Effect of ion viscosity on shear stabilization of drift dissipative instability

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(Submitted July 18, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **26**, No. 4, 333–336 (20 August 1977)

The influence of the ion mass on the stabilization of drift oscillations by shear was investigated in a toroidal $l=3$ stellarator. A threshold shear value that depends on M_i and starting with which a strong suppression of the oscillations sets in has been observed. It is shown that the drift oscillation level in the entire range of shear variation is smaller the larger the ion mass.

PACS numbers: 52.35.Py, 52.55.Gb

Suppression of drift instabilities of a plasma in a magnetic trap by means of shear or ion viscosity was already investigated theoretically[1–7] and experimentally ([7–10] and the review[11]). The purpose of the present study was to verify experimentally the interrelation between these two stabilizing factors. We report below some results on the influence of ion viscosity on shear stabilization of a drift-dissipative instability of the plasma of a stationary microwave discharge in various gases (helium, neon, argon, and xenon). In contrast to the experiments of[8,9], where the ion viscosity was determined by the pressure of the working gas, i.e., by the ion—neutral collision frequency, we measured the ion viscosity by using its dependence on the mass of the working-gas ion.

The measurements were performed in the "Saturn" toroidal $l=3$ stellarator. The microwave power fed to the plasma (at the frequency of the electron-cyclotron resonance was ~ 10 W. The plasma density and the electron temperature were measured by a microwave technique and with Langmuir probes, while the characteristics of the low-frequency oscillations were determined with Langmuir probes placed on the outside in the central plane of the torus, as well as with a correlation receiver. The experimental conditions were: $H_0 = 3.1$ kOe, angle of rotational transformation on the outermost magnetic surface $t_0 \lesssim 0.5$, average radius of this surface $\bar{r}_0 \lesssim 6.3$ cm, average plasma radius $r \lesssim 5.5$ cm, major radius of torus $R = 36$ cm, dimension of density gradient $a = [(1/n_e)(dn_e/dr)]^{-1} \lesssim 1.5$ cm, $n_e \leq 3\times 10^{11}$ cm^{-3}, $T_e \lesssim 8$ eV, and $T_i \ll T_e$. The shear in the region of the maximum gradient of the plasma density $\theta = (a\bar{r}_0/R)(dt/dr)_{\bar{r}_0}$ ranged from ~ 0.01 to ~ 0.1. Particular attention was paid to maintaining the plasma characteristics for all gases approximately the same

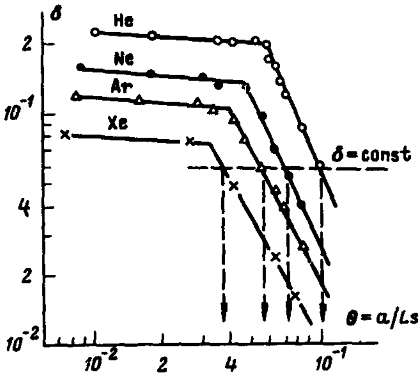

FIG. 1. Effect of shear (θ) on the level of the drift oscillations (δ) for different gases.

(at fixed plasma-configuration parameters). A study of the wave structure and of the frequency of the observed fluctuations ($\omega \approx 3\times 10^4$ sec^{-1}; $k_\perp \approx 0.25$ cm^{-1}; $k_\parallel \approx 0.04$ cm^{-1}; $k_r \approx 4$ cm^{-1}) has shown that the oscillations of the plasma in the region of the density gradient are due to long-wave drift-dissipative instability.[10]

We investigated the dependence of the level of the drift oscillations, $\delta \equiv \langle \tilde{n}_e^2 \rangle^{1/2}/\bar{n}_e$, averaged over the frequency spectrum, on the plasma parameters and the value of the shear. Figure 1 shows, for various gases, the change of the oscillation level with increasing shear. As seen from the plots in Fig. 1, each gas has its own threshold shear θ_{cr}, such that at $\theta < \theta_{cr}$ the change of the shear has practically no effect on the oscillation level. In this discharge regime (with small shear), the main stabilizing factor that determines the level of the drift oscillations is ion viscosity.

In the region $\theta > \theta_{cr}$, a sharp decrease of the low-frequency fluctuations is observed ($\delta \sim \theta^{-3/2}$), indicating the main stabilizing factor is here the crossing of the force lines. The value of θ_{cr} itself decreases with increasing ion mass approximately like $M_i^{-0.25}$ (upper curve of Fig. 2).

At fixed values of the shear in the regions $\theta < \theta_{cr}$ and $\theta > \theta_{cr}$, the amplitude

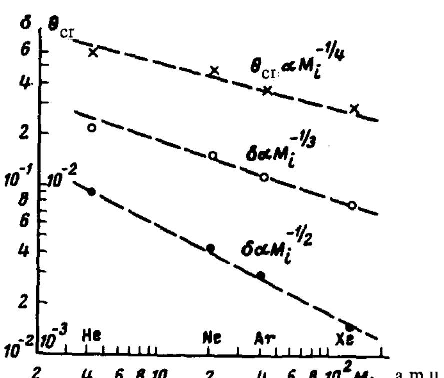

FIG. 2. Dependence of the critical shear (θ_{cr}) and of the drift-fluctuation amplitude (δ) on the ion mass: crosses —θ_{cr}; light circles—δ (at $\theta = 0.015$); dark circles—δ (at $\theta = 0.08$).

of the fluctuations varies like $M_i^{-0.3}$ and $M_i^{-0.5}$, respectively. By way of illustration, Fig. 2 shows data for two values of the shear: $\theta = 0.015 < \theta_{cr}$ (light circles) and $\theta = 0.08 > \theta_{cr}$ (dark circles).

From the data of Fig. 1 it can also be deduced that in the region $\theta > \theta_{cr}$ the shear at which some definite fluctuation levels are established in the various gases vary with the ion mass like $\theta_\delta \sim M_i^{-0.4}$.

The foregoing results thus point to a significant role of ion viscosity, both in the regime with small shear (the region $\theta < \theta_{cr}$) and in the regime with large shear (the region $\theta > \theta_{cr}$). The different relation between the stabilizing factors (shear and ion viscosity) manifests itself in both regime in the different dependences of the steady-state oscillation level on the ion mass ($\delta \sim M_i^{-0.3}$ and $\delta \sim M_i^{-0.5}$).

The observed dependences (of θ_{cr} on M_i, of δ on M_i at constant θ, and of θ on M_i at constant δ) are in satisfactory qualitative and quantitative agreement with the results of the theoretical investigations. In particular, at large values of the shear we find from[4] (with allowance for the fact that the connection between the steady state level of the oscillations and the linear growth rate γ is of the form $\delta \sim \sqrt{\gamma}$[12]) the following relations: $\delta \sim M_i^{-0.5}$ ($\theta = \text{const}$) and $\theta \sim M_i^{-0.5}$ (in the case $\delta = \text{const}$), which agree well with our present data.

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