EFFECTS OF DISCHARGE TUBE GEOMETRY ON PLASMA ION OSCILLATIONS

THESIS

Presented to the Graduate Council of the
North Texas State University in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF ARTS

By

David W. Simmons, B. S.

Denton, Texas

May, 1975

Simmons, David W., Effects of Discharge Tube Geometry on Plasma Ion Oscillations. Master of Arts (Physics), May, 1975, 196 pp., 8 tables, 80 illustrations, references, 18 titles.

This study considers the effect, on plasma ion oscillations, of various lengths of discharge tubes as well as various cross sections of discharge tubes. Four different gases were used in generating the plasma. Gas pressure and discharge voltage and current were varied to obtain a large number of signals.

A historical survey is given to familiarize the reader with the field. The experimental equipment and procedure used in obtaining data is given. An analysis of the data obtained is presented along with possible explanations for the observed phenomena. Suggestions for future study are made.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

Figure Page

Figure | Page

Figure | Page

Figure Page

Figure | Page

CHAPTER I

INTRODUCTION

The basic theory of plasma oscillations goes back to 1929, when Tonks and Langmuir[1] produced their now famous theory of plasma oscillations. Their theory was based on a zero-temperature plasma. Later, Landau[2] extended the theory beyond the zero-temperature restriction. His work seemed to show that there was not one unique oscillation of the plasma, but an entire range of oscillations bounded by the Langmuir frequency as the lower limit and on the high end by an oscillation whose wave length was equal to the Debye length.

When Gabor[3] studied the rate of energy exchange between an electron and the spectrum of plasma oscillations, he found values too small to be explained by the new theory. In 1955 while studying the energy transfer anomaly, Gabor and others found unpredicted oscillations in a plasma sheath. This sheath is a layer of ions between the plasma and the walls of the container.

Bohm and Gross[4] had developed an expanded theory which could explain these experimental observations. Later, Looney and Brown[5] produced an experiment to test the Bohm and Gross theory and obtained results which did not confirm the theory. In 1958, Drummond and Chang[6] used a method developed by

Sturrock to modify the Bohm and Gross theory. They produced an experiment which showed that the Looney and Brown experiment did not contradict the new theory but that the results of Looney and Brown had to be properly interpreted.

Although the original work of Tonks and Langmuir predicted ionic sound waves in plasmas, little study of these low-frequency oscillations was done until the early 1960's. One notable exception was the work of Revens[7] in 1933, when he studied a mercury vapor discharge in a spherical tube. He was able to observe the first and second overtones of a fundamental oscillation. Revens also showed that there might be radial ionic sound standing waves for a cylindrical tube. Longitudinal ionic sound standing waves were observed by Alexeff and Neidigh[8] while studying a magnetically supported plasma column. Other modes of standing waves were observed by Consoli, LeGardeur, and Slama[9] in 1961.

In the early 1960's, Crawford[10] studied a mercury vapor discharge in cylindrical tubes of various diameters. He suspected that the low frequency cutoff might be dependent on the tube size. From his work, it could be concluded that the ionic sound wave is enhanced by a constriction. Alexeff and Neidigh[11] then performed extensive studies of ion oscillations in magnetically supported plasma columns and in spherical discharge tubes. They found for both systems that the fundamental oscillations and the overtones observed correspond well to theoretical calculations of dependence on ion mass and system size. They also observed predictable damping of the oscillations due to the presence of the neutral gas. Woods[12] studied low pressure discharges and was able to develop a dispersion relation which took into account the boundary of these waves.

The boundary of a plasma is not strictly a rigid wall but a flexible positive ion sheath. The effect of the sheath on the plasma oscillations was studied by Bertotti et al.[13] and Cavaliere et al.[14] They found that the presence of a sheath prevented the reflection of ion-acoustic waves. Rosa and Allen[15] in 1969 developed a plasma model which took into consideration the absorption of ion-acoustic waves by the sheath. They stated that the resonant modes of the radial ion-acoustic modes were not standing waves as had been thought earlier. They developed a two-fluid model in which hot electrons and cold ions flow in opposite directions due to the electric field.

The normal modes of low frequency waves in a positive column in a magnetic field were analyzed by Crawford, Ewald, and Self.[16] They found there were both ion-acoustic and electron waves for a given frequency, and that for typical laboratory systems, the ion-acoustic waves are damped. They were also able to explain some experimentally observed, previously unexplained, damped waves as symmetric electron wave modes. In 1969, Demokan, Hsuan, Lonngren, and Stern[17] studied how an externally produced micorwave signal couples to the low frequency resonance modes. As part of their results, they found that the plasma geometry allowed only specific modes of ion wave resonance to exist.

In view of some discrepancies appearing in the total picture of plasma oscillation, and because most investigations were limited to a few vapors or gases, mostly Hg vapor studies, the work described below was undertaken.

The main thrust of this work was to make a comprehensive study of the plasma oscillations of H_2, D_2, He, and N_2O_4 gases as a function of the nature of the discharge tube. Since the plasma waves can be approximated as two types, transverse and longitudinal to the discharge stream, it seemed that the most fruitful study would be a study of discharge tube cross-section and electrode separation for fixed cross-section tubes. The investigation consisted, therefore, of varying the cross-section of a cylindrically shaped discharge tube whose electrode spacing was fixed, and observing the nature of the plasma fluctuations for various values of the parameters, pressure, discharge current, and discharge voltage. In addition, the longitudinal waves were explored by varying the electrode spacing while keeping the cross-section of the discharge tube constant.

A more complete discussion of the discharge tubes and their structure as well as a discussion of the equipment utilized in making the investigation of plasma oscillations will be found in Chapter II.

CHAPTER II

EXPERIMENTAL EQUIPMENT

In this work, the experimental procedure and equipment design are similar to that of Tang;[18] but for completeness, a discussion of the equipment including modifications is given here. Figure 1 is a block diagram of the equipment used.

The plasma was generated in a cylindrical tube, at low gas pressure, by a high voltage discharge. The radio frequency oscillations of the plasma were detected by a pickup coil and fed to an oscilloscope and a frequency counter. Four gases; He, H_2, D_2, and N_2O_4, were studied. Twelve discharge tubes were used for each gas. The voltage, current, and pressure were varied for each tube to obtain as many oscillations as possible.

To remove unwanted gases from the discharge area, a three-stage vacuum system was used. First a mechanical pump was used to create an initial vacuum. A diffusion pump reduced the vacuum further. Finally a liquid nitrogen cold trap was used to isolate residual gases. The pressure of the gas in the discharge tube was measured by a Hasting Gauge, and was, for normal plasma generation, in the range of 250 to 1500 microns.

