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OBSERVATION OF ION OSCILLATIONS IN A PLASMA

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Ion oscillations have been observed against the noise background of a discharge plasma (charge density approximately $10^{10}\,\mathrm{cm}^{-3}$). The results which have been obtained can be interpreted if it is assumed that the probe selectively detects oscillations characterized by a wavelength approximately equal to the radius of the ion sheath which surrounds the probe.

As is well known, ion oscillations with a limiting frequency

$$f_0 = \sqrt{ne^2/\pi M} \qquad (1)$$

have been observed in electron beams with compensated space charge.[1,2] However, no one has as yet been successful in observing oscillations of this kind in a gas-discharge plasma.[3] The existence of resonance effects at frequencies close to f_0 has been indicated by Rutgaizer and Kononenko.[4] In the present paper we describe a possible direct experimental observation of self-sustaining ion oscillations in a gas discharge plasma.

A plasma is formed in an arc discharge in mercury vapor (pressure approximately 10^{-3} mm) in a discharge tube 1 (cf. Fig. 1); the charge density in the plasma can be varied as required by changing the discharge current. The plasma contains a cylindrical probe 2 (diameter 100 μ and length 5 mm). If necessary it is possible to insert a similar fixed probe 3 near the first and the distance between these probes can be varied from 0 to 15 mm.

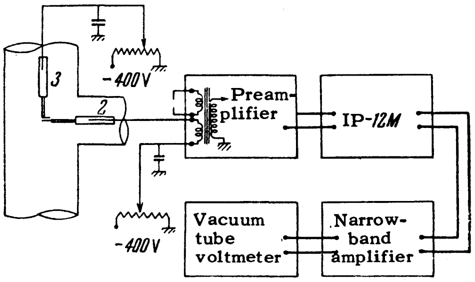

FIG. 1

An important factor in the observation of oscillations is the detection system. The signal picked up by the probe is fed to a preamplifier with transformer input and then to a superheterodyne amplifier (IP — 12M) and a special narrow-band amplifier[5] (band width approximately 100 cps) which consists of three stages with quartz filters (frequency 455 kcs). The sensitivity of the entire amplifier is approximately 2×10^{-8} v.

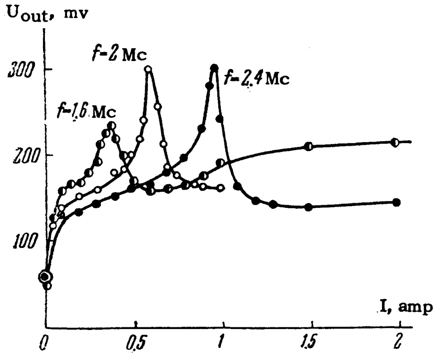

FIG. 2

The measurements are carried out as follows. The amplifier is tuned to a fixed frequency f and the dependence of the signal at the output of the amplifier on discharge current I (i.e., charge density in the plasma) is determined (Fig. 2). The signal at the output of the amplifier increases abruptly when the discharge is fired, and then increases more or less sharply as the discharge current is increased to approximately 0.1 amp; the signal variation then becomes a sensitive function of probe potential. If the negative potential of the probe is small (less than 30 — 40 v), the signal increases monotonically with further increase in discharge current. For negative probe potentials of large absolute value, however, the dependence of signal on discharge current exhibits a more or less clearly defined maximum. The position of this maximum depends primarily on the frequency f to which the amplifier is tuned; when f is increased the maximum is displaced in the direction of higher plasma charge densities (cf. Fig. 2).

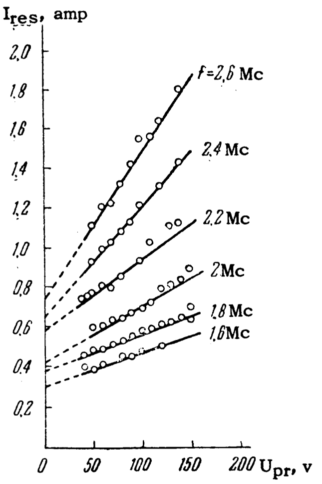

FIG. 3

It is reasonable to explain the results described above in the following manner. The signal, which increases monotonically with increasing discharge current, is due to plasma noise; the plasma ion oscillations must be detected against this background. A reduction in the bandwidth of the amplifier and an appropriate choice of the negative probe potential makes it possible to observe these oscillations, which appear in the form of maxima such as those shown, for example, in Fig. 2. An increase in the negative probe potential reduces the probe current component associated with the fast plasma electrons and thus reduces the noise signal picked up by the probe as long as the negative probe potential remains within proper limits. The important role played by the probe potential is indicated by the dependence of resonance current (we shall call the discharge current at which the indicated maximum in the output signal is observed the resonance current) on probe potential. In Fig. 3 we show the dependence of resonance current I_{res} on probe potential U_{pr} obtained at various frequencies f. These curves can be obtained (indicating oscillations) only in the frequency range 1 — 3 Mcs, and only for a definite range of probe potentials. One of the reasons for the limited frequency range is the characteristic of the amplifier system which is used. The ratio of the signal to intrinsic noise in this device has a maximum in the region of 2 Mcs and falls off away from this frequency.

