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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*On leave from Plasma Physics Laboratory, Princeton, New Jersey.

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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-

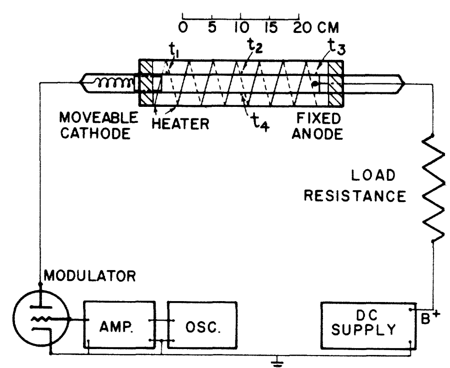

FIG. 1. Discharge tube, heater, and modulating circuit. Thermocouples on wall at t_1, t_2, t_3, and t_4.

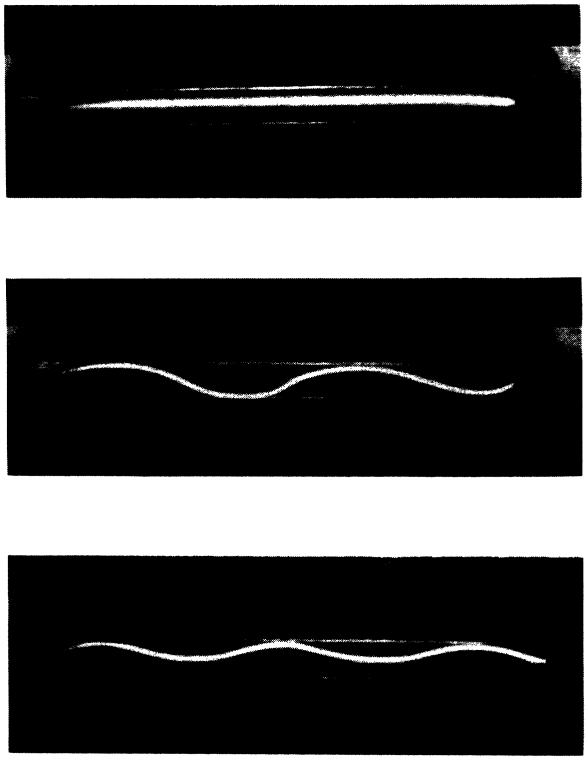

FIG. 2. Constricted krypton discharge. $p=23.5$ mm Hg, $I=40$ mA. Top: Unmodulated. Center: 90% modulation, $\omega_{0,1}/2\pi=5.56$ kc/sec. Bottom: 65% modulation, $\omega_{1,0}/2\pi=11.60$ kc/sec.

mined by the boundary condition $J_m'(\omega_{n,m}a/c)=0$ (particle velocity vanishes at wall) and the condition that the density be a single-valued function of the azimuthal angle φ. (a is the internal radius of the cylindrical tube and c the speed of sound in the gas.) All of the resonances in Table I except those in parentheses can be ascribed to azimuthal modes $m=0$ or $m=1$. The preferential excitation of the $m=0$ modes is to be expected because of the cylindrical symmetry of the tube. The excitation of the $m=1$ modes is probably connected with the displacement of the discharge path from the tube axis, establishing a preferred direction perpendicular to the axis. The bottom row contains the effective gas temperature, T, computed from $a\omega_{0,1}/1.84=(\gamma kT/m)^{1/2}$. Here $\gamma=\frac{5}{3}$, $a=1.30$ cm, and 1.84 is the first zero of J_1'. Since the gas temperature varies within the discharge, being greatest near the cathode and near the axis, it is not possible to compare a single measured temperature with this computed temperature. The next-to-the-bottom row contains the average of the readings of the external wall temperature at the middle of the tube made with thermocouples t_2 and t_4. The wall temperature at the cathode was from 15° to 100°K greater than this, depending on the discharge conditions.

From Table I it can be seen that the observed resonance frequencies are independent of pres-

Table I. Observed frequency spectrum.

n m	$\omega_{n,m}/\omega_{0,1}$ (theor)	Krypton $p=13.2$ mm Hg $I=15$ mA modulation 30% (unheated) $\omega_{n,m}/\omega_{0,1}$	Krypton $p=31.7$ mm Hg $I=20$ mA modulation 15% (unheated) $\omega_{n,m}/\omega_{0,1}$	Krypton $p=13.2$ mm Hg $I=100$ mA modulation 35% (unheated) $\omega_{n,m}/\omega_{0,1}$	Krypton $p=23.5$ mm Hg $I=100$ mA modulation 35% (heated) $\omega_{n,m}/\omega_{0,1}$	Argon $p=29.5$ mm Hg $I=10$ mA modulation 35% (heated) $\omega_{n,m}/\omega_{0,1}$	Argon $p=38.5$ mm Hg $I=100$ mA modulation 35% (heated) $\omega_{n,m}/\omega_{0,1}$
0 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0 2	1.66		(1.46)(1.63)				
1 0	2.08	2.07	2.14	2.10	2.11	2.07	2.04
0 3	2.28						
0 4	2.89						
1 1	2.90	2.85		2.88	2.89	2.85	2.86
0 5	3.48						
1 2	3.64			(3.62)			
2 0	3.81	3.78		3.84	3.81	3.86	3.80
0 6	4.07						
1 3	4.35						
2 1	4.63	4.58		4.63		4.55	
0 7	4.66						
1 4	4.87						
$\omega_{0,1}/2\pi$ (kc/sec)		5.37	5.38	5.75	6.91	10.45	10.54
T_{wall} (°K)		304	310	333	504	574	514
T(computed) (°K)		342	343	392	566	618	639

