason to believe that instability is established in plasma associated with streams of charged particles and the emergence of structures with a strong field in it. There are streams of particles in plasma, with the help of which generation of strong fields and anomalous particle transport take place. Electric domains appear in plasma due to the inequality of particle streams. Here and hereinafter under the electric domain implied the quasi-neutral in whole system which consists of a region (layer) with surplus negative charge and a region (layer) with surplus positive charge. The distance between these two regions (layers) of the domain exceeds the Debye screening length. The electric domains were detected in the plasma glow discharge [1] and in the cathode plasma in a magnetically insulated diode of the electron accelerator [2]. It should be noted that electric domain was also registered in a number of experiments (at breakdown near surface of dielectric, in a spark discharge and in high-current discharge at atmospheric pressure). The appearance of electrical domains in plasma relates to the phenomenon of charged particle self-organization in Nature. In the process of self-organization the plasma as a system of particles always strives to transition from a state with high values of energy (potential) to the state with the lowest values of energy (potential). In the process of transition in plasma the distribution of charges and fields is adjusted self-consistently so that the work on transition becomes minimal. The transition is performed by means of the electric domains. The fields and density gradients creates the flows of directed drift electron and ion in plasma, which are given in the following expressions

$$\vec{\Gamma}_e = -n_e \vec{u}_e(\vec{E},\vec{B}) - D_e \nabla n_e, \quad (1)$$

$$\vec{\Gamma}_i = n_i \vec{u}_i(\vec{E},\vec{B}) - D_i \nabla n_i, \quad (2)$$

where n is density, $\vec{u}$ is directed velocity, D is diffusion coefficient. Electrical domains appear in plasma due to the inequality flows of directed drift of ions and electrons [3]. An inequality of the directed drift flows, i.e. $\vec{\Gamma}_e \neq \vec{\Gamma}_i$, takes place in the charge separation zone. In a strong longitudinal electric field $\vec{\Gamma}_e > \vec{\Gamma}_i$. In a magnetic field the streams of particles are determined by their diffusion. In a weak magnetic field the flows are across the field $\vec{\Gamma}_e > \vec{\Gamma}_i$, in a strong - $\vec{\Gamma}_e > \vec{\Gamma}_i$. From the continuity equations for electrons and ions

$$\frac{\partial n_e}{\partial t} = -\nabla \cdot \vec{\Gamma}_e \ , \qquad (3)$$

$$\frac{\partial n_i}{\partial t} = -\nabla \cdot \vec{\Gamma}_i \, . \qquad (4)$$

and the Poisson equation for the electric field intensity

$$\nabla \cdot (\varepsilon \vec{E}) = 4\pi \rho_e \, , \qquad (5)$$

where ρ_e is space charge determined by the expression

$$\rho_e = e(n_i - n_e) \, , \qquad (6)$$

one can find that the change of the intensity of the electric field induced by the separation of the electric charges in the domain area is expressed in the following equation:

$$\frac{\partial \vec{E}_{ind}}{\partial t} = \frac{4\pi e}{\varepsilon} \left(\vec{\Gamma}_e - \vec{\Gamma}_i \right) . \qquad (7)$$

From equation (7) and Maxwell's equation in the form

$$\nabla \times \vec{B} = \frac{1}{c} \frac{\partial \vec{E}}{\partial t} + \frac{4\pi}{c} \vec{J} \qquad (8)$$

it follows that the bias current is determined by the difference of streams of charged particles. Between the regions of the electric domain a strong electric field is always set even for small voltages due to the negligible distance between the regions [3]. The origin of the electric domains in plasma is accompanied by generation of transverse electromagnetic waves [4]. Theory of domain instability in a gas-discharge plasma is given in [4].

