RESULTS OF NUMERICAL MODELING OF COLLISIONLESS DIFFUSION INDUCED BY ELECTROSTATIC FLUCTUATIONS

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Collisionless particle transport is considered on the base of interaction of plasma particles with wave packets arising as a result of the overlap of many wave modes. Results of calculation of diffusion coefficients are presented for different plasma parameters and parameters of magnetic configuration (plasma temperature, magnetic field value, wave amplitudes, etc.). Low frequency and lower hybrid drift waves are considered. Diffusion coefficients coefficients are obtained as results of averaging over sets of particle trajectories and particle energies.

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In this work some results of quantitative analysis of a new model of anomalous transport are presented. Non-uniform magnetized cylindrical plasma is considered. It is supposed that anomalous transport is a result of interactions of plasma particles with drift waves. Calculations are discussed for low frequency drift (LFD) and lower hybrid drift (LHD) waves.

The first feature of the model under consideration is the taking into account of the presence of wave packets as a sum of wave modes propagating along the azimuthal direction. Therefore in the framework of this model anomalous transport is a result of interactions of ions and electrons with large fluctuations of the electrostatic field of the mentioned wave packets. The similar model for tokamak plasma was supposed by W. Horton et al. [1, 2].

The important feature of our model is the possibility to calculate transport processes in sufficiently non-uniform plasmas. The point is that analysis of drift oscillations is restricted by the following conditions:

$$\chi_n = \frac{a}{n_0}\left|\frac{dn}{dr}\right| << 1,$$

$$\chi_B = \frac{a}{B_0}\left|\frac{dB}{dr}\right| << 1,$$

$$\chi_T = \frac{a}{T_0}\left|\frac{dT}{dr}\right| << 1,$$

or for the separate layer: $|n_2 - n_1| << n$, etc. Here n is the plasma density, B is the magnetic field, T is the plasma temperature, a is the plasma size (or the size of separate plasma layer); n_0, B_0, and T_0 are the scales of n, B, and T; n_1 and n_2 are boundary values of the plasma density for the given layer.

The second feature of our model corresponds to calculations of transport processes in sufficiently non-uniform plasmas. For such plasmas mentioned conditions are not fulfilled. In this connection we have suggested many layer model is used. The whole plasma is divided into many layers in this way that for every layer the conditions written above are fulfilled. In every layer many wave modes are propagated. Therefore this model can be named many layer many modes (MLMM) model. The wave modes of any two neighboring layers are overlapped in correspondence to results of wave equations for drift oscillations [3].

The estimations of diffusion coefficients in presented model are based on calculations of particles orbits in the plasma with LFD and LHD waves. To obtain particle orbits under the action of electrostatic fluctuations we use calculation model developed in [4].

In this study we deal with sufficiently non-uniform plasma of field reversed configuration (FRC). In the FRC plasma is confined in the region of closed magnetic field lines inside the separatrix. To calculate particle orbits and transport processes in the vicinity of the separatrix we use the following approximation of the radial dependence of the magnetic field:

$$B(r) = B_0 - \frac{dB}{dr}(a - r), \qquad (1)$$

where B_0 is the magnetic field value at the separatrix, dB/dr is the magnetic field gradient at the separatrix, a is the separatrix radius.

According the calculations carried out or both LFD and LHD the dependence of the coefficient of the anomalous diffusion is appears to be

$$D \sim \varepsilon^2 B^{-1}, \qquad (2)$$

where $\varepsilon = |e\varphi_0|/(kT_e)$ is the relative level of the electric potential fluctuations, φ_0 is the maximal amplitude of the electric potential of the wave, e is the charge of the electron, k is the Boltzmann constant, T_e is the electron temperature.

In Figs. 1 and 2, examples of the results of the numerical calculations of the particle transport under the action of LHD waves are presented. Different curves in this figures correspond the different series of calculations with different initial conditions (start energy and radial coordinate of the particle, etc.).

From the consideration of single interaction between the particle and electric field pulse radial displacements of the particle can be calculated. Using these displacements and averaged time interval between two interactions one can estimate the diffusion coefficient in the stochastic regime [4], that gives for LFD and LHD the Bohm-like relation:

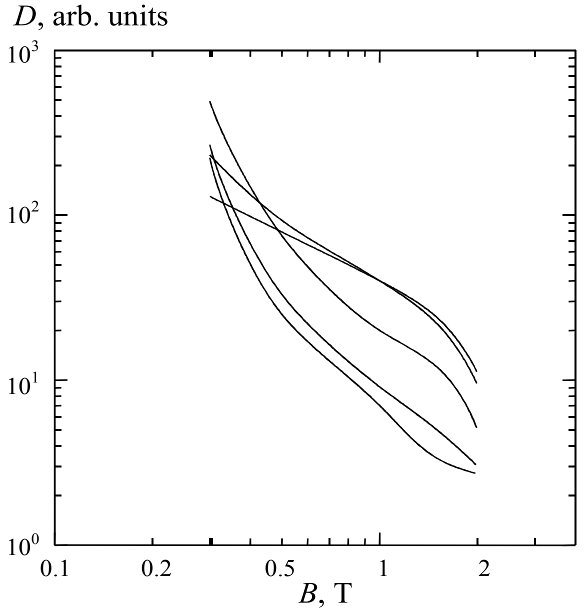

Fig. 1. Results of numerical calculation of diffusion coefficient vs magnetic field for different ion energy: LHD. ε=0.1 is assumed

