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INSTABILITY OF AN INHOMOGENEOUS PLASMA

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1. It has been shown theoretically [1] that oscillations can build up in an inhomogeneous plasma with phase velocities on the order of the velocities of the Larmor drift of the particles in a magnetic field. The resultant instability is called drift (universal) instability. In spite of the appreciable progress made in the theory, experimentally this form of instability has been little investigated. The purpose of this study was to investigate an inhomogeneous plasma produced in a low-pressure arc discharge with incandescent cathodes[2]. The first series of investigations [3] have been devoted to the behavior of such a discharge at low pressures (from 5×10^{-6} to 10^{-4} torr). It has been shown that a negative charge column is formed in this case and becomes unstable under certain conditions. This is manifest in the appearance of a torch which rotates in stationary fashion on the electron side, and breaks away from the region of the primary beam. The instability has a drift character, and the appearance of the torch is a result of the polarization of the plasma in the beam of primary electrons in the presence of azimuthal inhomogeneity in the density and of a difference in the drift velocities of the ions and electrons. In the present communication we describe briefly the main experimental results obtained at higher pressures (4×10^{-4} - 10^{-2} torr).

2. The plasma was produced in an equipotential volume of 76 mm diameter and 400 mm long, the cathode diameter being 10 mm. The working gas was for the most part hydrogen, and in some cases He, N_2, Ne, and Ar. The magnetic field ranged from 100 to 3000 Oe. A stationary discharge was produced in the chamber with U_a from 100 to 400 V and I_a up to 600 mA. The measurement of the plasma parameters, and of the oscillations that accompany the instability was by means of Langmuir probes, but in some cases a plasmoscope [2] was used.

3. The investigation of the plasma instability has shown that there are two characteristic regions. In the first there are no plasma oscillations and the diffusion has a classical character. In the second, oscillations are observed with a spectrum that depends on the plasma parameters, and the diffusion has both classical and anomalous behavior features. The conditions for the occurrence of the plasma instability, and the character of the instability, depend strongly on the initial transverse gradients of density, potential, and temperature. To determine these quantities, experiments were set up under the conditions

preceding the appearance of the instability. Measurement of the radial density and potential distributions has shown that two characteristic regions exist outside the arc column. Near the column, up to distances on the order of the ion Larmor radius r_i, there is an appreciable electron temperature gradient T_e, connected with cooling of the electrons by the collisions as they move transversely to the field. This produces in this region a potential gradient and a sharp drop in density, with a decrement q_1 of the order of several millimeters. In the second region, which is located several times r_i from the beam boundary, there is practically no temperature gradient and T_e is small. This leads to a constant potential and a slower decrease of density, with a decrement q_2 of the order of several centimeters. As shown by the measurements, the values of the decrement q_1 and of the electric field on the boundary of the arc column vary little with the discharge parameters, and the variation of the decrement q_2 is well described by the well known expression [4] $q_2 = \ell/\pi(\omega_i\tau_i)^{-1}$.

4. Oscillations of several dozen kcs frequency were produced in the plasma at magnetic field intensities (H_{cr}^{ac}). The observed oscillations of the plasma density or potential did not exceed as a rule 1% of the average values of these quantities. The character of the diffusion transverse to the magnetic field remained classical. The value of H_{cr}^{ac} depends on the type of gas and on the pressure, and does not vary with the anode current or with the discharge voltage. Figure 1, plotted in coordinates $\eta = a_0 r_i \sim Ha_0$ and $\xi = (\lambda_i/a_0)(T_e/T_i)^{1/2} \sim 1/Pa_0$, shows the boundary of this instability. The quantity $a_0 = 5$ mm is the radius of the arc column, T_e was assumed equal to 10 eV, while the ion-neutral collision cross sections were taken from [5] for $T_i = 1$ eV. An investigation of the spatial distribution of the amplitude and of the phase of the oscillations has shown that the wave propagating in the plasma is standing relative to the longitudinal axis of the apparatus and is traveling in the azimuthal direction. To clarify the nature of the instability, experiments were set up to determine the dependence of the oscillation frequency on the discharge parameters. We observed a realignment of the oscillation modes, such that the condition $n/m = \text{const}\ \ell/a_0\ (T_eA)^{1/2}\kappa$ was always satisfied (A is the atomic number of the gas, $\kappa = d \ln n_i/dr$, n and m are the oscillation modes in length and in azimuth). Knowing the values of n and m we could determine in each case the fundamental frequency of the oscillations and the phase velocity of the wave. It turns out that the frequency remains practically unchanged under varying discharge conditions and ranges from 20 to 30 kcs for hydrogen, the phase velocity being 2.2×10^6 cm/sec and coinciding

