SUPPRESSION AND PARAMETRIC AMPLIFICATION OF ION SOUND IN A PLASMA

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Submitted 15 January 1969
ZhETF Pis. Red. 9, No. 5, 278 - 281 (5 March 1969)

Parametric resonance at electron and ion plasma frequencies has been the subject of a number of studies [1 - 3]. In the present paper we report the results of an investigation of parametric amplification of ion-acoustic oscillations when a low-frequency electric field is applied to the plasma, as well as a number of data connected with the nonlinearity of the processes that occur in the plasma, namely the suppression of ion-acoustic oscillations and resonant amplification at the frequency $f = 3f_0$, where f_0 is the frequency of the ion-acoustic oscillations.

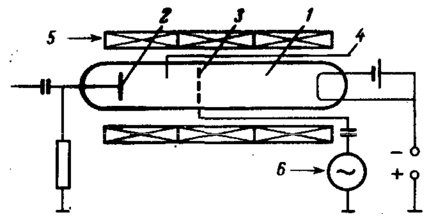

Fig. 1. Diagram of setup: 1 - cathode, 2 - anode, 3 - grid, 4 - Langmuir probe, 5 - solenoid, 6 - low-frequency generator.

The experiments were performed with the setup illustrated in Fig. 1. The discharge tube was 5 cm in diameter and 23 cm long. The tungsten cathode was directly heated. A grid and a cylindrical Langmuir probe, both movable, were located between the anode and the cathode. The grid had the form of an asterisk and was made of molybdenum wire 0.4 mm in diameter. The working gas was argon at a pressure $P \approx 10^{-3}$ mm Hg. The discharge current and the voltage were varied in the intervals 0.1 - 0.4 A and U_a = 30 - 50 V, respectively. A longitudinal magnetic field of intensity H = 0 - 50 Oe was applied to the tube. The electron temperature was T_e = 4 eV and their density was $n_e \sim 10^{10}$ cm^{-3}.

The flow of current excited in the plasma low-frequency oscillations corresponding to the fundamental mode of the standing ion-acoustic wave between the grid and the anode. Indeed, the frequency of the observed oscillations was independent of the discharge current, varied in inverse proportion to the distance between the grid and the anode, and agreed well with the value calculated from the formula

$$f_0 = 1/L\sqrt{kT_e/m_i},$$

where m_i is the ion mass and L the distance between the grid and the anode.

A sinusoidal voltage from the generator was applied to the grid, which was at a floating potential. The oscillations excited in the plasma were picked off from the anode or from the probe.

The experiments were performed under two conditions, with different values of the amplitudes U of the spontaneously excited ion-acoustic oscillations: 1) $eU/kT_e \ll 1$ and 2) $eU/kT_e \leq 1$. The results pertaining the the former case are shown in Figs. 2 (curve 1) and Fig. 3 (curve 1). When an alternating electric voltage of definite magnitude is applied to the plasma, amplification of the ion-acoustic oscillations takes place (Fig. 2, curve 1). This effect does not appear if the amplitude of the external signal has either low or sufficiently high. The amplitude of the ion-acoustic oscillations has resonances at external-

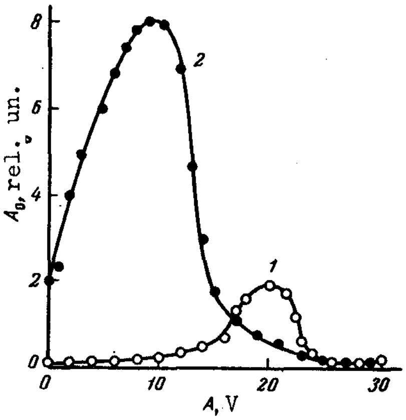

Fig. 2. Amplitude A_0 of ion-acoustic oscillations vs. external-signal amplitude A: 1) L = 7 cm, f_0 = 22 kHz, f = 45 kHz; 2) L = 4.5 cm, f_0 = 34 kHz, f = 68 kHz.

