

WAVE FIELDS AND TRANSPORT IN PLASMA

V.I. Khvesyuk

Bauman Moscow State Technical University,

2nd Baumanskaya Str., 5, 105005 Moscow, Russia, e-mail: khves@power.bmstu.ru

Analysis of different kinds of wave fields in plasma induced by waves propagating in plasma is made. It is shown that the possible cause of collisionless diffusion is scattering of particles on complex field arising as a result of summarising of many wave modes.

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1. INTRODUCTION

As a rule models of collisionless anomalous transport in plasma are based on quasi-linear theory [1-4]. The simplest approach of anomalous processes takes into account interactions only between two subjects in plasma: charged particles (electron and ions) and low amplitude wave modes. Interactions “wave-wave” and “particle-particle” are not taken into account.

Recently a new model of the wave fields in tokamaks have suggested by W. Horton et al. [5, 6]. This model focuses attention on formation of large electrostatic wave fluctuation (wave packets) representing the summation of many wave modes propagating in plasma.

In this paper similar approach for cylindrical plasma is discussed. Really model implies following picture of the wave field. It includes two components. First component is the background of the weak wave oscillations in plasma. Their averaged a such that they exert negligible action on particles. On the background of the weak oscillations large wave packets are formed. It is the second feature of the model. In the frame of this approach the reason of anomalous transport is the influence of the large field fluctuations (wave packets) on particles.

For cylindrical plasma at fixed radius r the set of azimuthal wave modes appears. These modes satisfy the conditions of existence: $2\pi r/\lambda = \text{integer number}$ (λ is the wavelength), and they have similar amplitude values. Different modes rotate with different velocities. On the background of these modes the wave packets arise and decay. At different radii of non-uniform plasma different sets of wave modes are formed. In the whole the complex picture of the wave field arises.

2. TRANSPORT IN CYLINDRICAL MAGNETIZED PLASMA

It is supposed that amplitudes of all wave modes at fixed radius r are the same and they are equal E_0 . Here wave modes with the same phase velocity are considered. In this case total electrostatic field takes the form

$$E(s, t) = E_0 \cos(k_0 s - \omega_0 t) \sum_{n=-N}^{n=N} \sin \left[n \Delta \omega \left(\frac{s}{v_{ph}} - t \right) \right], \quad (1)$$

where s is the azimuthal coordinate, $v_{ph} = v_{ph}(r)$ is the phase velocity, $E_0 = E_0(r)$, k_0 and ω_0 are the wave vector and frequency, $\Delta \omega$ is the frequency shift. All parameters of the plasma, magnetic field and electric field (1) are choose in such a way that the drift approach to the particle

motion is fulfilled. Then corresponding equation is

$$\frac{dr}{dt} = \frac{E(s, r, t)}{B(r)}, \quad (2)$$

where $B(r)$ is the magnetic field.

The phase angle of the wave θ is introduced. Than the map of Eq. (2) with electric field Eq. (1) in (r, θ) phase plane is the following:

$$\begin{aligned} r_{j+1} &= r_j + K(r) \cos \theta_j, \\ \theta_{j+1} &= \theta_j + 2 \frac{\omega_0}{\Delta \omega}. \end{aligned} \quad (3)$$

Note that $K = \frac{E_0(r)}{B(r)} \langle T \rangle$, where $\langle T \rangle$ is averaged time of the wave packets passage with the respect of magnetized particles. Condition of stochastization is [7]

$$\bar{K} = \left| \frac{\delta r_{j+1}}{\delta r_j} - 1 \right| = \left| \frac{\delta K}{\delta r_j} \right| \gtrsim 1.$$

Therefore K has to be a function of the radius in order to satisfy the stochastization condition

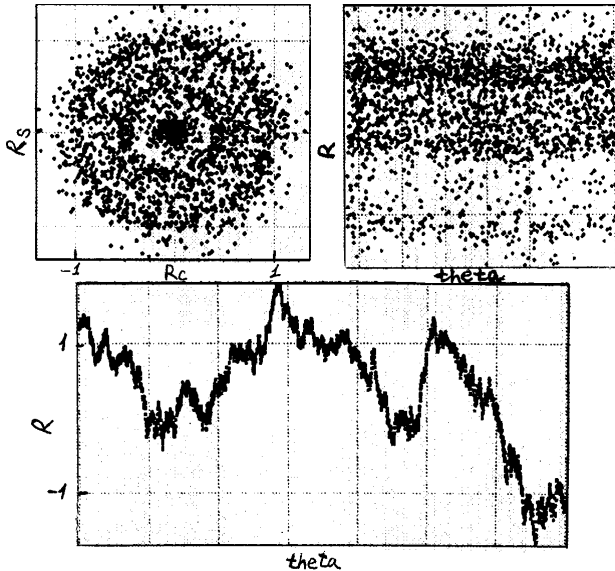
Some results of calculations are presented in the Figure.