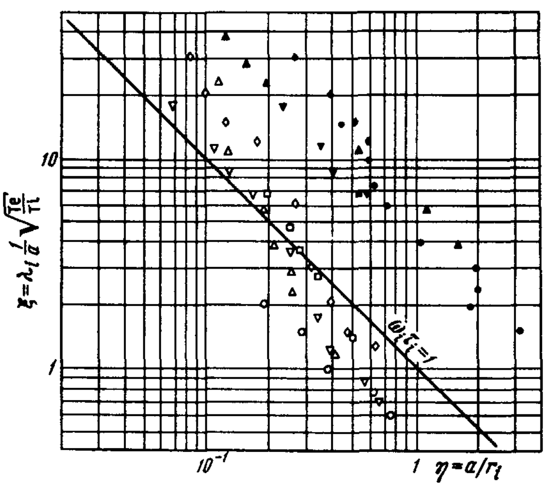

Fig. 1

	H_2	He	N_2	Ne	Ar
Ion sound	○	△	▽	◇	□
Drift	●	▲	▼	◆	■

in order of magnitude with the sound velocity in the plasma $c_s = (\gamma T_e/m_i)^{1/2} = 4.5 \times 10^6$ cm/sec. The experiments performed with different gases agreed well with the $\sim m_i^{-1/2}$ variation. These results made it possible to suggest that longitudinal ion-sound waves were excited in this case.

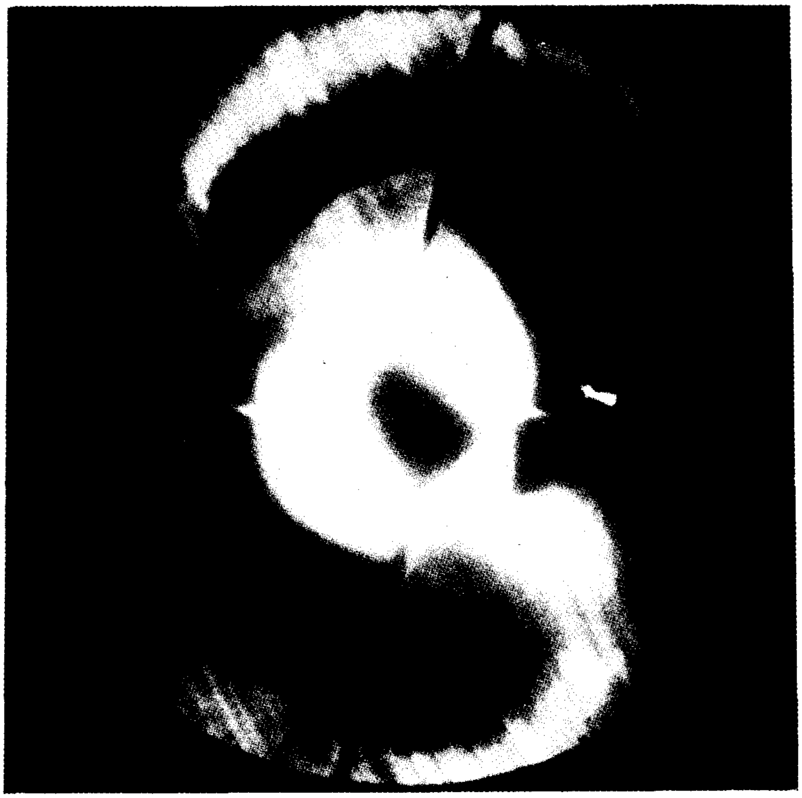

Fig. 2

5. An increase of the magnetic field to H_{cr}^{dr} leads to a sharp change in the character of the transverse diffusion and to the development of intense plasma oscillations. The values of H_{cr}^{dr} depend in practice only on the pressure and on the type of the gas. A probe analysis of the phase relations in the oscillations, and a study of the plasmograms have shown that in this case torches break away from the primary column and propagate considerable distances transversly to the magnetic field. Fig. 1 shows the experimental values of (H_{cr}^{dr}) for different gases. The character of the instability varies with the magnetic field. Near the critical field, as a rule, a stable torch structure is observed (Fig. 2), which