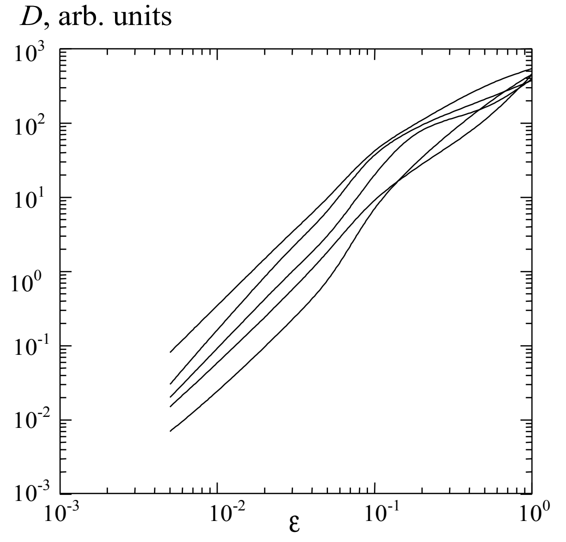

Fig. 2. Results of numerical calculation of diffusion coefficient vs relative amplitude ε for different ion energy: LHD. B=1 T

$$D \approx \varepsilon^2 kT_e (eB)^{-1}. \qquad (3)$$

The scaling law of the averaged particle confinement time corresponding to the diffusion coefficient Eq. (3) is as follows:

$$\tau \sim \varepsilon^{-2} B_0 a^2 T. \qquad (4)$$

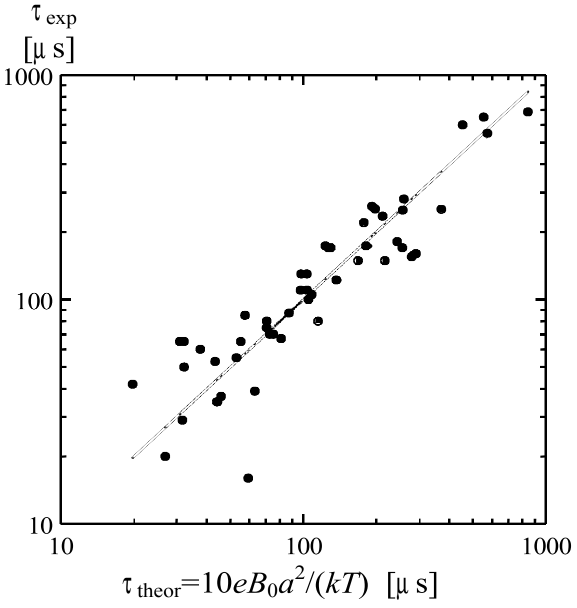

Fig. 3. Comparison of experimental data for FRC particle confinement time [7-10] with the estimations of Ref. [6]

Note that the confinement time estimated from diffusion coefficient Eq. (3) agrees with that previously suggested in Refs. [5, 6] for the field reversed magnetic configurations. In Fig. 3 the comparison of experimental data for FRC particle confinement time [7-10] with the estimations of Ref. [6] is presented.

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РЕЗУЛЬТАТИ ЧИСЕЛЬНОГО МОДЕЛЮВАННЯ БЕЗЗІШТОВХУВАЛЬНОЇ ДИФУЗІЇ, ІНДУКОВАНОЇ ЕЛЕКТРОСТАТИЧНИМИ ФЛУКТУАЦІЯМИ

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Беззіштовхувальна дифузія розглядається з позиції взаємодії частинок плазми й хвильових пакетів , що виникають внаслідок перекриття багатьох хвильових мод. Для різних значень параметрів плазми й магнітної конфігурації (температури плазми, значення магнітного поля, амплітуди хвиль тощо) представлені результати розрахунків коефіцієнтів дифузії. Коефіцієнти дифузії були отримані в результаті усереднення по траєкторіям та енергіям частинок.

РЕЗУЛЬТАТЫ ЧИСЛЕННОГО МОДЕЛИРОВАНИЯ БЕССТОЛКНОВИТЕЛЬНОЙ ДИФФУЗИИ, ИНДУЦИРОВАННОЙ ЭЛЕКТРОСТАТИЧЕСКИМИ ФЛУКТУАЦИЯМИ

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Бесстолкновительная диффузия рассматривается на основе взаимодействия частиц плазмы и волновых пакетов, возникающих в результате перекрытия многих волновых мод. Для различных значений параметров плазмы и магнитной конфигурации (температура плазмы, величина магнитного поля, амплитуды волн и т.д.) представлены результаты расчетов коэффициентов диффузии. Коэффициенты диффузии были получены в результате усреднения по траекториям и энергиям частиц.