*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-2.010 (2002)*

# Investigation of Diffusion in Plasmas with Low Frequency Waves

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*Numerical model for plasma in nonuniform magnetic field at the presence of electric field with low frequency waves is developed. The opportunity of suppression of radial diffusion or turbulent transport via controlling of radial electric field is demonstrated. Two criteria of diffusion in plasma with strong density gradient are found.*

The low frequency instabilities have received the considerable attention as a mechanism for anomalous transport. However, linear and nonlinear theories are usually based on the electrostatic and local approximation. Here we investigate a new model of turbulent plasma that is used nonlocal approximation. The most important distinction of this model from "standard" transport model (e.g. [1]) is taking into account the real structure of plasma body (density profile, formation and geometry) and magnetic field (nonuniformity). Such approach allows to search influence of complex radial dependence of magnetic field and density on confinement time and to resolve this problem for configurations consisting different types of instabilities. We are considering the low frequency drift and lower hybrid drift instabilities in nonlocal approximation. In that way easily to estimate the distribution of different modes along radial direction. Some preliminary results based on this approximation are received recently [2].

Previous work on anomalous transport are based on equations and correlations [3], using in their own calculations constant gradient (its maximum value). So in their expressions gradient depends on coordinates, but, eventually, all values are calculated for one maximum gradient.

Originally the model based on nonlocal approximation was developed to study of the mechanism of anomalous diffusion in plasma with the high beta version of the dissipative drift modes (for a field reversed configuration) [4]. Instabilities with variable gradients are taken into account when the particles transfer in plasma is considered. Calculations are carried out for the range of plasma parameters, reached in experiments. Nonlocal dispersion relation is used in the analysis. Nonstationary electromagnetic field of the waves propagated in plasma is modeled.

Particles dynamics in nonuniform magnetic field at the presence of electric field with low frequency drift waves is studied. Presence of longitudinal drift waves results in the anomalous diffusion perpendicular to magnetic field and waves phase velocity. Such a diffusion only happens inside of a domain where respective waves exist. Global radial transport may occur in case of domains superposition. This transport is followed by chaostization of particles orbits.

Numerical model is developed where plasma is represented as a aggregate of superposable layers containing wave packets. Packet is an assembly of wave harmonics with equal phase velocities but different frequencies. Properties of a certain packet depend on the resonance condition for the given layer. Layer's spatial localization, its width, properties of layer's packet are functions of plasma inhomogeneity, i.e. profiles of temperatures, density, magnetic field. These quantities change when going from one layer into another. During calculation models of plasmas with significant nonuniformities (like spherical torus, field reversed configuration and spheromak) and linear profiles (e.g. slab) of values were used.

The opportunity of suppression or intensification of particles diffusion via controlling of radial electric field is numerically demonstrated. Two quantities are found to be criteria of possibility of particles transfer in nonuniform plasma:

$$K_1 = \frac{E_0 \cdot c}{B \cdot \omega \cdot s} \geq 1 \tag{1}$$

without radial electric field and under condition of radial electric field

$$K_2 = \frac{c \cdot E_0 \cdot \cos(\pm \frac{\pi \cdot E_r}{B \cdot V_{ph}})}{B \cdot (\omega \pm \frac{E_r \cdot k}{B}) \cdot s} \geq 1 \quad , \tag{2}$$

where $E_0$ and $E_r$ are the drift wave (single harmonic) amplitude and radial electric field respectively, $\omega$ is the drift wave frequency, $k$, $V$ are the wave number and phase velocity, $s$ is the distance between layers, $B$ is the magnetic field, A is the correction factor taking into account the multitude of harmonics in a packet.

The particle behavior with different $K_1$ and $K_2$ is shown on the Fig.1.

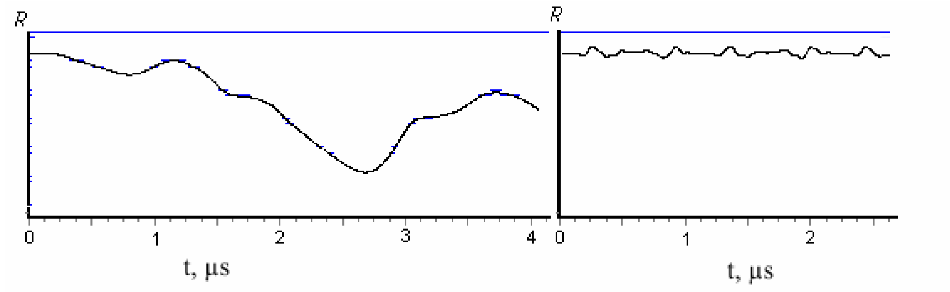


Fig. 1. Diffusion/transport process dependence upon external electric field is illustrated by ion motion in the field of the wave packet of 4 harmonics. Left figure – there is no externally applied electric field, $K_1=1.4$; right case – the particle motion by the presence of electric field, $K_2=0.6$. Example is given for the low frequency drift waves.