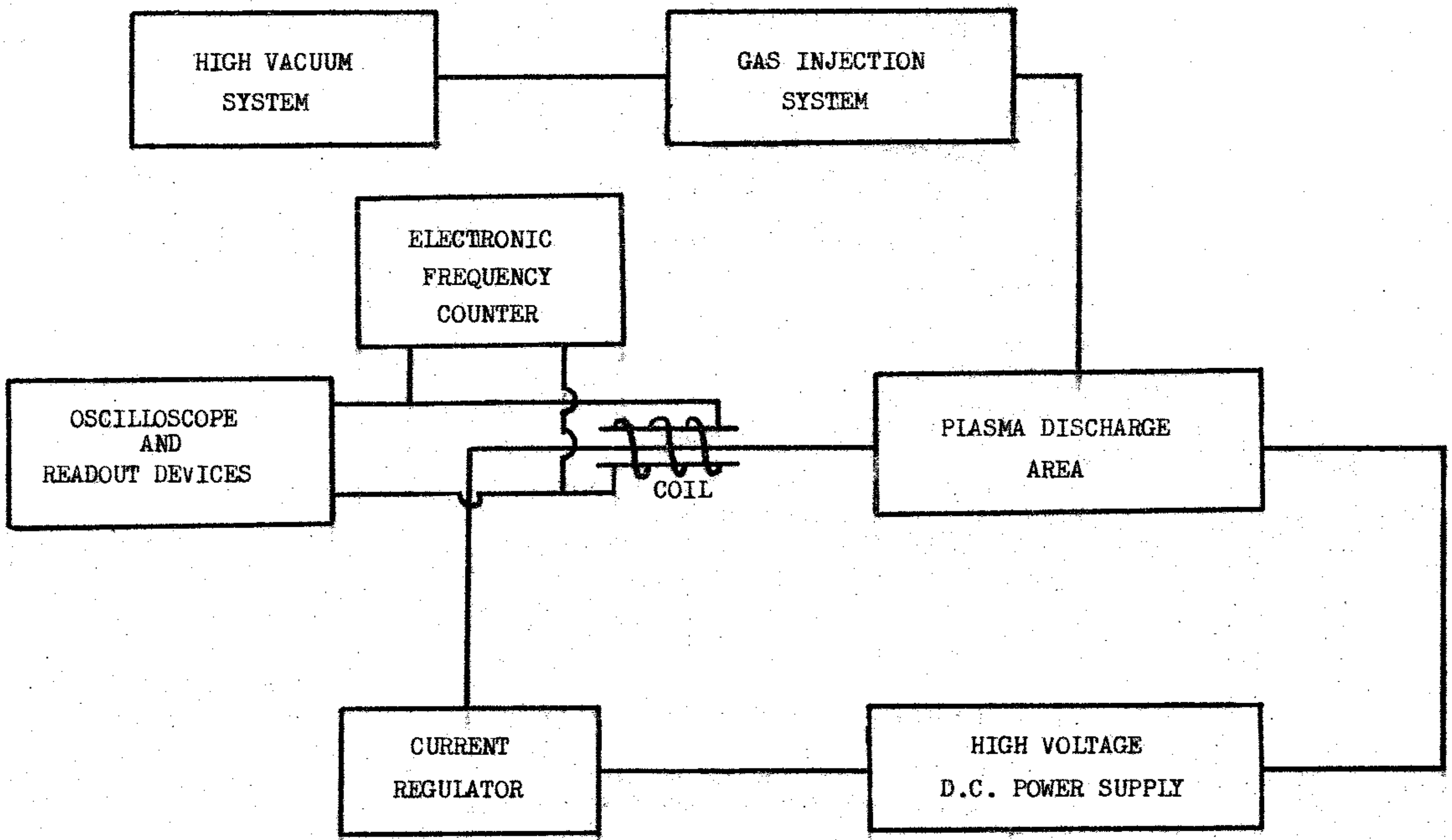


Fig. 1--Block diagram of apparatus

The discharge voltage was supplied by a variable high voltage power supply, which was continuously variable from 750 to 3550 volts. The discharge current was controlled by a variable current regulator and monitored by a digital voltmeter.

The radio frequency oscillations of the plasma were detected by a coil wrapped around the discharge tube. The coil was made of 1000 turns of copper wire. The output of the coil was fed through shielded cable to both an oscilloscope and a frequency counter. Pictures were taken of the signals that appeared on the oscilloscope.

A simple glassware system, shown in Figure 2, was used to hold a given gas sample and meter it into the discharge tube. A gas reservoir was filled with the appropriate gas sample after it had been evacuated. The gas was then admitted into the discharge tube by a doser valve. This procedure allowed the gas pressure to be increased by a discrete amount, usually 250 to 300 microns.

A conical ground glass joint allowed for easy changing of the discharge tubes. A valve was added to Tang's system so that the discharge tubes could be brought to one atmosphere of pressure prior to removal. The addition of this valve was necessary to prevent loss of a particular gas sample stored in the reservoir.

The discharge tubes were made from pyrex tubing attached at one end to a conical ground glass joint and sealed at the

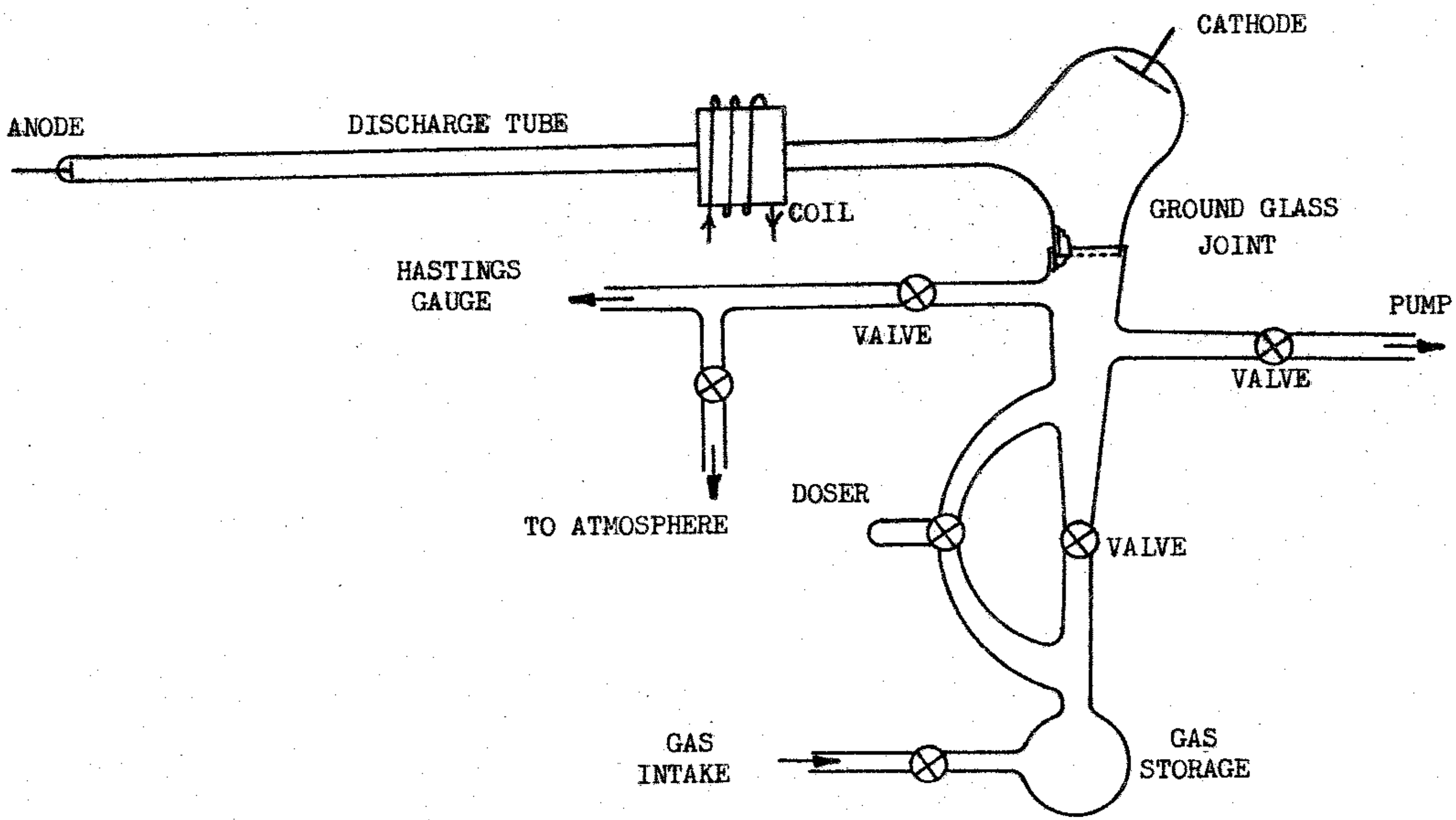


Fig. 2--Glassware system

other end. The electrodes were tungsten. The anode was mounted in the sealed end of the tube while the cathode protruded through the wall above the ground glass joint. All twelve discharge tubes were of the same design and varied only in size. The discharge tubes were in two groups. One group was used in the length study. The other group was used in the cross-section study. The first group consisted of seven tubes, all having an inside diameter of 6 mm., while the electrode spacing varied from 6 to 23 cm. The second group had an electrode spacing of 20 cm. and varied in inside diameter from 1.7 to 6 mm. One tube was used in both groups.