3. CONDITION OF AMBIPOLAR TRANSPORT

In this Section the ambipolar condition in the context of considered approach is formulated. In the simplest case of fulfilling of drift approach for electrons and ions within any wave packets this task is considered. Equality of electrons and ions transport flows from equality of averaged direct velocities of different particles with respect to averaged group velocity of wave packets. In the case $\nabla B \neq 0$ the following expression is obtained:

$$\langle V_e \rangle - \langle v_g \rangle \pm \frac{E_r}{B} = \langle V_i \rangle + \langle v_g \rangle \mp \frac{E_r}{ZB}, \quad (4)$$

where E_r is the stationary radial electric field, $B = B_z(r)$ is confining magnetic field directed along z -axis, Z is the ion charge number, $\langle V_e \rangle$ and $\langle V_i \rangle$ are averaged gradient drift velocities of electrons and ions, respectively, $\langle v_g \rangle$ is the averaged wave group velocity. Signs “+” or “-” are determined by the direction of E_r .



Example of calculation of the map (Eq. (3))

4. SUPPRESSION OF ANOMALOUS TRANSPORT

In Ref. [8] it was shown that the considered model explains in principle the reason of suppression of anomalous transport. In mentioned work only influence of steady state electric field E_r was taken into account.

Here the possible reason of increase of E_r due to the growth of temperature is discussed. It is well known that namely added heating results in rise of E_r and suppression of the transport in tokamaks [9]. Gradient drift velocities are

$$\langle V_e \rangle = \frac{k_B T_e}{eB} \chi_B,$$

$$\langle V_i \rangle = \frac{k_B T_i}{ZeB} \chi_B,$$

where k_B is the Boltzmann constant, T_e and T_i are electron and ion temperatures, respectively, $\chi_B = |\nabla B|/B$.

Averaged time of interaction of the particle (electron) with the wave packet is (see Eq.(1)):

$$\langle \tau \rangle = \frac{h}{V_e - \langle v_g \rangle \mp \frac{E_r}{B}}, \quad (5)$$

ХВИЛЬОВІ ПОЛЯ Й ТРАНСПОРТ У ПЛАЗМІ

В.І. Хвесьюк

Виповнено аналіз різних типів хвильових полів, які викликані розповсюдженням хвиль у плазмі. Показано, що причиною беззіштовхувальної дифузії може бути розсіювання частинок у складних полях, які виникають внаслідок складання багатьох хвильових мод.

ВОЛНОВЫЕ ПОЛЯ И ТРАНСПОРТ В ПЛАЗМЕ

В.И. Хвесьюк

Выполнен анализ различных типов волновых полей, вызываемых распространяющимися в плазме волнами. Показано, что причиной бесстолкновительной диффузии может являться рассеяние частиц на сложных полях, возникающих в результате сложения многих волновых мод.

where h is the averaged width of wave packet. Averaged displacement of particles as a result of the interaction is

$$\langle |\Delta r| \rangle = \frac{\langle \tilde{E} \rangle}{B} \langle \tau \rangle, \quad (6)$$

where $\langle \tilde{E} \rangle$ is averaged electric field of the wave packet.

We assume that $\langle v_g \rangle$ is independent on temperature. Then from Eqs. (5) and (6) follows that increasing T_e and T_i lead to decreasing $\langle \tau \rangle$ and $\langle |\Delta r| \rangle$. The initial reason is increase of averaged gradient drift velocities under increase of plasma temperature. Eq. (4) establishes the dependence of E_r on plasma temperature:

$$E_r = \left| \langle V_i \rangle - \langle V_e \rangle + 2 \langle v_g \rangle \right| B.$$

Here E_r is increasing dependence on plasma temperature.

Therefore increase of the temperature leads to increase of E_r . In turn $\langle \tau \rangle$ and $\langle |\Delta r| \rangle$ are decrease in agreement with Eqs. (5) and (6). The similar dependence is observed in experimental investigations [9].

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