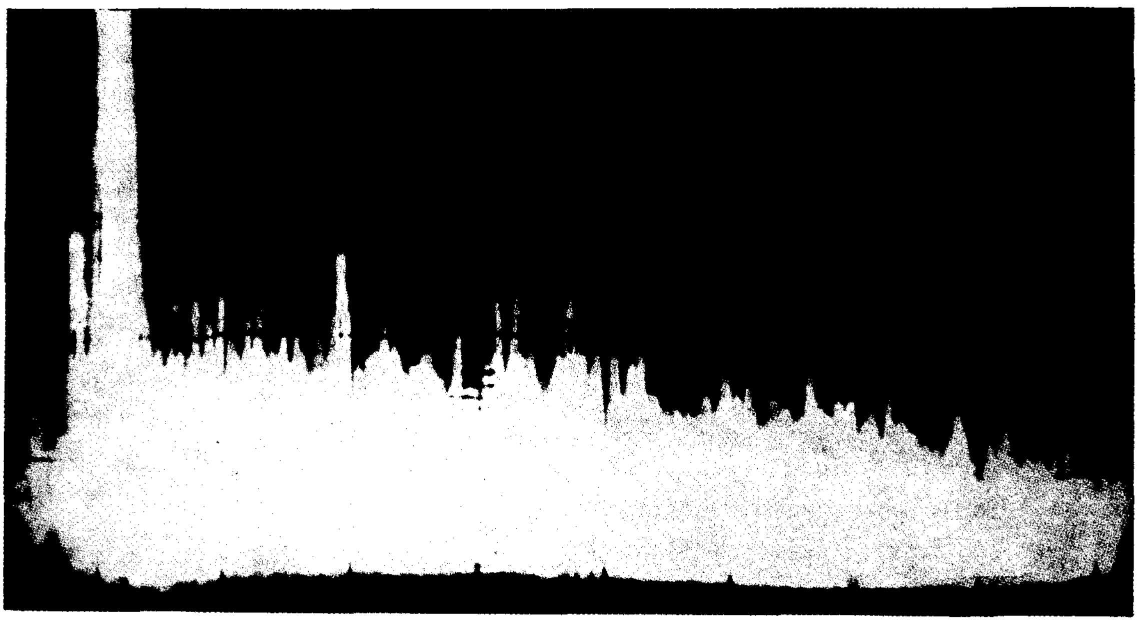

Fig. 3. Spectrum of oscillations on probe at H = 2500 Oe.

rotates in a stationary fashion on the ion side. With increasing field, the rotation ceases to be stationary, but one can still separate in the oscillation spectrum the frequency corresponding to the rotation, against the background of a broad noise spectrum. Further increase in H leads to a strong randomization of the oscillations (Fig. 3). The analysis of the instability has shown that it can be identified with the developed drift-dissipative instability described in [6]. The limit of this instability corresponds to the condition $\omega_i\tau_i > 1$, as is well confirmed experimentally (Fig. 2).

It must be noted that when this instability sets in the ion-sound oscillations do not disappear, and the number of produced torches always coincides with the number of the mode m for the ion sound near the instability limit.

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DEPENDENCE OF THE DENSITY OF ROTATING LIQUID HELIUM ON THE ANGULAR VELOCITY

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The question of the change in the density of rotating helium II, compared with its motionless state, is of considerable interest in view of the presence in it of quantized Onsager-Feynman vortices [1]. In particular, we frequently encounter the assumption, both spoken and published, that the presence of vortex filaments so to speak "loosens up" the rotating helium II.

To ascertain the velocity dependence of the density of helium II we undertook an experiment, in which a sensitive pycnometer was set in rotation. This pycnometer (Fig. 1) is a 52.57-cc copper bulb connected to a glass capillary (length 60 mm, i.d. 1.75 mm). The top of the capillary expands into a small sphere, and the bottom is glued into the sleeve of the valve used to regulate the amount of liquid helium in the pycnometer. During the measurements the valve was closed, and the pycnometer is illuminated with a daylight lamp and viewed in a cathetometer. The accuracy of each individual reading was in this case ± 0.005 mm, and the scatter of the experimental data did not esceed ± 0.2 mm, making it possible to measure the relative change of the density with accuracy $\Delta\rho/\rho = \pm\ 0.0009\%$. The entire pycnometer was placed in a vessel made of organic glass and in a liquid-helium bath. This vessel was set in rotation in the usual fashion, with the drive shaft passing through a collar coaxial with the