The discharge tube area was isolated in a wire screen Faraday Cage to help stabilize the plasma and to prevent the pickup coil from detecting stray signals.

CHAPTER III

DATA

A discussion of each kind of plasma produced is given below. Particular aspects of the plasma which appear to be important in constructing a plasma model are given. The signals which appear to be independent of the molecule or atom from which the plasma is generated are noted. Those signals which appear to be characteristic of a given neutral species are noted as well.

There were three basic signals observed for the gases and tube sizes studied. There were sine wave signals which had both simple and complex patterns (See Figures 9b and 9c). Next, sawtooth waves were observed (See Figures 4a and 6a). Finally damped oscillatory waves were seen (See Figures 4e and 10c). In general the damping itself was periodic. The damping period was dependent on the discharge current. For the short tubes the plasma was very hard to sustain and in some cases no plasma signals or ionization were obtainable.

He Length

The signals of the He plasma in the longer tubes lay predominately in the mid-50 KHz to mid-60 KHz range. All three types of signals were seen. The sawtooth waves had a higher frequency than the other waves. As the tube length was lessened, the 50 to 60 KHz signals generally became weaker. Apparent harmonics of this signal, however, became stronger as the tubes were made shorter. For the 6-cm.-length tube, two high frequency harmonics from the plasma were modulated by a low frequency signal (See Figures 15a and 16e). One of these modulated signals (See Figure 15a) had a very high frequency of 910 KHz.

He Cross Section

Signals in the 50-KHz range were present for the largest tubes. For the smaller tubes, apparent harmonics became stronger as was observed for the He length study. The sawtooth signals appeared in only one small tube of 3.5 mm. diameter. There was a possible increase in the frequency of the 50-KHz range signals for the smaller tubes; however, the plasma was unstable for these tubes and only a few signals could be obtained.

H_2 Length

A 50-KHz to 55-KHz signal appeared throughout the range of tube lengths. These signals were the strongest of the spectrum for the longest tubes. They became weaker as the tube length was decreased. High frequency signals began to appear for the shorter tubes except where stability was a problem. For the 17-cm.-length tube, a unique effect was noted. For two signals (See Figures 25c and 25e) the striations became deformed. Instead of being disk-shaped across the entire tube cross-section, the striations collapsed and adhered alternately to the top and bottom of the tube but not to the sides (See Figure 3). The spacing between striations varied with pressure. The spacing for 600 and 1200 microns were 1.3 and 1.1 cm. respectively.

H_2 Cross Section

The 50-KHz range signal was dominant in the largest tubes. High frequency signals, possible harmonics of the 50-KHz signal, were seen for the 3.5-mm. diameter tube. The plasma was unobtainable for the 1.7-mm. diameter tube. It was unstable for the 2.3-mm. diameter tube and only damped signals were obtained.

D_2 Length

Again a large 50-KHz to 60-KHz signal ran through the range of tube lengths. High frequency harmonics were present throughout the range of tubes. The sawtooth signals appeared, in general, to increase in frequency as the tubes shorten. There were many complex combinations of signals present.

D_2 Cross Section

The 50-KHz to 60-KHz signal seen in the 6 mm. diameter tube became less prevalent in the smaller tubes. The harmonics of the sine wave could not be seen. The sawtooth

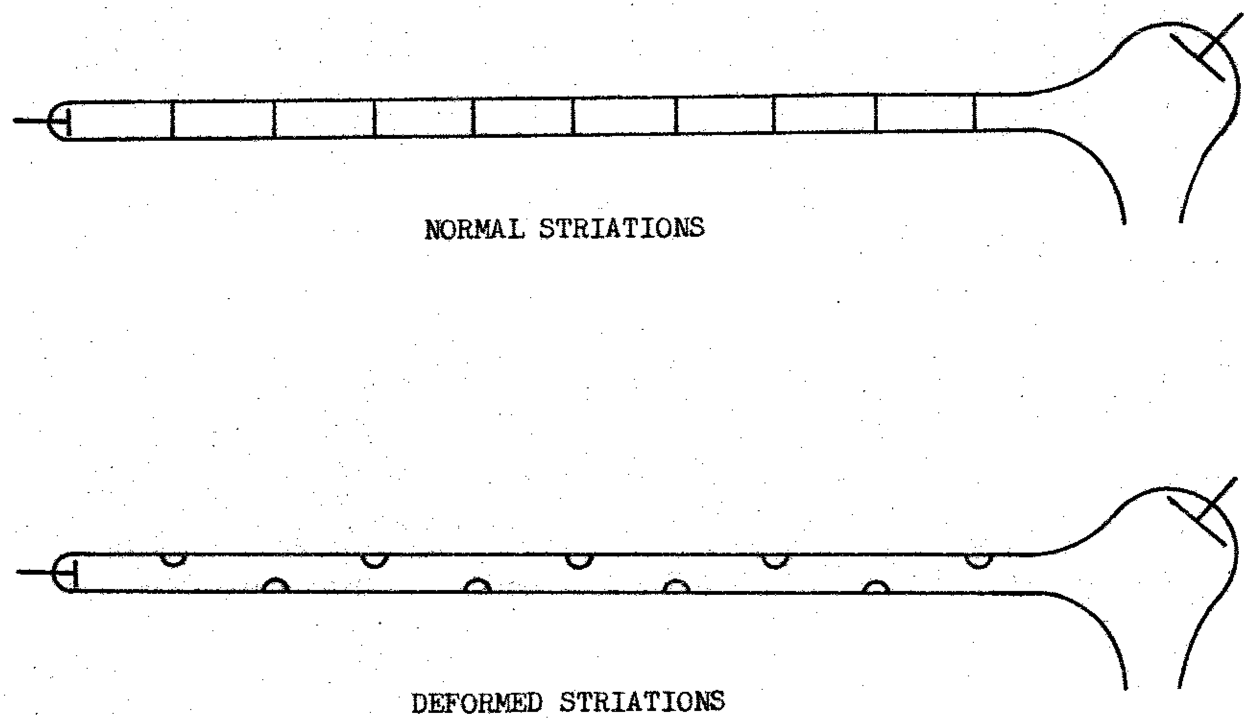


Fig. 3--Normal and deformed striations

waves became more numerous for the smaller tubes to the virtual exclusion of other signals.

The two gases H_2 and D_2 were chosen for analysis because of their identical electronic properties but different physical properties. This experiment did not produce a clear-cut set of frequencies which could be assigned to the deuterium ion or to the hydrogen ion. It seems reasonable to expect such oscillations due to the motion of each mass ion. It is suggested that this aspect of the experiment be explored further by other investigators.

N_2O_4 Length

A mid-50-KHz signal dominated the spectrum for the longer tubes, and was present throughout the range of lengths. There were some harmonics for the shorter tubes. Especially notable were the very high frequency signals for the 6-cm.-length tube. These signals had frequencies of 1,400 KHz and 2,000 KHz (See Figures 72a, 72d and 73a).

N_2O_4 Cross Section

The signals from the 6-mm.-diameter tube were very noisy. The largest one was damped and had a frequency of 77 KHz. The 5.2-mm.-diameter tube had a more stable plasma. There were several 50-KHz to 60-KHz signals and many harmonics. As the tubes narrowed, a 54-KHz signal established itself firmly in the spectrum.

The next chapter gives a summary of the probable sources of the oscillations observed.

