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DRIFT-DISSIPATIVE WAVES AND ENSUEING STEADY STATE OF A PLASMA COLUMN

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1. INTRODUCTION. Spontaneously excited low-frequency oscillations[1] with a frequency of the order of the characteristic drift frequency ω^* are identified as drift-dissipative waves[2] and are responsible for the anomalous diffusion observed in a weakly ionized helium plasma column produced by a helical microwave discharge source (see Fig. 1). Plasma parameters are : density, 5×10^9-8×10^{10} cm^{-3}; gas pressure, 1-7$\times10^{-3}$ Torr ; electron temperature T_e, 3-15 eV ; ion temperature T_i, 0.2-1.4 eV ; magnetic field B_o, 850-2200 Gs.

2. THEORY. The plasma consists of hot electrons and hot ions in the presence of background neutral particles and is described by means of the linearized two-fluid equations in which T_e and T_i are introduced by scalar pressure laws and in which only electron-neutral and ion-neutral momentum transfer collisions are included. The radial temperature inhomogeneity is negligible with respect to the density inhomogeneity. The bounded plasma problem is solved in the actual cylindrical geometry.

The static fluid model is characterized by a radial Gaussian equilibrium density profile, $\langle N\rangle(r) = \langle N\rangle_o\, e^{-\alpha r^2}$, where $\langle N\rangle_o$ is the equilibrium density on the column axis. Assuming quasineutrality, strong field approximation, classical ambipolar diffusion and symmetry of revolution, one obtains from the equilibrium momentum equations the radial component of the static electric field, $E_{or} = (KT_i/e\langle N\rangle)(\partial\langle N\rangle/\partial r)$. The value of E_{or} is experimentally verified and found to be negligible for the calculation of the drift wave dispersion relation. We have furthermore checked that the additional possible static effect resulting from the drift wave induced diffusion does not modify the aforesaid value of E_{or}.

Using the $e^{-i\omega t}$ perturbed linearized two-fluid continuity and momentum equations[3] and the Poisson equation, we calculate the dispersion relation for the drift waves in the quasistatic approximation. A first calculation which does not take collisions and mean particle drift velocities into account leads to

$$k_\perp^2 = -(1-\frac{\omega_{ci}^2}{\omega^2})(k_\parallel^2-\frac{\omega^2}{V_S^2}) + 2\alpha n\frac{\omega_{ci}}{\omega} \qquad (1)$$

where $k_\parallel$ is the wavenumber parallel to $\bar{B}_o$, $k_\perp$ is the radial wavenumber and n/r the azimuthal one ; ω_{ci} is the ion-cyclotron frequency and V_S is the ion-acoustic speed. The last term is the extra nonuniform term with respect to the dispersion relation of the ion-acoustic waves in the uniform plasma column[4,5]. This dispersion relation provides an approximate value of $k_\perp$ and when $k_\perp^2V_S^2/\omega_{ci}^2 << 1$, one retrieves the standard Kadomtsev dispersion relation[6].

When we further take collisions and drift velocities into account, we then obtain a dispersion relation which can be written as a polynomial of the sixth degree in ω with complex coefficents[7]. Only one of the six complex roots satisfies the condition for drift waves : $|\omega| << \omega_{ci}$, Im ω > o. The behaviour of the real and imaginary parts of this root is plotted as a function of $k_\perp$ in Fig. 2 and shows the existence of a region of unstable modes. The maximum of the imaginary part occurs at a $k_\perp$-value which is in good agreement with the value obtained from equation (1) when one inserts the observed most strongly excited Re ω-value of the drift wave spectrum. The importance of taking the diamagnetic drift velocity of the ions into account is very pronounced. Indeed, the neglect of the diamagnetism of the ions with respect to that of the electrons results in the disappearance of the unstable region of Fig. 2. This is demonstrated in Fig. 3 by gradually decreasing the value of the ion diamagnetic velocity by decreasing T_i, the other plasma parameters remaining constant.

The steady state density distribution in the plasma column is calculated from the diffusion equation and is given by :

$$\langle N\rangle(r,z) = \sum_{l=1}^{\infty} C_l J_o\left(p_l \frac{r}{d}\right) \exp\left(- \frac{p_l}{d} \sqrt{\frac{D_\perp}{D_\parallel}}\, z\right) \qquad (2)$$

where p_l is the l-the root of the Bessel function J_o, d is the radius of the metal vacuum chamber, $D_\perp$ and $D_\parallel$ are the anomalous diffusion coefficients the values of which are considered in the next section and C_l is a constant determined by means of the boundary condition at z = o.

3. EXPERIMENTAL RESULTS. Several measurements have been carried out which identify spontaneously excited waves as drift-dissipative waves. The observed waves propagate mainly in the azimuthal direction, in the same sense as the electron diamagnetic drift velocity, and have an azimuthal mode number n = 1. The value of $k_\perp$ derived from dispersion equation (1) is corroborated by the measurement of the radial behaviour of the wave amplitude (Fig. 4). Axially, the waves have a wavelength of the order of the length of the plasma column and they propagate from the plasma source towards the end plate, in the direction of $\bar{B}_o$. Finally, the dependence of the wave frequency on T_e is in agreement with that of a drift wave. The anomalous diffusion coefficient $D_\perp$ resulting from the insertion of the experimental data into the theoretical formulae[6] and the experimental value of $D_\parallel$ lead to a steady state density distribution (equation 2) of the plasma column which is in very satisfactory agreement with the measured one. The observed anomalous diffusion and the ensueing steady state density profile in the plasma column are therefore explained by means of the observed drift waves.

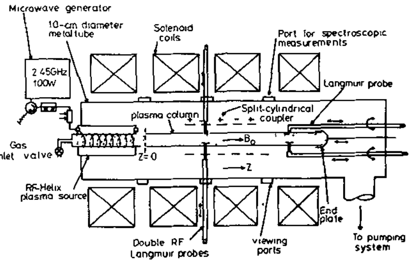

Fig.1 - Schematic diagram of the experimental apparatus.

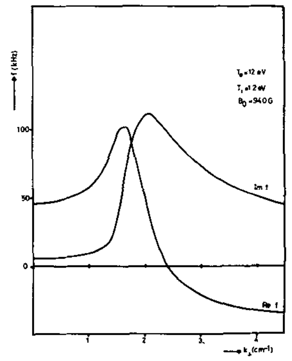

Fig.2 - Theoretically computed behaviour of the real and the imaginary part of the drift wave frequency as a function of $k_\perp$.

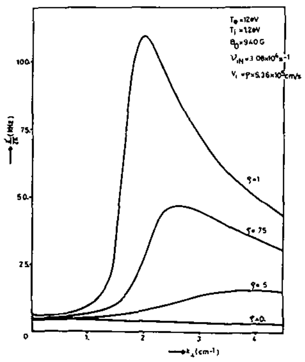

Fig.3 - Theoretically computed behaviour of the growth rate of the drift instability as a function of the ion thermal velocity.

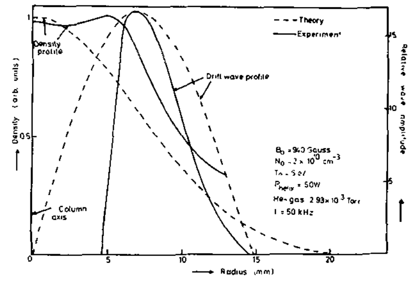

Fig.4 - Relative radial equilibrium density profile and relative axial electric field amplitude as a function of radial distance.

4. REFERENCES.

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