In order to explain the dependence of resonance current on frequency f and probe potential we turn to the familiar expression for the frequency of ion oscillations (cf. reference 6)

$$f = f_0/\sqrt{1 + ne^2\lambda^2/\pi kT_e}, \tag{2}$$

where f_0 is the limiting frequency given by Eq. (1) and λ is the wavelength. From Eq. (2) we can get an expression for the plasma charge density n, which is determined by the discharge current, for given values of f and λ:

$$n = f^2/(e^2/\pi M - e^2f^2\lambda^2/\pi kT_e). \tag{3}$$

We shall not try to justify here the assertion that the probe exhibits a selective response to oscillations at a wavelength λ close to the order of magnitude of the radius of the ion sheath that surrounds the probe; we can only call attention to the fact that this assertion allows a qualitative interpretation of the relations shown in Fig. 3. Since the radius of the ion sheath increases with increasing probe potential, the quantity n and consequently the resonance current should increase with increasing frequency f and with increasing negative probe potential U_{pr}. This effect is observed in the present experiments.

Furthermore, the following inequality follows from Eq. (3):

$$\lambda^2 < kT_e/Mf^2, \tag{4}$$

this inequality indicates a limit on the negative potential of the probe, as has been observed in the experiments described above. To compare the relation in (4) with experiment, we give the following example. Under the present conditions ($T_e = 3.8 \times 10^4$°K) with $f = 2 \times 10^6$ cps, computed by means of Eq. (4), we have $\lambda_{max} = 6.4 \times 10^{-2}$ cm. The experiment indicates (cf. Fig. 3) that when $f = 2 \times 10^6$ cps it is impossible to observe oscillations at a negative probe potential greater than 150 v; the resonance current for this potential is 0.9 amp. The calculation shows that with this plasma (anode current 0.9 amp) an ion sheath with a radius of 6.4×10^{-2} cm is formed at approximately 130 v. The fact that the experimental and calculated values of the maximum probe potential are of the same order of magnitude is also evidence in favor of the assertion made above concerning the selective effect of the ion sheath at the probe.

It follows from Fig. 3 that the concentration n_0 and, consequently, the resonance current I_{0res} corresponding to the limiting frequency f_0 should be determined for $\lambda \rightarrow 0$, i.e. by extrapolation of the curves in Fig. 3 to zero probe potential. In Fig. 4 we show the dependence of $\sqrt{I_{0res}}$ on frequency obtained by extrapolation of a number of experimental lines. Here we also give the calculated line obtained by means of Eq. (1) and the experimentally determined depend-

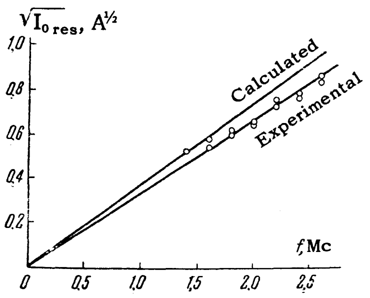

FIG. 4

ence of charge density in the plasma on discharge current: $n = 3.1 \times 10^{10}\ I$ (I in amperes). It is apparent that the discrepancy between the experimental and calculated lines does not exceed the differences frequently observed in investigations of electron plasma oscillations; this discrepancy may be attributed to experimental errors, errors in the extrapolation procedure, etc.

The comparison shown in Fig. 4, together with the facts indicated above, would seem to indicate that in the present experiments we have actually observed ion oscillations and have qualitatively verified the relation given in Eq. (2).

The complexity of the effects which attend the detection of oscillations by the probe also appear in the following interesting fact. If a second probe is placed in line with the measurement probe and the second probe is kept at a negative potential, the ion-oscillation signal is increased — the signal-to-noise ratio reaches 10 — 20 under these conditions. However, the dependence of resonance current on the potentials of the two probes is complicated and has not yet been interpreted.

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[1] K. G. Hernqvist, J. Appl. Phys. **26**, 544, 1029 (1955).

[2] E. G. Linder and K. G. Hernqvist, J. Appl. Phys. **21**, 1088 (1950).

[3] Armstrong, Emeleus, and Neill, Proc. Irish Acad. **54**, 291 (1951).

[4] V. D. Rutgaizer and K. I. Kononenko, Уч. зап. Харьковского гос. ун-та, (Sci. Notes, Khar'kov State University) **64**, 203 (1955).

[5] D. E. Hildreth, Electronics **28**, 166 (December, 1955).

[6] L. Tonks and I. Langmuir, Phys. Rev. **33**, 195 (1929).

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