CHAPTER IV

DISCUSSION

In this chapter a discussion is given of the plasma oscillations observed. They are analyzed with respect to any correlation to tube size, theoretical models, and possible future study. As mentioned in Chapter III, three types of signals (sine wave, sawtooth, and periodically damped waves) were seen. The sine waves are to be expected from a simple harmonic oscillator model and have been seen in previous experiments. The sawtooth waves are unexpected from a simple model and might be best explained from some type of excitation relaxation standpoint as suggested by Demokan, Hsuan, Lonngren, and Stern.[17]

The periodic damping of signals was not mentioned in any paper reviewed. This damping may be due, however, to gas damping. According to Alexeff and Neidigh[11] un-ionized gas atoms can collide with ions and damp out the ionic sound wave. It is worth noting that the period of the damping varied with the discharge current.

The size study seems to show that the discharge tube size has some effect on the ion oscillation. As noted in Chapter III, there was a decrease of low frequency signals and an increase of high frequency signals in both the shorter and the smaller cross-section tubes. This is in partial agreement with Crawford's[10] predictions of a low frequency cut-off, which is dependent on tube dimensions, and enhancement of ion sound waves by a constriction. While the higher-frequency signals were enhanced in the narrower tubes, they appeared to be harmonics of the same base frequency.

The goals and objectives of this investigation have been satisfied in that a significant amount of data has been obtained for a broad range of masses of gases under different conditions of discharge. The signals recorded appeared to be independent of gas mass and dependent upon discharge tube geometry. This work has uncovered several interesting channels of interest in plasma behavior which can be explored. A more complete explanation concerning the lack of mass dependence of the oscillations is an area in which future study might be done. Also, further investigation is necessary to explain the damped sine waves that were observed, as well as the deformation of the striations that was observed in this study.

APPENDIX I

Photographs of the oscilloscope trace of signals generated in various plasmas at various pressures, currents and voltages.

Pressure 250 microns
Current 100 microamps.
Voltage 3480 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(a)

Pressure 250 microns
Current 70 microamps.
Voltage 3000 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(b)

Pressure 500 microns
Current 90 microamps.
Voltage 3220 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(c)

Pressure 500 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
1 volt/div.
20 microsec./div.

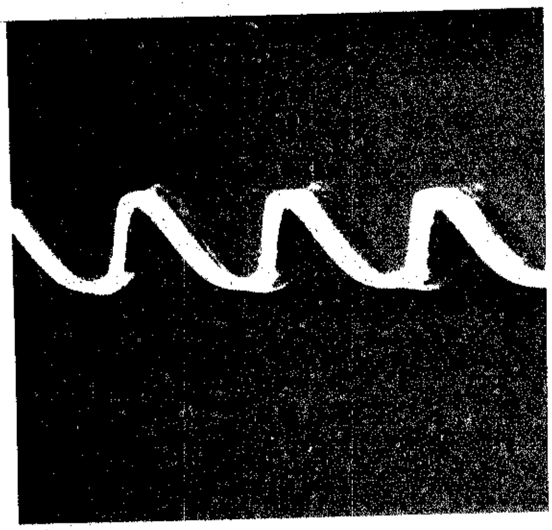
(d)

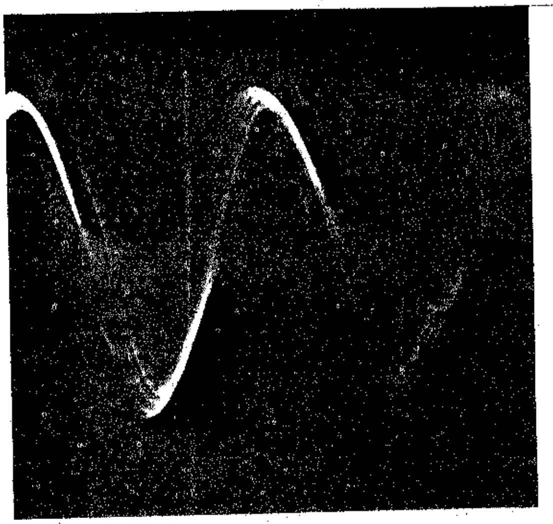
Pressure 500 microns
Current 16 microamps.
Voltage 2365 volts

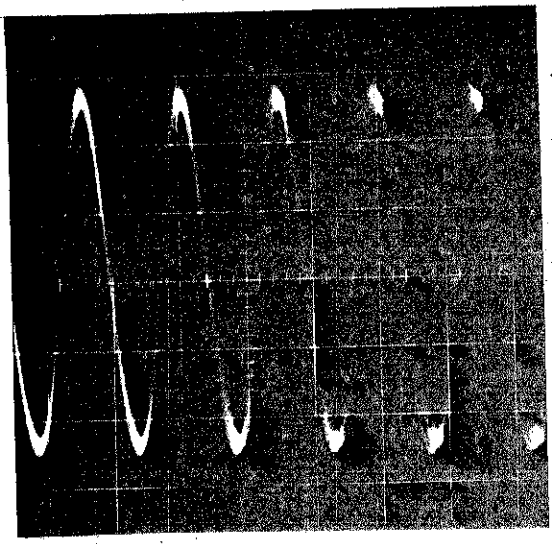
Oscilloscope settings
5 volts/div.
50 microsec./div.

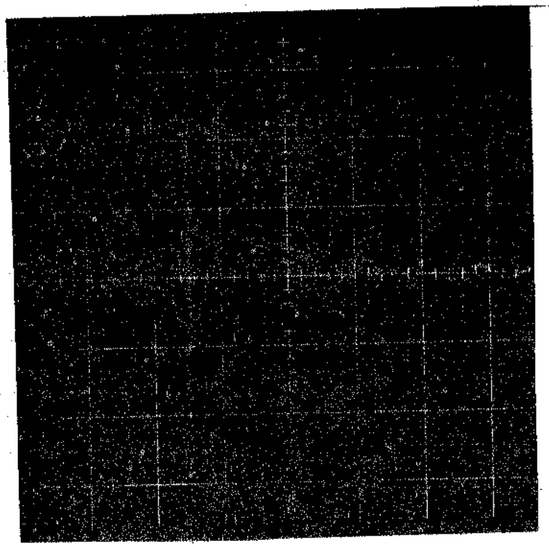
(e)

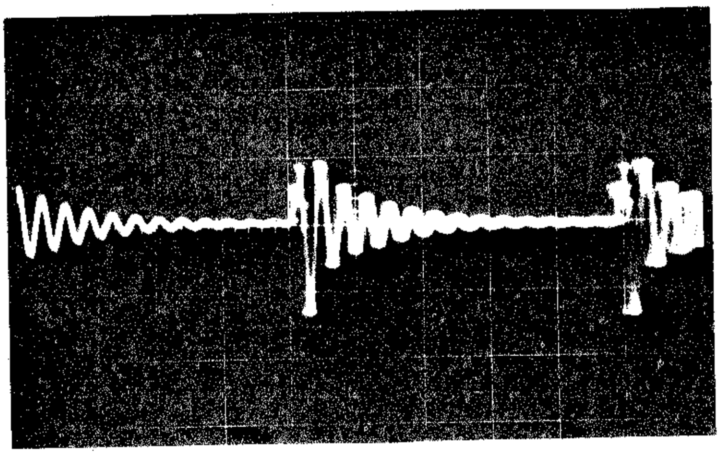
Fig. 4--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 23 cm. in length.











Pressure 750 microns
Current 40 microamps.
Voltage 2735 volts

Oscilloscope settings
2 volts/div.
100 microsec./div.

