1962-10-15

Electrostatic turbulence in a reflex discharge

Chen, Francis F.; Coopers, Alfred W.

Physical Review Letters

Physical Review Letters, v.9, October 15, 1962, no.8, pp.333-336
http://hdl.handle.net/10945/47525

PHYSICAL REVIEW LETTERS

VOLUME 9 OCTOBER 15, 1962 NUMBER 8

ELECTROSTATIC TURBULENCE IN A REFLEX DISCHARGE*

Francis F. Chen† and Alfred W. Cooper‡
Plasma Physics Laboratory, Princeton University, Princeton, New Jersey
(Received August 14, 1962)

A continuous spectrum of low-frequency oscillations is found in many types of gas discharge which are maintained by a flow of current. Previous studies[1] of such oscillations in reflex discharges have shown that they are not caused merely by local fluctuations in cathode emission, but are a more fundamental characteristic of the plasma. That ion waves can be excited by a longitudinal current has been shown theoretically[2]; and indeed, oscillations in discharges at low magnetic fields have been shown[3] to be ion waves. It is the purpose of this experiment to see whether the continuum of oscillations at high magnetic fields can be decomposed into ion waves with a distribution of frequencies.

This is accomplished by using correlation techniques to measure the longitudinal wavelength of each frequency component of the fluctuations. Such techniques, well known in aerodynamic turbulence and in control systems engineering,[4] have been used previously on plasmas by Batten, Smith, and Early,[5] and by Bol.[6] The chief difficulty of the present experiment lies in the accurate alignment of the measuring probes along a line of force. Since wavelengths and correlation lengths perpendicular to B may be expected to be much shorter than those parallel to B, and indeed were found to be so in preliminary measurements, a large error in the longitudinal correlation will result from a small error in alignment.

The steady-state plasma column studied is 1.3 cm in diameter and 55 cm long and is created by a reflex discharge with one hot and one cold cathode. The hot cathode, 1.9 cm in diameter, is a dispenser cathode indirectly heated by a pancake filament carrying direct current. An anode plate pierced by a hole 1.3 cm in diameter is mounted 1.5 cm from each cathode. The gas used (helium) is flushed continuously. The magnetic field is variable from 0 to 7900 gauss, and has a maximum axial variation of 2% in the plasma region. Three electrostatic probes (P_3 to P_5), 0.07 mm in diameter and 1 mm long, with insulating sleeves 1 mm in diameter, enter the discharge radially through side ports spaced evenly along the column. Two probes of similar construction, mounted perpendicularly onto shafts parallel to the discharge, can be moved along B and can be rotated to sample different radii.

These probes, whose shafts project through the end plates of the discharge vessel, are aligned by means of a small electron beam, 0.25 mm in diameter, from a movable electron gun located behind the cold cathode. For each setting of the probes, this cathode is temporarily removed, and first the further and then the nearer probe is rotated until a maximum of beam current is intercepted. The fraction of the total beam current which is collected by the probe tips indicates that the beam does not spread appreciably with the magnetic fields and pressures used. In this manner the probes can be aligned to an accuracy of 0.1 mm; an error much greater than this would give inconsistent results.

A survey of the oscillations shows three general types of behavior, as illustrated in Fig. 1: (I) At low magnetic fields the discharge is quiescent; (II) at moderate fields there is a periodic oscillation which doubles in frequency as the field is lowered; (III) at high fields, above about 750 gauss, there is mostly incoherent hash with a simple frequency superimposed. This behavior is insensitive to the external circuit of the discharge, to a slight misalignment of the electrodes, and to the discharge current. The coherent frequency in region (II) increases with B and joins smoothly onto that of region (III). This frequency is merely that of an asymmetric plasma rotating under a radial electric field. We are concerned with the incoherent hash in region (III) and not with this rotation frequency, since a periodic oscillation cannot cause enhanced diffusion. The frequency spectrum of the oscillations, taken with a narrow-band frequency analyzer, shows that the power is concentrated near zero frequency, the more so for higher pressures, and that no phenomenon is apparent at the ion cyclotron frequency. The density fluctuations are large, generally greater than 50%.