Drift approximation for particles with $\rho_c << L$ (Larmor radius smaller than scale length of magnetic field, plasma pressure and electric field inhomogeneities) is used for previous figures. Confinement conditions of magnetized and nonmagnetized plasma for different areas inside volume are considered. Calculations for particles and areas with $\rho_c$ comparable to L are also made and the result is that low frequency waves may explain particle and energy transport in dependence on parameters of wave packet (amplitude, phase velocity). The ion diffusion in the plasma with the lower hybrid drift instabilities is shown on Fig. 2. The modulation of the electric field is also presented.

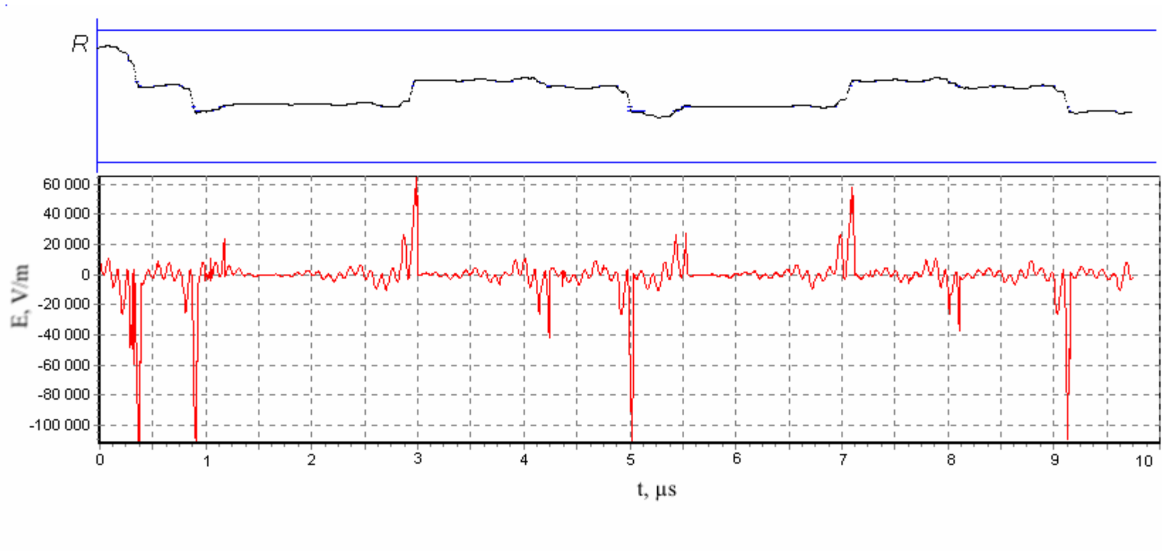


Fig. 2. Particle motion at $K_1=1.3$. Electric field fluctuations are in the lower hybrid drift region. For both figures the number of layers in the plasma volume is equal 5.

The cyclotron resonance interaction between particle and wave leads to absorption and radiation of the waves. At that waves and charged particles are changed energy and pulse between them. Absorption of the wave leads also to growing of the energy of the particle and, consequently, its gyroradius. If we have an interest for the motion of Larmor rings, caused resonance interaction then makes sense speak about this interaction only when the following condition performing $k\rho>1$. If it is not executed, that the displacement of the charged particles extensively (or even basically) is conditioned by change of the sizes of Larmor rings. In this case, for example, particles loss out of system will require the increase their Larmor radius to the size of the system. So, the turbulence is reduced for $s$ (plasma radius/average gyroradius) $\approx$ 1...2. This conclusion complies with experiments [5] (if ions have orbits comparable in scale to the size of the plasma, the predicted modes of MHD instability have much reduced growth rates) and the work [6] where is shown that kinetic effects supress instability growth when the ratio of plasma radius to ion orbit radius is small.

The major conclusions of the study are summarized as follows

1) modeling of anomalous transport in plasma with drift waves is presented in details

2) plasma geometry and particles energy have influence on the transport processes

3) external electric field may control the particles diffusion.

The present level of research on plasma at the presence of electric field has left many issues unresolved, particularly transport theory and plasma microinstabilities. The gap between the present experimental and theoretical data must be overcome by further theoretical research.

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