(a)

Pressure 750 microns
Current 90 microamps.
Voltage 3050 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(b)

Pressure 1000 microns
Current 10 microamps.
Voltage 2340 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

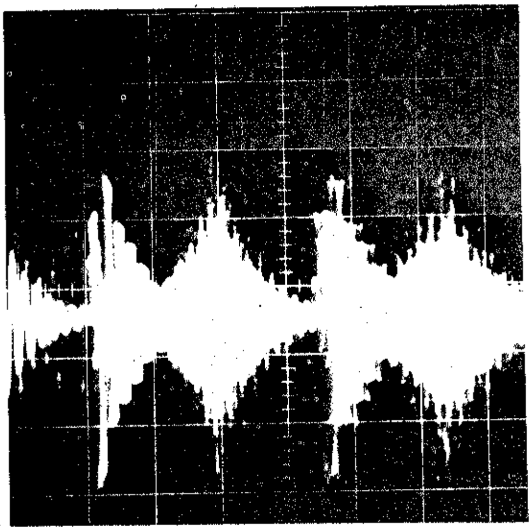
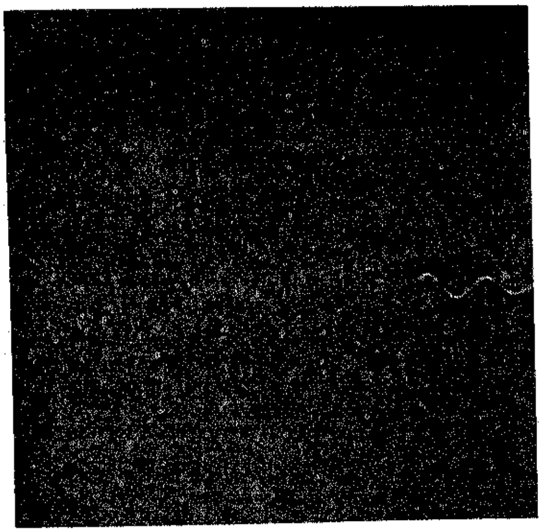
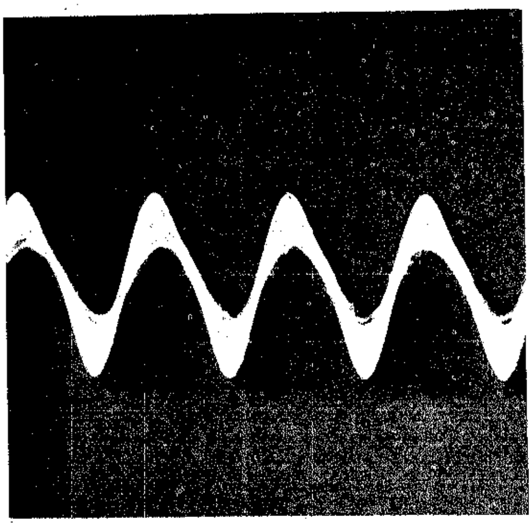
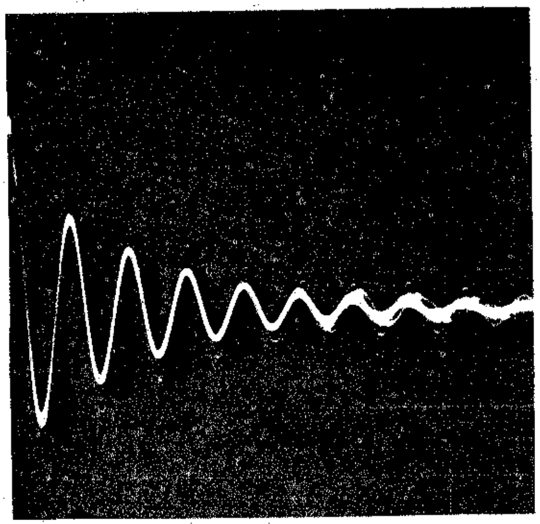
(c)

Pressure 1000 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(d)

Fig. 5--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 23 cm. in length.

Pressure 300 microns
Current 74 microamps.
Voltage 2455 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(a)

Pressure 300 microns
Current 19 microamps.
Voltage 2250 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(b)

Pressure 600 microns
Current 8 microamps.
Voltage 2140 volts

Oscilloscope settings
2 volts/div.
100 microsec./div.

(c)

Pressure 600 microns
Current 96 microamps.
Voltage 2415 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(d)

Pressure 900 microns
Current 44 microamps.
Voltage 2300 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

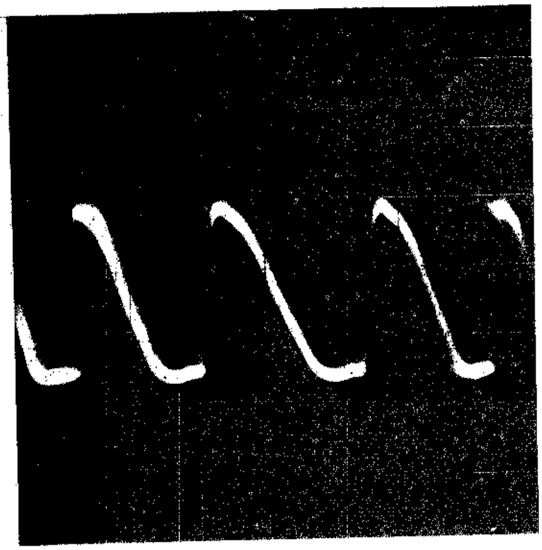
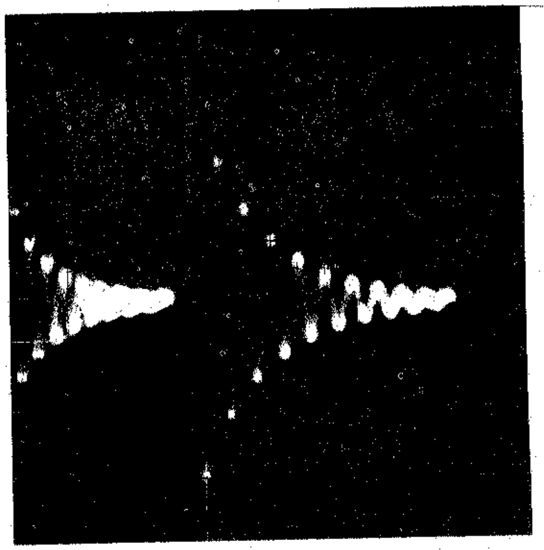
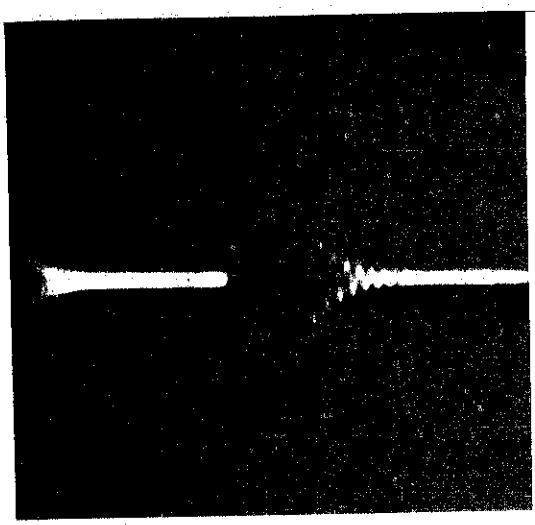
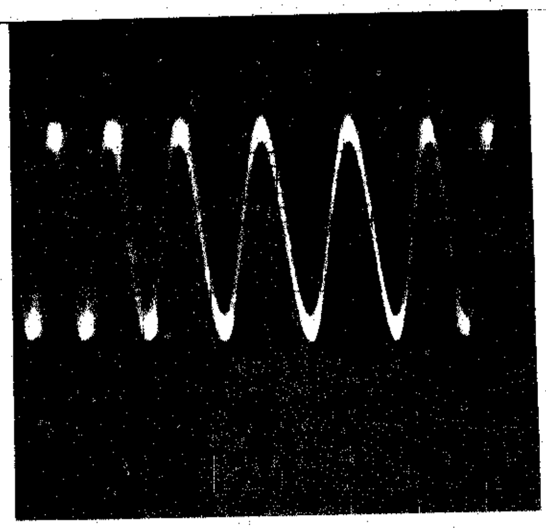
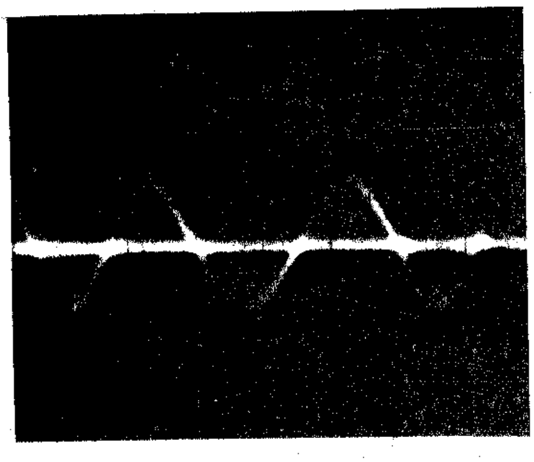
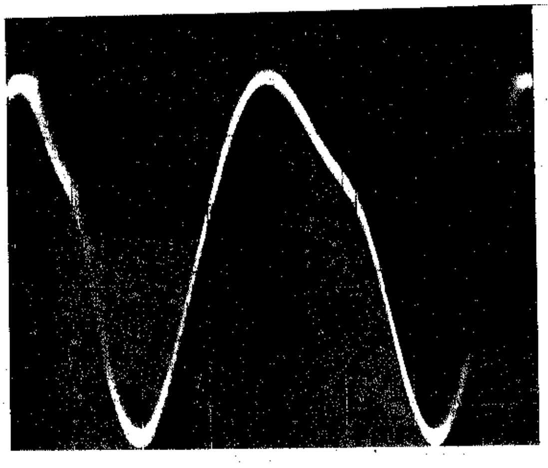
(e)