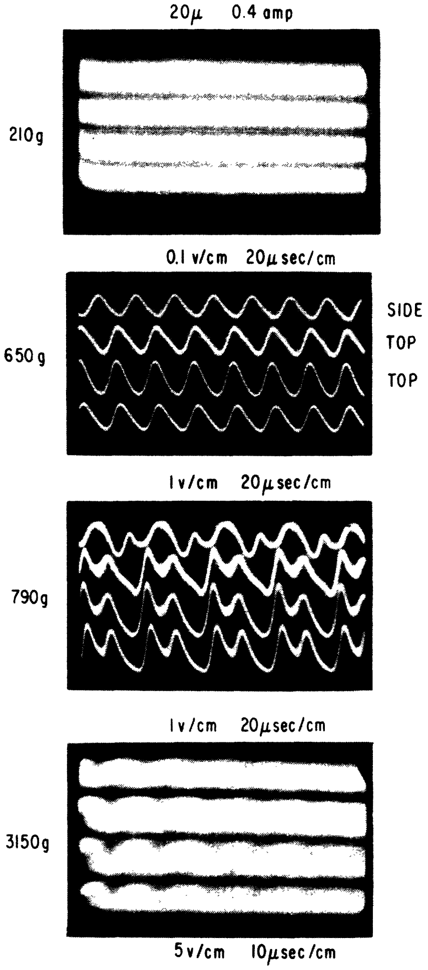

FIG. 1. Oscillations in potential of floating probes. The middle traces in each case are of probes P_3 (nearest to the cold cathode) and P_4 (at the mid-plane of the discharge). The top trace is that of a probe rotated 90° about the discharge axis. The bottom trace is of P_5 and is out of phase because of a misalignment.

Under typical conditions for the experiment reported here the discharge potential was about 30 volts, the ion density about 10^{11} to 10^{12} cm^{-3}, and the electron temperature in the vicinity of 3 eV.

For correlation measurements both probes were biased 100 volts negative to the anodes, and the saturation ion current fluctuation signal from each probe fed through a high-pass electronic filter to one input of a Tektronix type CA differential preamplifier and oscilloscope. The sum or difference of the two signals was fed from the output of the oscilloscope through a potential divider and a variable attenuator to a radio receiver with bandwidth about 3 kc/sec, which provided frequency selection. The signal from the i.f. stage of the receiver was displayed on an ac VTVM. A variable time delay can be inserted in one signal path to the preamplifier. If A and B are the two probe signals, and S and D their algebraic sum and difference, then the normalized cross-correlation function R defined by

$$R = \langle AB\rangle_{\rm av} / \tfrac{1}{2}(\langle A^2\rangle_{\rm av} + \langle B^2\rangle_{\rm av}) \tag{1}$$

is given by

$$R = (1 - P)/(1 + P), \tag{2}$$

where

$$P = \langle D^2\rangle_{\rm av} / \langle S^2\rangle_{\rm av}.$$

After adjusting the gains so that $\langle A^2\rangle_{\rm av} = \langle B^2\rangle_{\rm av}$, P is measured by the change in the attenuator necessary to keep the VTVM reading unchanged as the sign of B is changed at the differential amplifier input. Note that keeping the peak (rectified) value of the receiver i.f. output constant is the same as keeping the rms value constant, since this output is essentially a sine wave. If a unique dispersion relation $\omega = kv$ is obeyed, a plot of R vs probe separation d will be a cosine of kd.

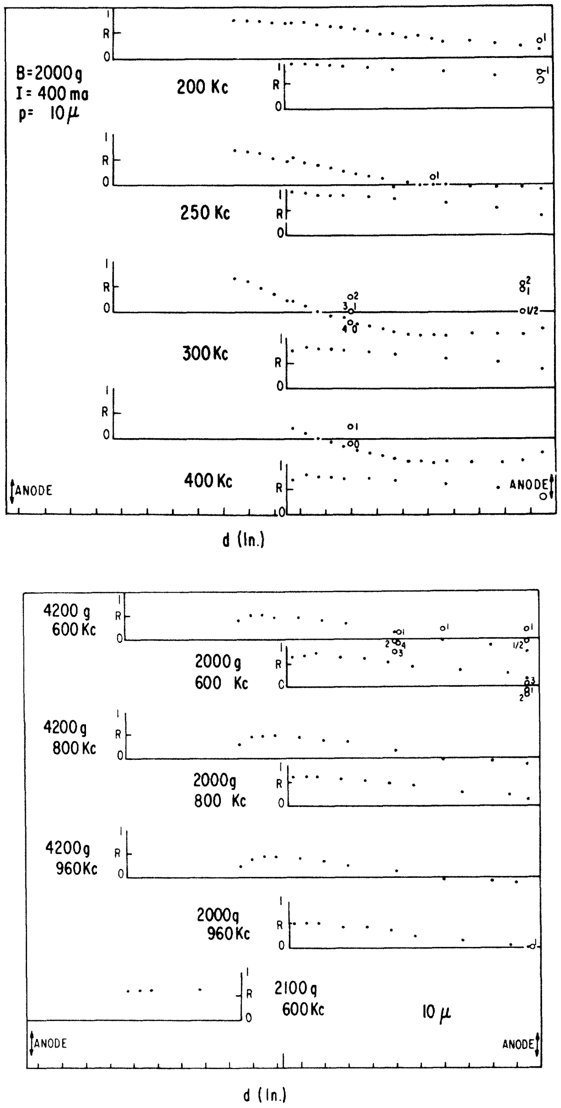

FIG. 2. The cross-correlation function R as a function of probe separation d at various frequencies. In each plot, one probe is fixed at the position of the vertical axis while the other is moved. Open circles are points taken with a time delay on one probe signal; the numbers indicate the number of quarter-periods of delay. The hot cathode lies to the left of the figure.

