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EXCITATION OF LOW-FREQUENCY WAVES IN A CURVED MAGNETIC FIELD GEOMETRY

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In thermal cesium and potassium plasmas in a straight magnetic field geometry, low-frequency oscillations (in the 5- to 30-kc/sec range) have been observed.[1] They appear only when an ion sheath was present near the tungsten plate where the plasma was produced. The oscillation frequencies fell into three different groups: 9 to 12 kc/sec, 17 to 20 kc/sec, and 26 to 29 kc/sec; i.e., they were, roughly, in the ratio 1:2:3. In each range the frequency turned out to be independent of the magnetic field strength B, for B between 2000 and 5000 gauss. Measurements of the relative phases of the oscillations at different locations in the plasma provided evidence for density perturbations traveling azimuthally, with one maximum ($m=1$) for the first range of frequencies, two maxima ($m=2$) for the second range, and three maxima ($m=3$) for the third. The azimuthal component of the phase velocity turned out to be the same in all three cases. The oscillations could be interpreted as low-frequency ion waves propagating at right angle to the existing density gradient and the magnetic lines. For a plasma of such a low β (ratio of material to magnetic pressure) as thermal alkali plasmas ($\beta \approx 10^{-7}$), these waves are quasielectrostatic waves, with the E vector parallel to the k vector. With no steady radial electric fields in the plasma column, both ions and electrons have macroscopic velocities of equal magnitude and opposite sign, in the azimuthal direction, to balance the pressure gradients. The magnitude of the phase velocity of the waves coincides with that of these macroscopic velocities.

With straight magnetic lines, these waves were observed only when an ion sheath was present at the hot tungsten plate. Without an ion sheath, however, these waves are expected also to be excited when the magnetic lines are curved.[2] In this note we report the excitation of these low-frequency waves in a curved magnetic field geometry.

The experimental arrangement (ALMA II) is similar to the Q-1 and Q-3 alkali plasma devices in Princeton. The plasma is produced by contact ionization of cesium atoms on a hot (~2300°K) tantalum plate. The plasma is confined radially by a uniform magnetic field (up to 3000 gauss), and at the opposite end of the column terminated by a second tantalum plate which can be heated also to ~2300°K ("double-ended" operation) or left at room temperature and allowed to assume its floating potential ("single-ended" operation). The plasma column has a diameter of approximately 3 cm. Experiments were conducted with two different lengths, 160 cm and 80 cm. The neutral gas pressure is kept in the 10^{-6} mm Hg range. With densities of about 10^{11} cm^{-3}, this device is capable of percentage ionizations of 30% or larger. Measurements were made with Langmuir single probes with areas of ~1 mm^2. The curvature of the magnetic lines was obtained by superimposing upon the homogeneous magnetic field B_0 a suitable transverse magnetic field B_t. This additional field, in the plane of the resulting magnetic lines, has quite closely the form $B_t = B_t{}^* l$, where l is the distance from the middle plane of the device and, therefore, changes sign at $l = 0$. Over the distance between the two tantalum plates, the resulting B field lines are quite closely circular, with the radius of curvature R being determined by $B_t{}^*/B_0$. Experimentally, R was obtained from the displacement of the plasma column at the middle plane of the device.

With $B_t{}^* = 0$, the plasma was adjusted to "quiescent" conditions (absence of ion sheath). Then, if the B_t field was applied, oscillations in the 5-kc/sec to 30-kc/sec range were observed, provided that the curvature of the magnetic lines was sufficiently large ($R \lesssim 30$ m). To make sure that applying the B_t field did not, somehow, produce an ion sheath at the tantalum plate, the temperature of the plate was raised by ~200°K, but the oscillations remained unchanged. The above experiments were performed with two lengths of the plasma column (80 cm and 160 cm), in both the "single-ended" and "double-ended" operation.

To establish that the oscillations were indeed of the same type of those of reference 1, we measured (a) the frequency of the oscillations, (b) the relative amplitude of the oscillations as a function of radial position, (c) the phase relation between pairs of points at different locations in the column. As for (a), two "modes" of oscillations were observed, the $m = 1$ and $m = 2$ modes, with frequencies in the range of 5 to 8 kc/sec and 12 to 15 kc/sec, respectively. Occasionally also higher frequencies (~20 kc/sec) appeared.

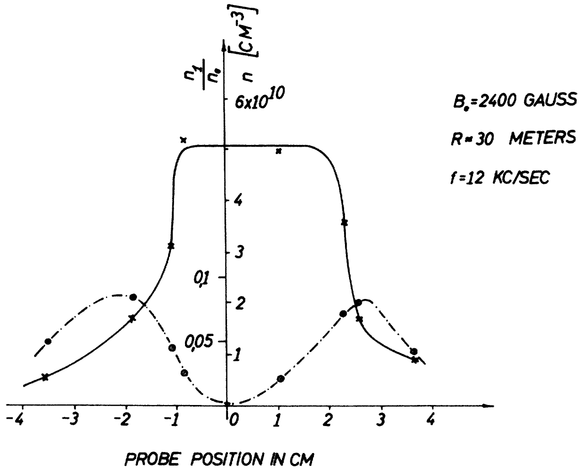

FIG. 1. Radial distribution of density (solid line) and relative density fluctuation (dot-dash line) at the middle plane of the device.

