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STRONG TURBULENCE IN PARTIALLY IONIZED PLASMAS

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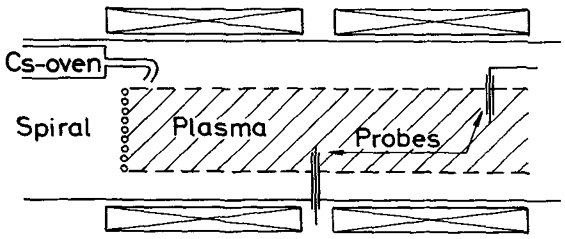
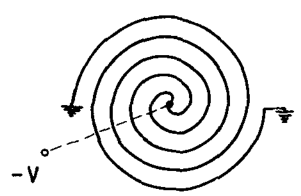
Introduction: The variation of the power spectrum of turbulent potential fluctuations in a rotating low-β plasma was investigated for varying neutral background pressures. For low pressures we find an f^{-5} spectrum. At a well-defined neutral pressure where the ion neutral collision frequency is close to the ion cyclotron frequency we observed a pronounced change in the universal part of the spectrum, resulting in an approximate $f^{-3.5}$ spectrum.

Experimental results: The experiment was conducted in a caesium plasma produced by surface ionization on a hot (∿ 2000 K) spiral made of 2 mm-diameter tantalum wire. The hot filament imposed an almost parabolic potential variation across the plasma column, giving rise to an electric field, $\underline{E}_o$, which increased linearly with radius; the field direction being towards the center of the plasma column. Together with a homogeneous confining magnetic field, variable in the range 0.7-3 kG, this electric field gave rise to a nearly shear-free, "solid body" $\underline{E}_o \times \underline{B}/B^2$ rotation of the entire



(a)



(b)

plasma column. The length of this column was ∿ 1 m and its radius, R ∿ 4 cm. Plasma densities were 10^{9}-10^{10} cm^{-3} and temperatures $T_e \sim T_i \sim 0.2$ eV. Figure 1 shows the experimental set-up schematically. Figure 2a shows the radial potential profile and Fig. 2b the corresponding density variation and density fluctuations $\tilde{n}$ at a low neutral pressure, p = 10^{-5} mm Hg. For further details see refs. /1-2/. (The abscissa in Fig. 1 of ref. /2/ should be corrected as shown in Fig. 2 here). These profiles are somewhat varying with neutral pressure. Fluctuations in floating potential were detected as in ref. /2/. We obtained power spectra like those shown in Fig. 3a. Continuous spectra, indicating fully developed strong turbulence, were found. Fluctuation levels $\tilde{n}/n_o$ were in the range 10-40%.

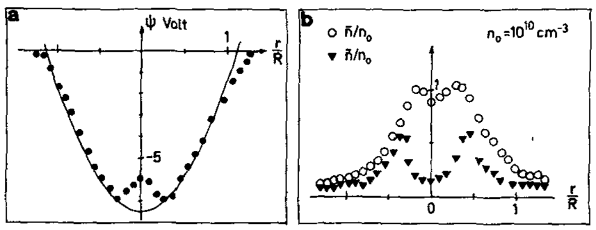


Fig. 2.

In the following we shall be concerned only with the high frequency, or "universal", part of the spectrum. Two subranges were distinguished, denoted "production" and "coupling". Recent theoretical investigations /3/ predict a wavenumber dependence k^{-3} and k^{-5} of the potential power spectrum G(k) in the two subranges at low neutral pressures. (The spectrum is defined, assuming locally homogeneous and isotropic turbulence, so that $\langle\phi^2\rangle = \int_0^\infty G(k)dk$.) Due to the rapid rotation of the plasma column we may rely on Taylor's hypothesis when comparing measured frequency spectra with theoretical wave number spectra, i.e., assume $\omega \simeq k\bar{V}_o$, where $\bar{V}_o$ is the magnitude of the plasma mean drift velocity at the position of the detecting probe. Spectra obtained by this assumption agree with the definition above.

After increasing the neutral background pressure, p, with argon or nitrogen we observed a change in the spectral index for the two subranges. The index variation is shown in Fig. 3b as a function of p/B or in more relevant terms ν/Ω_i, where ν is the ion-neutral collision frequency and Ω_i the ion cyclotron frequency. When calculating ν we took a representative collision cross section $\sigma = 7\cdot 10^{-14}$ cm^2. In reality σ varies somewhat with ion velocity, but this will not qualitatively affect our interpretation of the following.