Pressure 1200 microns
Current 29 microamps.
Voltage 1875 volts

Oscilloscope settings
0.5 volts/div.
5 microsec./div.

(f)

Fig. 6--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 20 cm. in length.

Pressure 250 microns
Current 49 microamps.
Voltage 3150 volts

Oscilloscope settings
10 volts/div.
10 microsec./div.

(a)

Pressure 500 microns
Current 2 microamps.
Voltage 1900 volts

Oscilloscope settings
5 volts/div.
100 microsec./div.

(b)

Pressure 500 microns
Current 70 microamps.
Voltage 2760 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

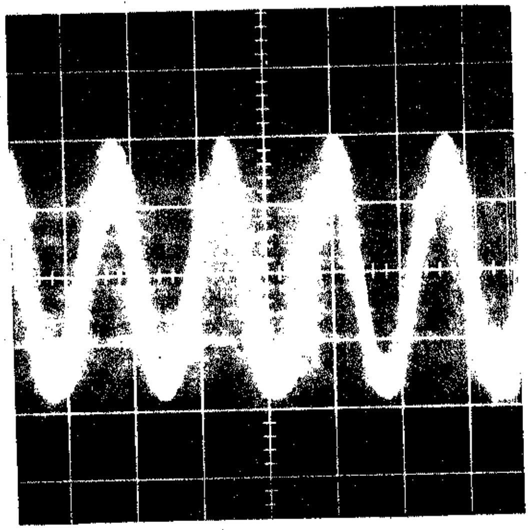
(c)

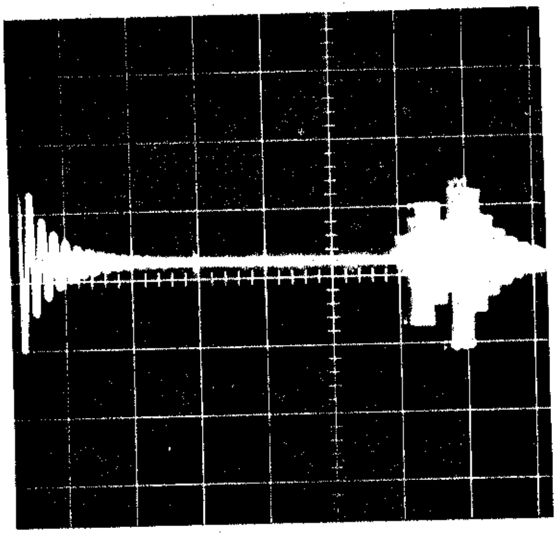
Pressure 500 microns
Current 90 microamps.
Voltage 3150 volts

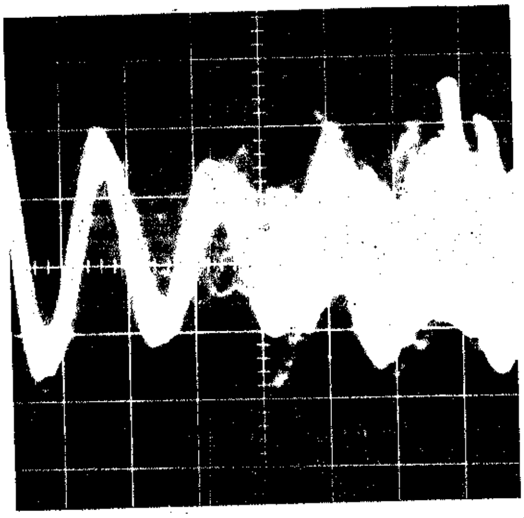
Oscilloscope settings
0.2 volts/div.
2 microsec./div.

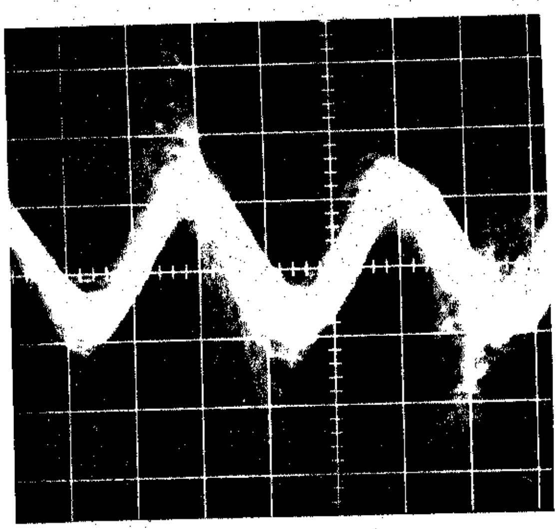
(d)

Fig. 7--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 17 cm. in length.









Pressure 750 microns
Current 59 microamps.
Voltage 2565 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(a)

Pressure 750 microns
Current 19 microamps.
Voltage 2030 volts

Oscilloscope settings
0.1 volts/div.
50 microsec./div.

