dicated by Reed and Sodem [3], but they did not observe the complex structure of the $r_H^*(\phi)$ dependence in the vicinity of directions parallel to [111] and [110].

[1] N. E. Alekseevskii, K. Kh. Bertel', A. V. Dubrovin, and G. E. Karstens, ZhETF Pis. Red. 6, 637 (1967) [Sov. Phys.-JETP 6, 132 (1967)].
[2] N. E. Alekseevskii, A. V. Dubrovin, G. E. Karstens, and N. N. Mikhailov, Zh. Eksp. Teor. Fiz. 54, 350 (1968) [Sov. Phys.-JETP 27, 188 (1968)].
[3] W. A. Reed and R. R. Soden, Phys. Rev. 173, 677 (1968).

CRITICAL FIELDS AND STRUCTURE OF ION-ACOUSTIC INSTABILITY OF THE PLASMA OF AN INDUCTION HIGH-FREQUENCY DISCHARGE IN H_2, Ar, AND Hg IN A MAGNETIC FIELD

V. L. Vdovin, V. D. Rusanov, and D. A. Frank-Kamenetskii
Submitted 12 June 1969
ZhETF Pis. Red. 10, No. 3, 120 - 125 (5 August 1969)

A study of a weakly ionized HF discharge plasma has shown that when the magnetic field reaches the critical value of the plasma becomes unstable both in an induction discharge [1, 2] and an E-discharge [3, 4] (alternating field $\vec{E}_\sim \parallel \vec{H}_0$). The critical fields H_{cr} in a hydrogen plasma were compared in [4] with the theoretical values of the ion-acoustic instability of an inhomogeneous plasma [5, 6], and good agreement was obtained.

Since the ion sound is essentially determined by the electron temperature T_e and by the ion mass M_i, to determine the nature of the instability it is of great interest to study the plasma of various gases. In addition, it is of interest of compare the structure of the oscillations that build up with the structure predicted in [5]:

$$\omega \approx -k_y\sqrt{T_e/M_i} > \Omega_i, \quad k_y \gtrsim \kappa(\Omega_i r_i)^{-1}, \quad k_z^2 \lesssim k_y^2(b_i/b_e)$$

(the magnetic field is directed along the z axis, the density gradient along the x axis, Ω_i - $eH/M_i c$, τ_i is the time between the ion-neutral collisions, and $\kappa = dn/n\,dx$).

We report in this paper the results of measurements in an induction HF discharge plasma in hydrogen, argon, helium, and mercury vapor, in which the electron temperature changed by a factor of 12 and the ion mass by a factor of 100. We measured the critical magnetic fields, the frequencies, and the spatial structure of the developing oscillations. The spatial correlation of the oscillations and of the noise was studied. The results are identified as ion-acoustic instability of an inhomogeneous plasma.

The plasma ($f = 20$ MHz, $n_e = 10^9 - 10^{10}$ cm^{-3}, $H = 0 - 600$ Oe, gas pressure $P = 2 \times 10^{-2}$ Torr in H_2, He, Ar and $p = 4 \times 10^{-2} - 2.6 \times 10^{-4}$ Torr in mercury vapor) was produced by a six-turn loop 10 cm long, placed over a glass tube of diameter $2a = 3.2$ cm and length 100 cm. T_e varied with the pressure, for example, $T_{Hg} = 1.2$ V, $T_{Ar} = 3.2$ V, $T_{H_2} = 5$ V, and $T_{He} = 9$ V at $P = 4 \times 10^{-2}$.

1. The critical magnetic fields of the various gases are plotted in Fig. 1 in coordinates $\eta = a/\tau_H\sqrt{b_e/b_i}$ and $\xi = \sqrt{T_e/M_i}\,\kappa\tau_i = \lambda_i/a\sqrt{T_e/T_i}$, in which the individual features of the gas are lost [5]. Here b_e and b_i are the ion and electron mobilities, and r_H the ion Larmor radius calculated from the electron temperature. The solid line indicates the theoretical limit of the ion-acoustic instability [5, 6]. The values of T_e were taken from experiment at $H = H_{cr}$, and b_e and b_i were assumed [7] equal to (in cm^2/sec-V-Torr): a) hydrogen - $b_i = 10^4/P$,