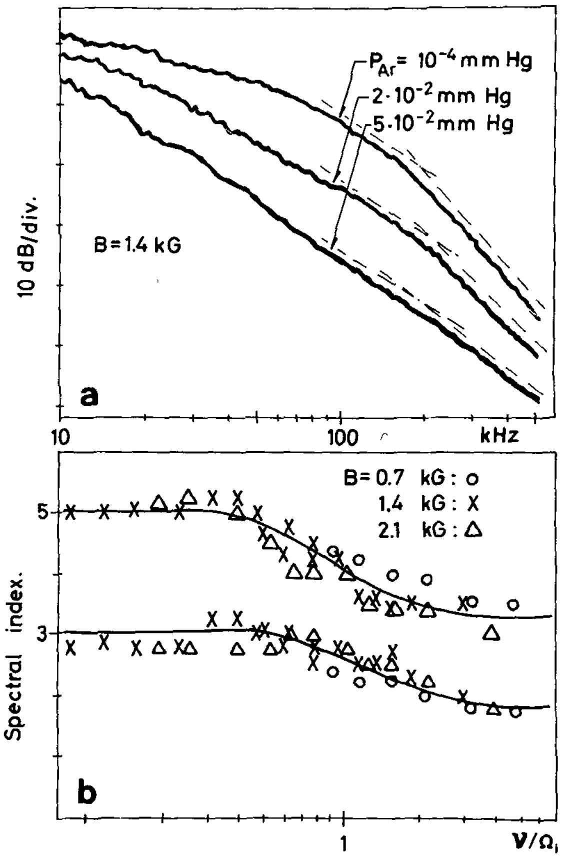


Fig. 3.

By cross-correlating the signal from two Langmuir probes across and along the plasma column we found that the perturbations were strongly field-aligned and travelled in the azimuthal direction. Filtering the two probe signals before performing the correlation, we determined the effective dispersion relation for the fluctuations and found for the subranges in question that the propagation velocity was close to the calculated $\underline{E}_o \times \underline{B}/B^2$ rotation velocity.

For low neutral pressures we identify the instability driving the turbulence as a gradient-driven "universal" instability where the "centrifugal force" on the ions enhances the growth relative to a non-rotating plasma column /4/. For higher neutral pressures (ν comparable to Ω_i), theory /5/ predicts strongly field-aligned perturbations, travelling with the $\underline{E}_o \times \underline{B}$ electron velocity in agreement with our observations. The linear growth rate, Γ, for these instabilities contains two terms: i) a gradient term, and ii) a term that may give rise to instability (the Farley-Buneman instability /5/) also in uniform plasmas.

$$\Gamma \simeq (V_{eo}-V_{io})\frac{\nu_i}{\Omega_i}\frac{1}{n_o}\frac{\partial n_o}{\partial \xi}+\frac{\nu_e k_\perp^2}{\Omega_e \Omega_i}[(V_{eo}-V_{io})^2-c_s^2].$$

By calculating $(V_{eo}-V_{io})$ at the edge of the plasma column we found that the change in spectral index sets in when $(V_{eo}-V_{io}) > c_s$, i.e., when the last term changes sign, thus enhancing the instability. We determined the ion velocity from the ion rotation frequency, ω_x, using the relation $(1+2\,\omega_x/\Omega_i)$ $[(\omega_E/\Omega_i)-(\omega_x/\Omega_i)-(\omega_x/\Omega_i)^2]=(\omega_x/\Omega_i)(\nu/\Omega_i)^2$, where ω_E is the uniform $\underline{E}_o \times \underline{B}$ rotation frequency. Note that an increase in the $\underline{B}$-field requires a roughly proportionate increase in collision frequency ν, i.e., an increase in neutral pressure, to produce the same ω_x. This is precisely what is indicated by Fig. 3b.

References:

/1/ N. D'Angelo, H.L. Pécseli and P.I. Petersen, J.Geophys.Res. 79 (1974) 4747

/2/ T. Mikkelsen and H.L. Pécseli, Phys. Rev. Lett. 41 (1978) 951.

/3/ C.M. Tchen, H.L. Pécseli and S.E. Larsen, Risø Rep. No. 365 (1977).

/4/ T.K. Chu, B.Coppi, H.W.Hendel and F.W. Perkins, Phys. Fluids 12 (1969) 203.

/5/ A. Rogister and N. D'Angelo, J.Geophys. Res. 75 (1970) 3879.