(b)

Pressure 1000 microns
Current 9 microamps.
Voltage 1840 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

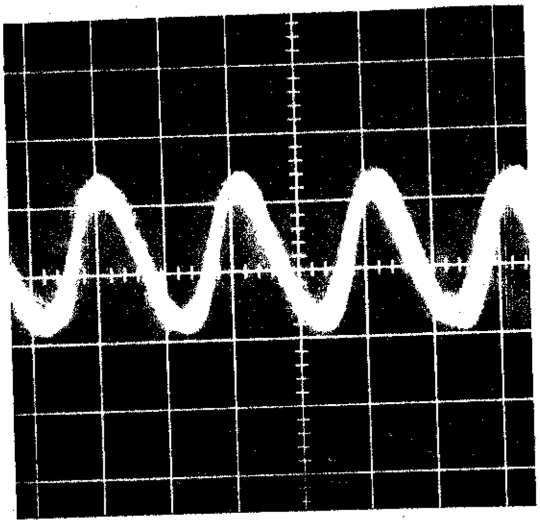
(c)

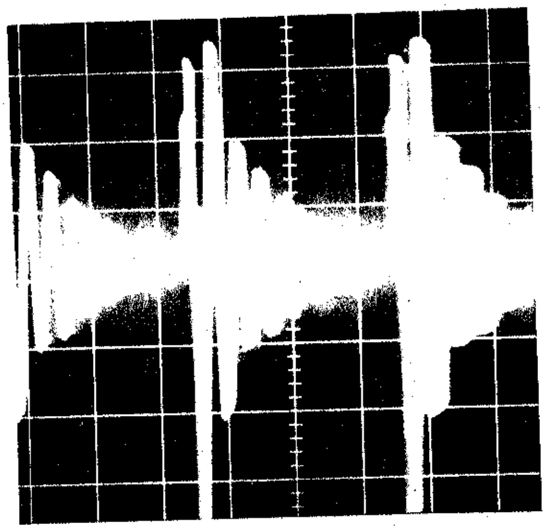
Pressure 1000 microns
Current 42 microamps.
Voltage 2170 volts

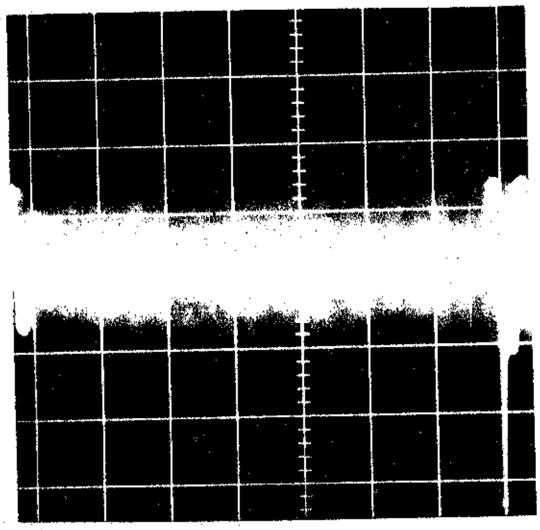
Oscilloscope settings
2 volts/div.
5 microsec./div.

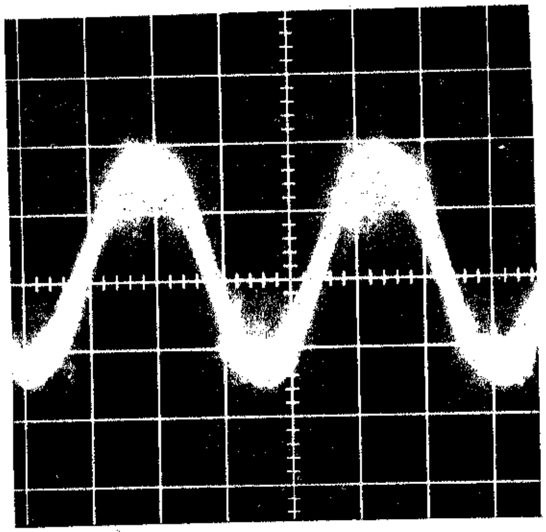
(d)

Fig. 8--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 17 cm. in length.









Pressure 250 microns
Current 6 microamps.
Voltage 1700 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(a)

Pressure 250 microns
Current 31 microamps.
Voltage 2141 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(b)

Pressure 250 microns
Current 10 microamps.
Voltage 3040 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

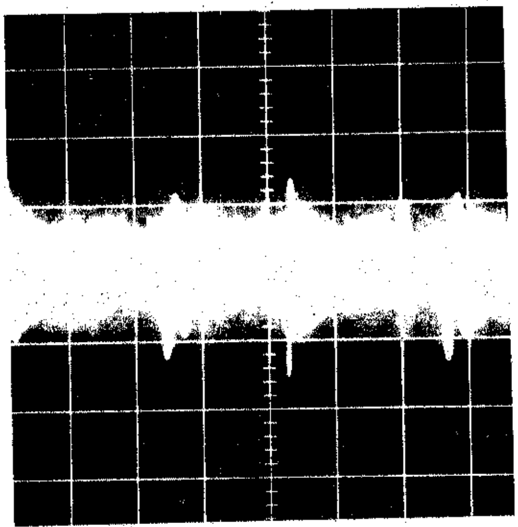
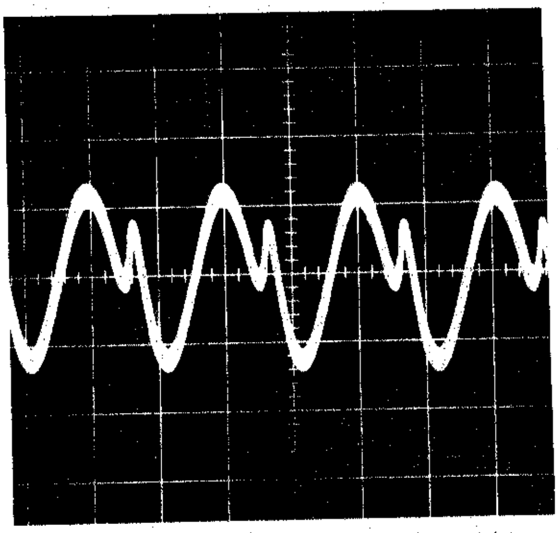
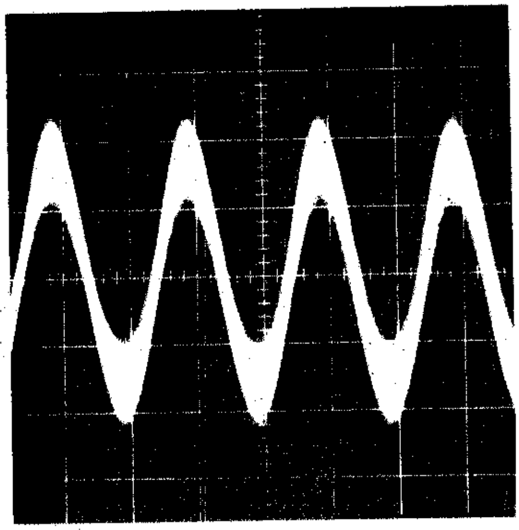
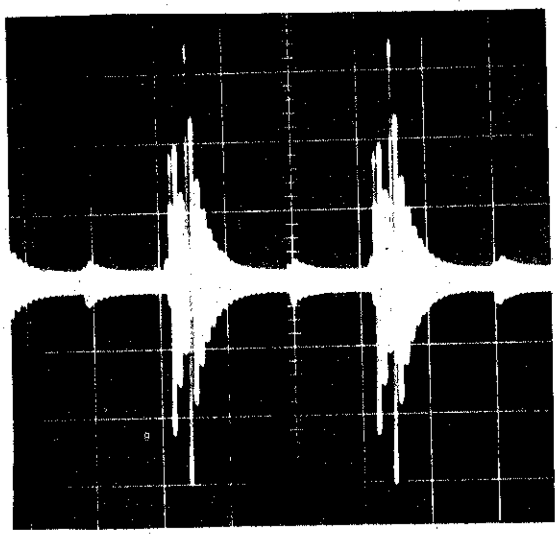
(c)

Pressure 500 microns
Current 3 microamps.
Voltage 1700 volts

Oscilloscope settings
2 volts/div.
200 microsec./div.

(d)

Fig. 9--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 13 cm. in length.