The main difference between laboratory and space plasma lies in the level of localization and density of energy. Laboratory plasma is created inside a metal chamber of a cylinder shape. The chamber of experimental installation is a hollow resonator from the standpoint of radiophysics. Plasma is element of an oscillating system. The internal action in the system is carried out by means charge separation in plasma, external – with help of the resonator. The coupling between elements of the oscillating system is realized by electromagnetic waves generated during charge separation and formation of electric domains. Proofs of this phenomenon are the experiments on the electrical breakdown in air between two electrodes at high voltage [5]. Two cases were studied. In the first case, the electrodes were placed inside a cylindrical chamber, which was also the resonator. In the second case the chamber was absent. Voltage between electrodes was registered by kilovoltmeter. In the experiments it was found that in presence of the chamber the breakdown occurred at a lower voltage than in its absence.

In plasma laboratory, which is located in the chamber the reflected waves appear as a result of electromagnetic waves interaction outgoing from plasma with walls of chamber. Ultimately, as a result of interaction of the incident, reflected, and re-reflected waves in an oscillatory system the resonance of field strength is installed. The plasma goes into the state of anomalous diffusion across the longitudinal magnetic field [6]. In experiments on investigation of plasma spreading (diffusion) in magnetic insulated diode of the accelerator was revealed that the velocity of plasma in a state of anomalous diffusion increased by order as compared with the velocity typical of classical diffusion [7]. Generation of own microwave plasma radiation was revealed in the range of wave lengths $(3 < \lambda < 6cm)$ which is comparable to the diameter of the anode $(D_a = 5cm)$. Thus, the frequency of own electromagnetic plasma oscillations coincides with the characteristic frequency of resonator which is determined by the diameter of the anode. The anode was a resonator. There are different modes of generation of electrical domains in plasma, which are also characteristic of plasma in semiconductors.

For many decades, there were no experiments on research of dependence of plasma confinement time on the magnitude of the magnetic field induction. This blank can be compensated by means of experiments that were carried out at accelerators with magnetically insulated diodes. In [8] and in the author's experiments it was revealed that dependence of the confinement time of plasma on the value of magnetic field induction has a parabolic character. There is an extremum at the dependence of the confinement time of plasma (of pulse duration) on the value of the magnetic field induction [8]. The presence of this extremum can be explained by the fact that at some value of the magnetic field ($B=B_{opt}$) there is equality of directional drift fluxes of ions and electrons crosswise of the longitudinal magnetic field [7]. In the area of weak fields (at $B<B_{opt}$) electrons move faster than ions. In the area of strong fields (at $B>B_{opt}$) ions move faster than electrons. In both cases there is formation of electric domains. The most dangerous is the high-frequency hybrid mode of domain instability, which is implemented in the stage of violation of magnetic insulation. This mode also takes place in the main stage in magnetically insulated diodes with a virtual cathode–vircators. The transition of plasma in tokamaks in the hybrid mode correlates with the advent of powerful own microwave radiation from the plasma, appearance of fast ions and electrons and generation of neutrons. The process of fusion in this event has accelerating character. There are good reasons to believe that the demonstration reactor in the best case will allow satisfying the curiosity. Available experience attests that only correct problems have solutions. It should be noted that statement of the problem of obtaining a controlled thermonuclear reaction was carried out at presence of very poor understanding of plasma physics. Many researchers believe that known methods of magnetic and inertial confinement fusion are too expensive and that their time of implementation is too big to ever become practical sources of energy.

The domain instability is a characteristic state of plasma at the existing electric and magnetic fields and gradients of density and temperature. The explanation of the anomalous processes in the plasma with one position can be given only on the basis of the plasma theory domain. Irregular oscillations of the plasma potential were assumed as basis of the theory of turbulent convection. The explanation that is not related to turbulence can be given to irregular oscillations of the potential. Irregular oscillations of potential are connected with generation of electrical domains in plasma in which the change of temperature and density takes place. Each subsequent electric domain is born in a less dense and much more hotter plasmas. The decrease of critical value of electric field strength also takes place, which promotes the transition of electrons into a state of runaway from collisions and appearance a new electric domain.

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