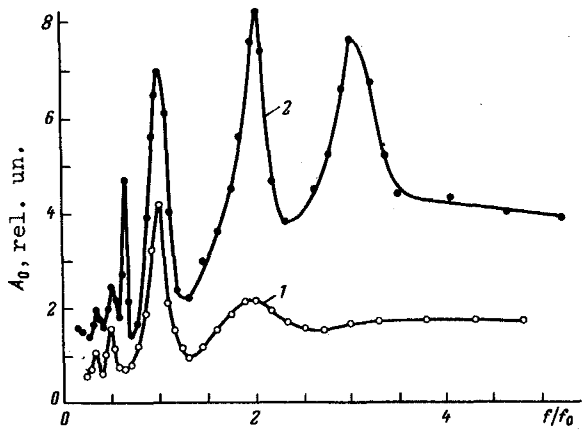

Fig. 3. Amplitude A_0 of ion-acoustic oscillations vs. external-signal frequency f: 1) L = 7 cm, f_0 = 22 kHz, A = 20 V; 2) L = 4.5 cm, f_0 = 34 kHz, A = 10 V.

signal frequencies $f = 2f_0/n$ (n = 1, 2, 3, 4, and 6; Fig. 3, curve 1).

The data pertaining to the second case are shown in Figs. 2 and 3, curves 2. Curve 2 of Fig. 2 indicates that there is no threshold for the amplification of the ion-acoustic oscillations. When the alternating grid voltage is sufficiently large, the natural oscillations are strongly suppressed, i.e., the ion-acoustic instability vanishes. The suppression of two-beam ion-acoustic instability was observed in [4]. It is seen from Fig. 3 (curve 2) that besides the frequencies $f = 2f_0/n$ (n = 1, 2, 3, 4, and 6), corresponding to parametric resonance, there is also resonance at the frequency $f = 3f_0$, thus indicating that the interaction between the alternating electric field and the natural oscillations of the plasma is nonlinear. The nonlinearity may be connected either with the rather high level of the natural oscillations or with the anharmonicity of the external action, since the amplitude of the alternating voltage is of the same order as the floating potential of the grid. In the case when $eU/kT_e \ll 1$, the oscillatory processes in the system can be described by an equation of the type

$$\frac{\partial^2 X}{\partial t^2} + \omega_0^2(1 + h\cos\omega t)X = 0,$$

where $h \ll 1$, $\omega_0 = \pi/L\sqrt{kT_e/m_i}$, and ω is the signal frequency. The alternating grid voltage can cause oscillations of the electric layer at the grid (i.e., a change of the wavelength), and also a periodic change of the electron temperature, resulting from the partial penetration of the field into the plasma [5].

In the former case we have

$$h \simeq \Delta L/L \simeq 1/L\sqrt{A/2\pi n_e e}$$

(A - amplitude of signal on grid), and in the latter case

$$h \simeq 2\delta\nu E/\omega E_0,$$

where ν is the frequency of the collisions between the electron and the neutral atoms, E the amplitude of the alternating electric field in the plasma, E_0 the intensity of the constant electric field, and δ the fraction of the energy transferred to the electrons by the neutral atoms in the collisions. Our estimates yield the same order of magnitude, $h \sim 10^{-2}$, for both cases.

To clarify the possible mechanism of parametric amplification, and als the effect of the suppression of ion-acoustic instability, further investigations are necessary.

When this communication was being readied for publication, we have learned of another investigation [6] in which parametric excitation of ion sound was observed at a frequency $f = 2f_0$.

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E R R A T A

In the article by E. M. Barkhudarov et al., Vol. 9, No. 5, the formula on p. 163 should read "$f_0 = 1/2L\sqrt{kT_e/m_i}$," and not "$f_0 = 1/L\sqrt{kT_e/m_i}$."