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Diffusion and Ionic Heating due to a Current Instability

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This work is concerned with the experimental study of the plasma turbulence, the mechanism of the diffusion and ionic heating associated with a current instability.

The experiment has been performed on a Q-machine. The plasma radius was 2cm, the length - 36cm, H = 1000G, $n \sim 10^9 - 10^{10} cm^{-3}$. The current in the plasma was controlled by changing of the potential of the cold electrode. The cold electrode was either a single disk (4cm in diameter), or a number of disks (diameter ~ 1cm) insulated from each other.

The experiments were carried out in the electron sheath regime. Thus the plasma was stable and the diffusion across the magnetic field was classical.

As it has been shown earlier [1], current passing through one of the 1cm electrodes excites the ion-cyclotron instability [2]. The critical drift velocity of the electrons for exciting this instability is $U_c \sim 35 V_{Ti} \ll V_{Te}$. Under the developed instability the plasma oscillations are regular with the amplitude $\tilde{n}/n \sim 0.1$ and there is no increase of diffusion.

Current passing through the whole plasma cross-section (4cm electrode or a composition of 1cm electrodes) at the same U_c excites low frequency oscillations close to the ion-sound waves [3] and turbulent fluctuations in the region of the ion-cyclotron frequency. When the instability is excited the diffusion increses sharply and ion heating takes place.

To explain these experiments the following model is proposed: when the electron drift velocity reaches U_c, the ion-cyclotron instability is excited. Because of the random character of the initial fluctuations the oscillations in different "current tubes" are not correlated and as a result of this the uncorrelated elecric fields appeare. These fields cause the plasma to escape across the magnetic field.

Low frequency oscillations of relaxating type appeare due to the break-down of the ion-cyclotron instability when the current decreases below the critical level.

The current decreasing is due to density decreasing because of the diffusion.

To check these hypothesis the experiment was performed in which the "current tubes" were simulated by the passing of the current through the 1cm-electrodes. There was found that really the oscillations in different "tubes" are uncorrelated. The excitation of oscillations in neighboring "tubes" lead to the drift of plasma across the magnetic field. The increase in number of "current tubes" leads to the growth of the oscillations amplitude, randomisation of this oscillations and the increase of the diffusion. When the number of "tubes" is sufficiently large and the diffusion increases strongly the low-frequency oscillations appeare. Thus the proposed model of the turbulence development is confirmed. The developed turbulent state was investigated. It was found that the potential oscillation amplitude reaches the value $\tilde{\varphi} \sim (0.5 - 1) T_e$ ($T_e \sim 0.2$eV). The correlation measurement showed that the correlation time τ of the random oscillations is ~ 1period, the average frequency ~ f_{ci}. The radial and asimutal correlation functions have a form of monotonous-falling down curves; the correlation length $l_0 \sim \lambda_\perp \sim 1$cm. The oscillations along the magnetic field are correlated.

Thus the excitation of the ion-cyclotron instability leads to the development of the anisotropic turbulence.

The diffusion coefficient under the developed instability is close to Bohm's one. As a matter of fact $D \sim H^{-1}$ and under H=1000G has a value $D = (1.5 \pm 0.3) \cdot 10^3 cm^2 sec^{-1}$ (under the same conditions $D_{ei} \sim 1 cm^2 sec^{-1}$, $D_B \sim 2 \cdot 10^3 cm^2 sec^{-1}$). The plasma flux across the magnetic field has a character of random bursts correlated with random fields, e.g. the diffusion character is turbulent. The turbulent diffusion coefficient for the case of anisotropic turbulence (which is nearly the same as our case) was theoretically found by Spitzer [4].

$$D = \frac{2c^2 \overline{E^2}}{H^2} \tau = 2k_1^2 k_2^2 k_3 \frac{cT}{eH},$$

where $k_1 = \frac{(\overline{E^2})^{1/2}}{\varphi/\rho_i}$; $k_2 = e\tilde{\varphi}/T$; $k_3 = \tau\omega_{ci}$.

By the Spitzer formula $D = 1.6 \cdot 10^3 cm^2 sec^{-1}$, which is in good agreement with the experimental data.

The excitation of instability is accompanied by the ion heating. The flux of fast ions has a character of bursts correlated the random fields. The ions energy grows with time. Thus one can state that the heating has a turbulent character. When the instability has developed, the ions transverse temperature is $T_{\perp i} \sim 1 - 2$eV. The estimation of $T_{\perp i}$ by the formula for stochastic heating by the turbulent fields [5]

$$T = T_0 + \frac{e^2 \overline{E^2} \tau \Delta t}{2M[1 + (\omega - \omega_{ci})^2 \tau^2]}$$

gives T ~ 1eV. This value is in good agreement with the experimental value.

References

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