The results of the correlation measurements of the density fluctuations on the axis of the discharge for frequencies below 200 kc/sec show good correlation ($R \approx 1$) for all probe separations. The correlation R falls slightly with increasing d, decreasing B, and increasing frequency f. The results for higher frequencies are shown on Fig. 2. The statistical errors are less than the diameters of the points. Accuracy of probe alignment is indicated by the smoothness of the curves, since each value of d required a realignment of the probes by the electron beam. The discontinuities at the mid-plane of the discharge are due to the slight irreproducibility of the discharge. In data not shown here, the correlation length (not wavelength) seems to decrease with pressure and increase with magnetic field.

From these data it is seen that the longitudinal wavelength of the oscillations is much too long for these to be ion waves. The wave velocity calculated from the measured quarter-wavelengths is of the order of 2×10^7 cm/sec, which is much larger than the acoustic velocity ($\sim 10^6$) and much smaller than the Alfvén velocity (10^9). The cause of the oscillations has not yet been determined.

Although the large fluctuations in potential associated with these density fluctuations might be expected to produce enhanced diffusion across the magnetic field, our measurements of the diffusion rate show no increase at the onset of the turbulence, in contradiction to the results of Bonnal et al.[7]

---

*Work sponsored by the U. S. Atomic Energy Commission.

†Temporary address: Centre d'Etudes Nucléaires, S.R.F.C., Fontenay-aux-Roses (Seine), France.

‡Permanent address: Naval Postgraduate School, Monterey, California.

[1] R. Bingham and F. F. Chen, Bull. Am. Phys. Soc. 7, 401 (1962); 6, 189 (1961).

[2] I. B. Bernstein and R. Kulsrud, Phys. Fluids 3, 937 (1960).

[3] I. Alexeff and R. V. Neidigh, Phys. Rev. Letters 7, 223 (1961); F. W. Crawford, Phys. Rev. Letters 6, 663 (1961); T. Consoli, R. Le Gardeur, and L. Slama, Compt. rend. 253, 1923 (1961); M. D. Gabovich, L. L. Pasechnik, and V. G. Yazeva, J. Exptl. Theoret. Phys. (U.S.S.R.) 38, 1430 (1960) [translation: Soviet Phys.–JETP 11, 1033 (1960)]; A. V. Nedospasov, Proceedings of the Salzburg Conference on Controlled Fusion, 1961 (to be published).

[4] J. G. Truxal, Control Systems Synthesis (McGraw-Hill Book Company, Inc., New York, 1955), p. 427 ff.

[5] H. W. Batten, H. L. Smith, and H. C. Early, J. Franklin Inst. 262, 17 (1956).

[6] Kees Bol (to be published).

[7] J. F. Bonnal, G. Briffod, and C. Manus, Phys. Rev. Letters 6, 665 (1961).

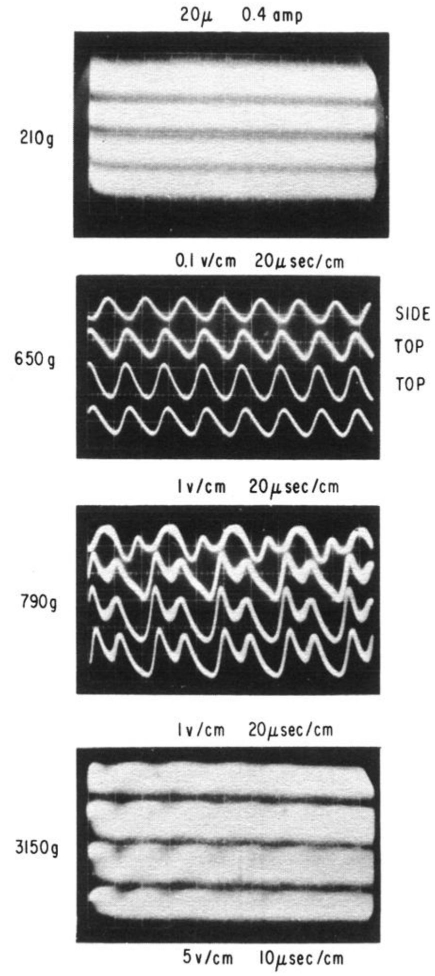

FIG. 1. Oscillations in potential of floating probes. The middle traces in each case are of probes P_3 (nearest to the cold cathode) and P_4 (at the mid-plane of the discharge). The top trace is that of a probe rotated 90° about the discharge axis. The bottom trace is of P_5 and is out of phase because of a misalignment.