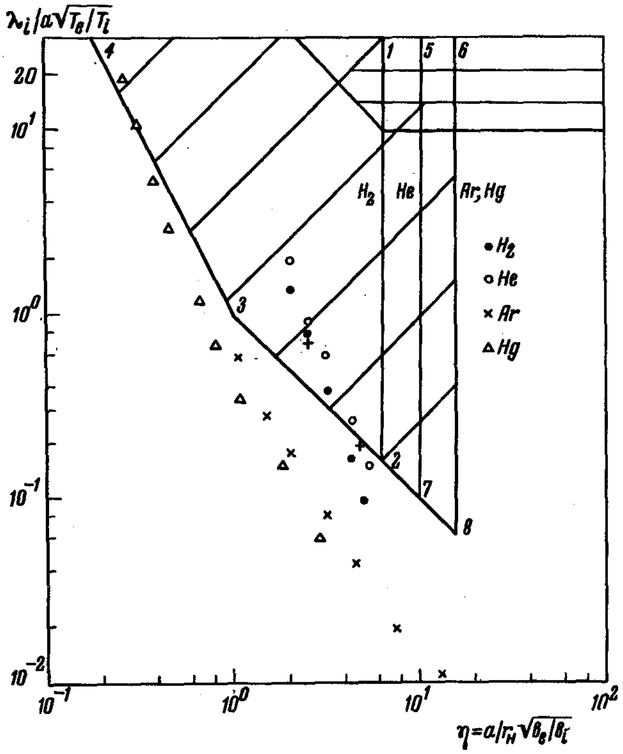

Fig. 1. Limit of onset of ion-acoustic instability. Experiment: ● - hydrogen, o - helium, × - argon, Δ - mercury. The solid line shows the theoretical values: H_2 - 1234, He - 5734, Ar and Hg - 6834 (abscissas - the quantity $\eta \sim H$, ordinates - $\xi \sim 1/ap$.

$b_e/b_i = 40$; b) helium - $b_i = 8.2 \times 10^3/P$, $b_e/b_i = 100$; c) argon - $b_i = 1.22 \times 10^3/P$, $b_e/b_i = 260$; d) mercury vapor - $b_i = 182/P$, $b_e/b_i = 230\ \sqrt{T_e}$.

2. The dependence of the ion current to the wall on the magnetic field, $I_W(H)/I_W(0)$ for hydrogen ($P = 10^{-1}$ Torr) and mercury ($p_{Hg} = 4 \times 10^{-4}$ Torr) is shown in Fig. 2. Starting with $H = H_{cr}$, the diffusion becomes anomalously large, and when $H >> H_{cr}$ the wall current saturates, i.e., D_{turb} is approximately independent of H, in agreement with the theoretical estimate $D_{turb} \sim \sqrt{T_e/M_i}\ \kappa^{-1}$ [6].

H_2		Hg	
p, Torr	*f*, kHz	*p*, Torr	*f*, kHz
$1.8 \cdot 10^{-1}$	200	$3.6 \cdot 10^{-2}$	8.6
$1.2 \cdot 10^{-1}$	200	$1.8 \cdot 10^{-2}$	9.1
$9 \cdot 10^{-2}$	220	$5.8 \cdot 10^{-3}$	16.7
$7 \cdot 10^{-2}$	235	$3.6 \cdot 10^{-3}$	33
$6.5 \cdot 10^{-2}$	240	$2.1 \cdot 10^{-3}$	36
$5.4 \cdot 10^{-2}$	250	$1.4 \cdot 10^{-3}$	60
$3.4 \cdot 10^{-2}$	440	$2.6 \cdot 10^{-3}$	36
$3 \cdot 10^{-2}$	480	$1.6 \cdot 10^{-3}$	60

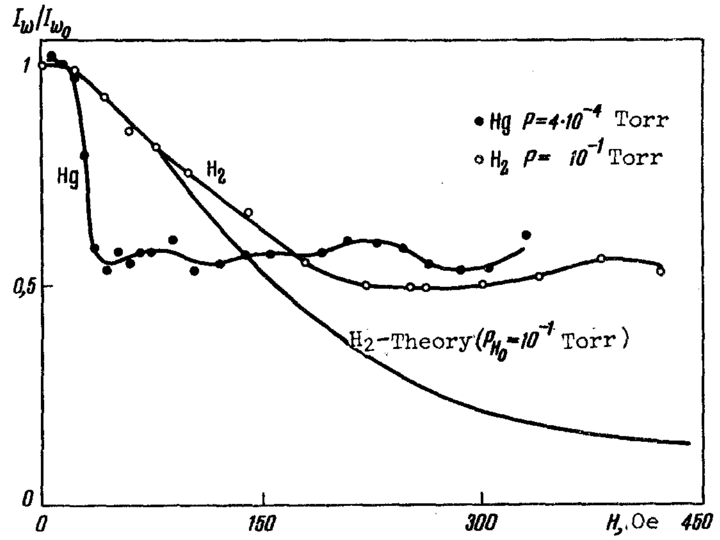

Fig. 2. Ion current to wall probe with guard ring as a function of the magnetic field in the diffusion (hydrogen) and collisionless (mercury) regimes.

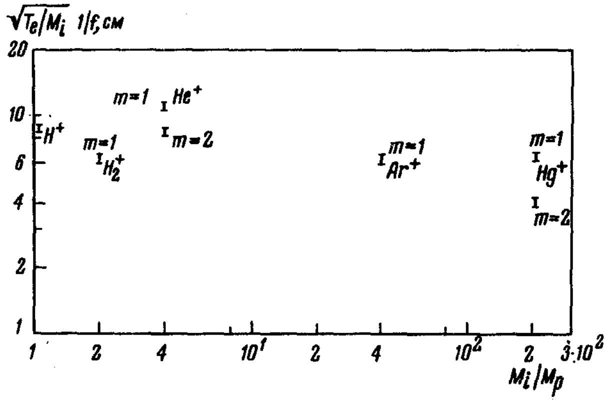

Fig. 3. The quantity $\sqrt{T_e/M_i}\times(1/f)$ vs. the ion mass for hydrogen, helium, argon, and mercury.