For the oscillations with frequency in the 12- to 15-kc/sec range, the frequency was roughly independent of the magnetic field strength, for B between 1000 and 2400 gauss. Furthermore, in the same range of B, the quantity $fB\xi$, where f is the frequency and ξ the e-folding length of the radial density profile, was found to be a constant (within 15%), in agreement with the results of reference 2.

As for (b), in Fig. 1 the radial density distribution and the relative density fluctuation n_i/n_e are given, for $B_0 = 2400$ gauss, $R = 30$ m, peak density $n \approx 5 \times 10^{10}$ cm^{-3}, $f = 12$ kc/sec. The relative density fluctuation has maxima at about the positions of the largest density gradients.

As for (c), the oscillations were found to be in phase at two corresponding points of two plasma cross sections separated by a distance of 35 cm. Furthermore, by moving a probe parallel to the axis of the device over a distance of 5 cm, no phase change was observed. For the oscillations with frequency in the 5- to 8-kc/sec range, the oscillations were 180° out of phase at two diametrically opposite points in the same plasma cross section; for the oscillations with the frequency in the 12- to 15-kc/sec range they were in phase. Further phase measurements were made with two probes which could be moved together across the plasma column and were separated by a distance of 1.4 cm. The results of these measurements are given in Fig. 2. The observed frequency was ~14 kc/sec, and the phase measurements agree fairly well with what

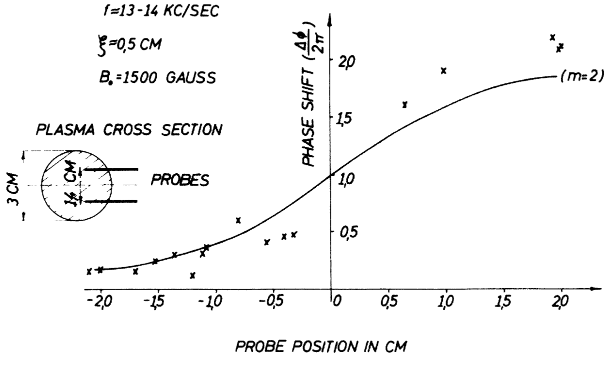

FIG. 2. Relative phase as a function of radial probes position. The solid curve is the calculated phase difference for an $m = 2$ perturbation. In this figure the 0 probe position corresponds to the center of the radial density distribution.

is expected for an $m = 2$ perturbation.

The question naturally arises of the effect of these oscillations on plasma confinement. Experiments with alkali plasmas in a straight magnetic field geometry have shown particle loss rates in agreement with the theory of classical diffusion.[3] On the other hand, recent experiments[4] on particle losses of a cesium plasma in a stellarator have yielded particle lifetimes of about 15 msec, i.e., much smaller than expected from classical diffusion and recombination.

One of the reasons for performing the present experiment was to investigate the above discrepancy in a device where the curvature of the magnetic lines could be varied continuously. At present, however, our results on this point are still far from conclusive. Further work is being done to clarify this question. Moreover, the investigation of the behavior of cesium thermal plasmas in different kinds of curved magnetic geometries (e.g., scallops, mirrors) is under way.

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RADIAL AND AZIMUTHAL STANDING SOUND WAVES IN A GLOW DISCHARGE

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While modulating a dc glow discharge to study the moving striations, a pronounced displacement, or kinking, of the constricted discharge path was observed at a series of discrete modulation frequencies. A study of this effect in argon and krypton over a range of gas temperature has established that the observed frequencies are those of radial and azimuthal standing waves of sound generated by the electrical oscillations imposed on the discharge.

The tube and circuit are shown in Fig. 1. The cathode could be moved along the tube with a magnet to change the discharge length. The heating wires wrapped around the concentric glass tube were used to raise the temperature of the discharge. The outside wall temperature of the tube was measured at four places (t_1, t_2, t_3, t_4) using thermocouples wired to the wall. The unmodulated discharge and the discharge strongly modulated at two of the critical frequencies are pictured in Fig. 2. Although the kink spacing along the tube generally decreased with increasing frequency, we found no evidence of resonances corresponding to longitudinal standing waves. The critical frequencies are independent of tube length and the kink spacings are not inversely proportional to the applied frequency.

The lowest frequencies at which the displacement of the discharge occurs and the ratios of the successive higher frequencies to this lowest frequency are given in Table I together with the relevant discharge parameters. The theoretical frequency spectrum $\omega_{n,m}/\omega_{0,1}$ is shown at the left, listed in order of increasing frequency and identified by the radial characteristic value n and the azimuthal characteristic value m deter-

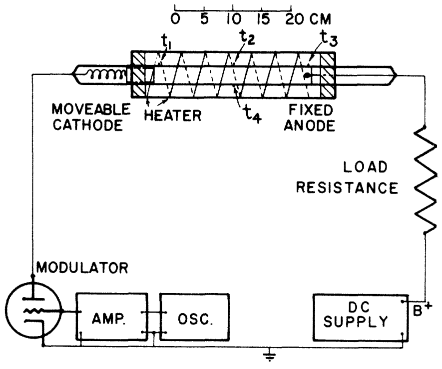

FIG. 1. Discharge tube, heater, and modulating circuit. Thermocouples on wall at t_1, t_2, t_3, and t_4.