sure and current, except as these affect the gas temperature, and that the dependence on molecular mass and temperature is characteristic of sound waves. It is clear that we are not observing the ionic sound waves reported by Crawford[1] and by Alexeff and Neidigh[2] because (1) our frequencies correspond to the gas temperature, not the electron temperature, and (2) the frequency spectrum is characteristic of the zeros of J_m', not J_m.

Measurements of the frequency spectrum in a tube with an internal radius of 0.83 cm gave frequencies higher in the ratio of 1.30/0.83, confirming the expected dependence on tube radius.

The frequency band over which a given mode was excited increased with increasing modulation. The data in Table I were obtained near the minimum modulation at which the displacement could be observed (10-35%). At these modulations the band width varied from 0.1 to 1.4 kc/sec. The displacement was often observed to move from the anode end of the tube toward the cathode as the frequency was increased, suggesting that at least a part of the frequency spread results from temperature gradients in the gas. The frequencies listed in Table I are those for which the displacement was greatest at the center of the tube.

At modulations greater than 50%, additional resonances were observed, in particular a weak resonance at $\omega_{0,1}/2$. It is thought that these additional resonances result from the excitation of standing sound waves by harmonics of the applied frequency, since the discharge voltage and the discharge current are rich in harmonics. The resonances at low modulation that cannot be ascribed to the $m=0$ or $m=1$ modes may result from higher azimuthal modes (as suggested by their position in Table I) or they may be lower azimuthal modes generated by harmonics of the applied frequency. Resonances at higher frequencies than those reported in Table I have been observed, but since the frequency spectrum is approaching a continuum it is difficult to identify the modes represented. If it is assumed that only $m=0$ and $m=1$ are excited, then these higher resonant frequencies can be assigned to the $n=3,4$; $m=0,1$ modes which they fit closely.

It is not known what influence sound waves have on the unmodulated discharge, but there have been frequent suggestions[3] that the space-charge oscillations accompanying the moving striations are coupled in some way to oscillations of the gas density. We did not notice any interference of the sound resonances with the standing light patterns[4] that were sometimes observed.

The phenomenon reported here may find application by providing a way of measuring the gas temperature in a constricted discharge from observations of the sound resonances. It is suggested that the converse effect, the production of electrical oscillations by sound waves generated in the tube by an external source, be searched for.

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*National Science Foundation undergraduate research participation student.

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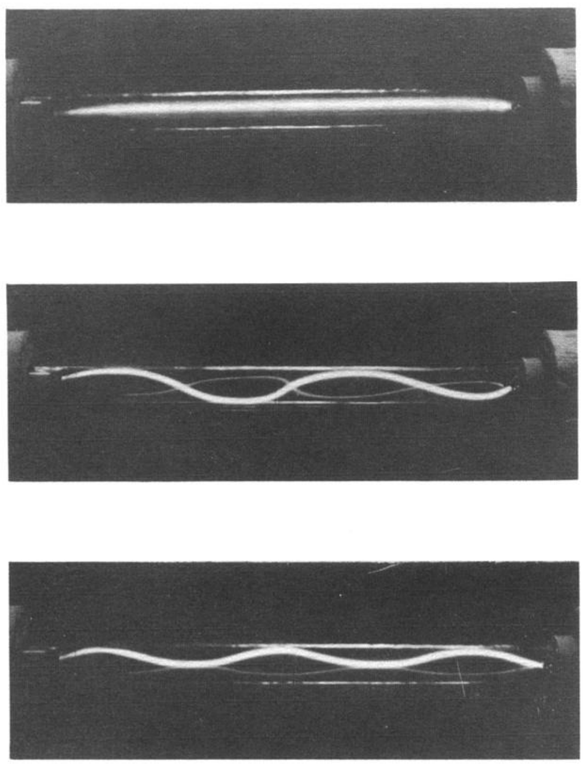

FIG. 2. Constricted krypton discharge. $p = 23.5$ mm Hg, $I = 40$ mA. Top: Unmodulated. Center: 90% modulation, $\omega_{0,1}/2\pi = 5.56$ kc/sec. Bottom: 65% modulation, $\omega_{1,0}/2\pi = 11.60$ kc/sec.