3. The frequencies of the oscillations excited in the plasma depend strongly on the type of gas, and depend quite little on the pressure. The frequencies first excited in the pressure interval 2×10^{-1} - 3×10^{-2} Torr are approximately 220, 110, 40, and 10 kHz in hydrogen, helium, argon, and mercury vapor respectively. These frequencies increase somewhat with decreasing pressure.

The dependence of the frequencies on the pressure in a hydrogen plasma is described in greater detail in the table. The results can be systematized by examining the dependence of the quantity $\sqrt{T_e/M_i}$ (1/f) on the ion mass. The result is shown in Fig. 3: in spite of the fact that T_e changes by a factor of 12 ($T_{He}/T_{Hg} \approx 12$), the mass M_i changes by 100 times, and the frequency f by 25 times, the quantity $\sqrt{T_e/M_i}$ (1/f) remains approximately constant and amounts to 6 - 6.5 cm in hydrogen, argon, and mercury and 11 cm in helium. We note that the perimeter of the discharge tube is 10 cm long. Finally, taking into consideration the values of the critical fields, we see that $\omega > \Omega_i$ for all gases.

4. A study of the phase shift of the signals from various points of the plasma has shown that the waves excited in the plasma are standing along the axis and traveling in azimuth. These waves are characterized the integers m and k, where m is determined by the relation $2\pi r = m\lambda_\phi$, and k is equal to the number of nodes along the tube axis. At pressures

larger than 3 x 10^{-2} Torr, the first to be excited is the oscillation with m = 1 and k = 3 (the plasma is inhomogeneous along the tube axis). At lower pressures, the first to be excited was the oscillation with m = 2, and excitation a the mode with k = 3 was observed in a mercury plasma. The longitudinal wavelength was approximately six times larger than the azimuthal one.

Finally, it was established that the wave travels in the direction of electron rotation in the magnetic field. At a field much stronger than critical, when there is a well developed turbulence (noise), the correlator was used to determine the spatial correlation coefficient of the noise $R(\phi)$. It turns out that the noise is well correlated in the entire volume of the plasma, i.e., the "mixing scale" postulated in [6] does not exist here.

We have thus shown that the critical magnetic fields, the diffusion, the characteristic oscillation frequencies, the structure of the unstable oscillations, and the direction of their motion, in a wide range of electron temperatures and ion masses (H_2, He, Ar, and Hg), are in good agreement with the theory of ion acoustic instability of an inhomogeneous plasma [5, 6].

We note that the instability considered here differs noticeably from the ion acoustic instability of a discharge with an incandescent cathode [8], in which a buildup of longitudinal "ambipolar" sound was observed, and the diffusion remained classical.

The authors are grateful to B. B. Kadomtsev and A. V. Timofeev for useful discussions.

[1] C. I. Ransom and H. Schluter, Phys. Lett. 13, 313 (1964).
[2] V. L. Vdovin, V. D. Rusanov, and D. A. Frank-Kamenetskii, Nuclear Fusion 6, 169 (1966).
[3] B. Svilkin and A. A. Zaitsev, Izv. Vuzov Radiofizika 7, 844 (1964); E. I. Powers, Phys. Fluids 8, 1155 (1965).
[4] I. Polman, Phys. Lett. 15, 48 (1965); Plasma Phys. 9, 471 (1967).
[5] A. V. Timofeev, Dokl. Akad. Nauk SSSR 152, 84 (1963) [Sov. Phys.-Dokl. 8, 890 (1964)].
[6] B. B. Kadomtsev, in: Voprosy teorii plazmy (Problems of Plasma Theory), v. 4, pp. 201 and 300, Gosatomizdat, 1964.
[7] E. W. McDaniel, Collision Phenomena in Ionized Gases, Wiley, 1964.
[8] M. Vlasov, ZhETF Pis. Red. 2, 274 (1965) [JETP Lett. 2, 174 (1965)]; M. Vlasov, Dissertation, M., 1966.

HALL COEFFICIENTS OF FERROMAGNETS IN THE PARAPROCESS REGION

T. N. Igosheva
Submitted 12 June 1969
ZhETF Pis. Red. 10, No. 3, 125 - 129 (5 August 1969)

To describe the Hall effects in ferromagnets in the paraprocess region, a three-term expression was used in [1]:

$$E = R_0 H + R_J J_s + R_i J_i , \qquad (1)$$

where E is the Hall emf per unit current through the sample and per unit sample thickness, R_0 and R_J are the ordinary and anomalous Hall coefficients, R_i is the Hall coefficient corresponding to the true magnetization J_i (equal to the difference between the total magnetization (J) and the spontaneous magnetization (J_s) of the sample), and H is the true magnetic field intensity in the sample, $H = H_e - NJ$, where H_e is the intensity of the external magnetic field and N is the demagnetizing factor of the sample. It was stated in [1] that