Pressure 500 microns
Current 60 microamps.
Voltage 2150 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(a)

Pressure 750 microns
Current 135 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(b)

Pressure 750 microns
Current 17 microamps.
Voltage 2000 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

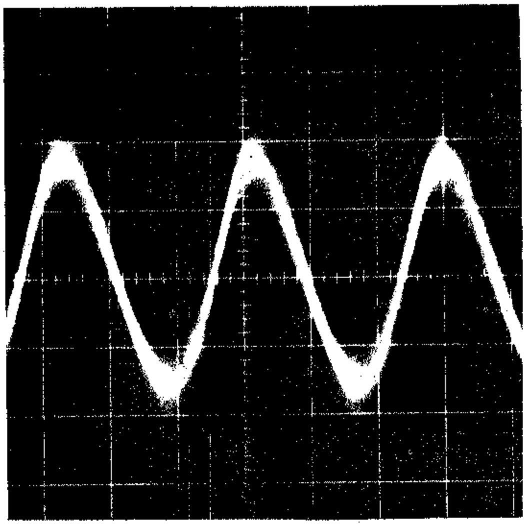
(c)

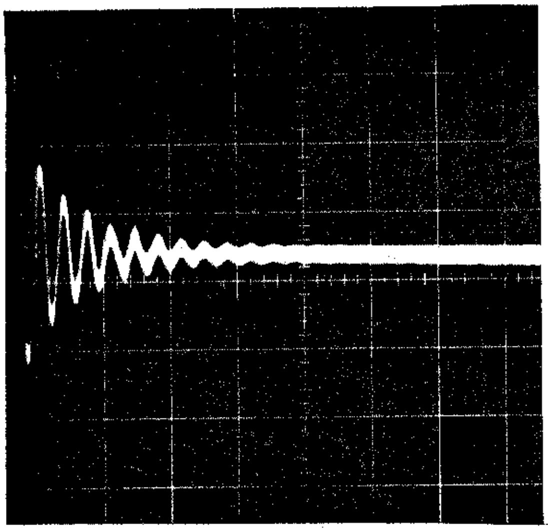
Pressure 1000 microns
Current 131 microamps.
Voltage 3550 volts

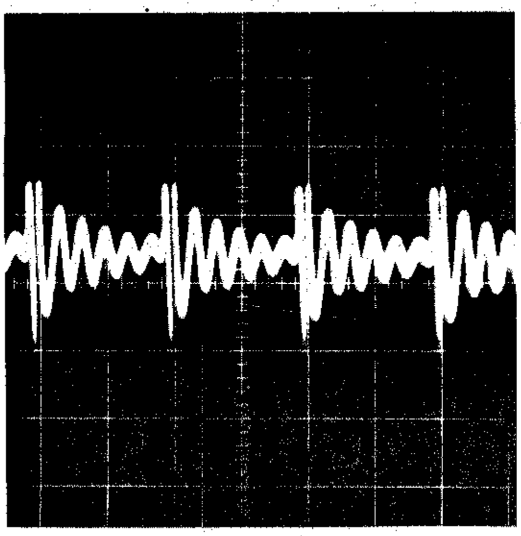
Oscilloscope settings
2 volts/div.
100 microsec./div.

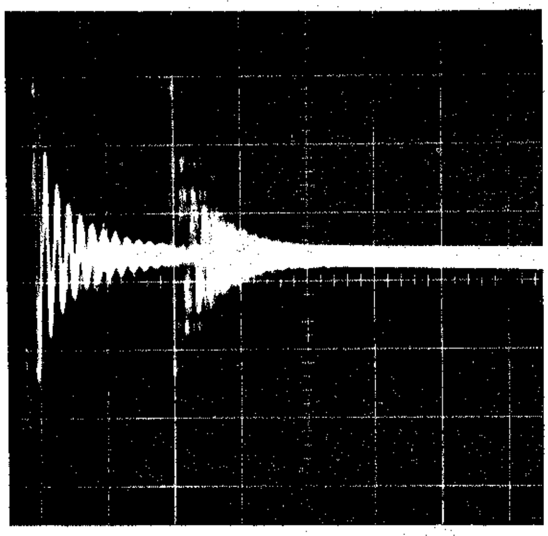
(d)

Fig. 10--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 13 cm. in length.









Pressure 300 microns
Current 53 microamps.
Voltage 1550 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(a)

Pressure 300 microns
Current 139 microamps.
Voltage 3550 volts

Oscilloscope settings
0.01 volts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 21 microamps.
Voltage 1300 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(c)

Pressure 300 microns
Current 100 microamps.
Voltage 2000 volts

Oscilloscope settings
0.01 volts/div.
2 microsec./div.

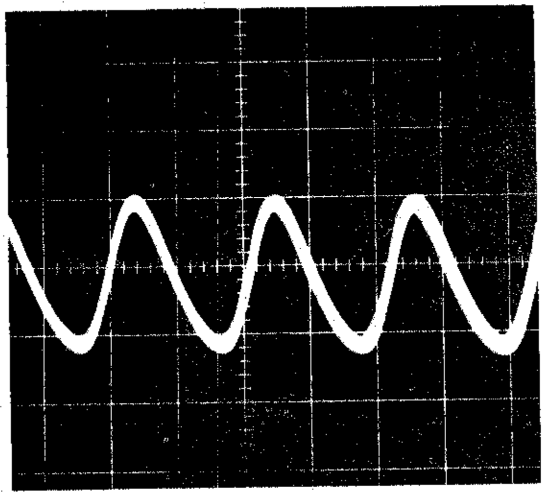
(d)

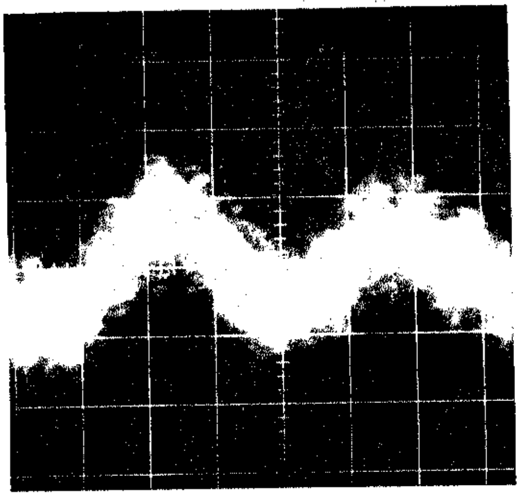
Pressure 300 microns
Current 4 microamps.
Voltage 1200 volts

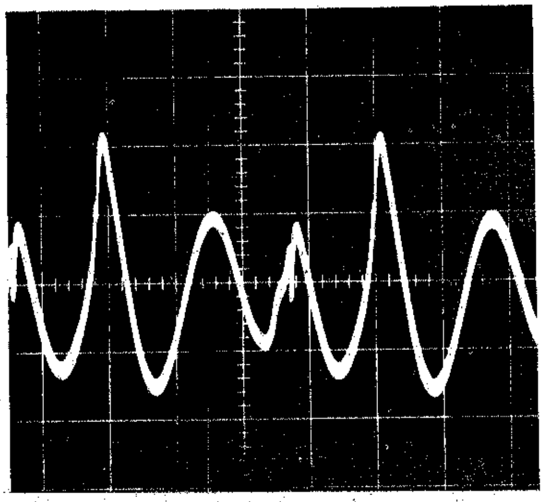
Oscilloscope settings
1 volt/div.
50 microsec./div.

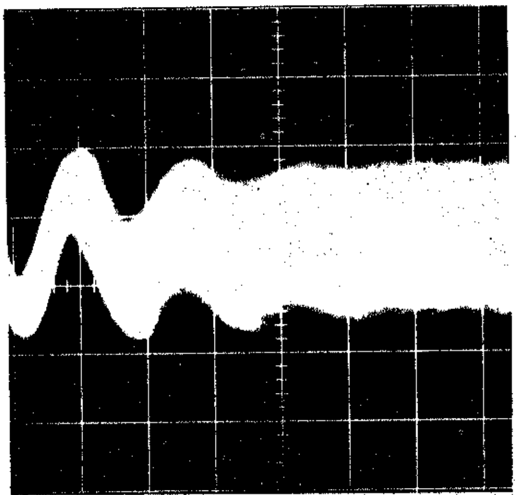
(e)

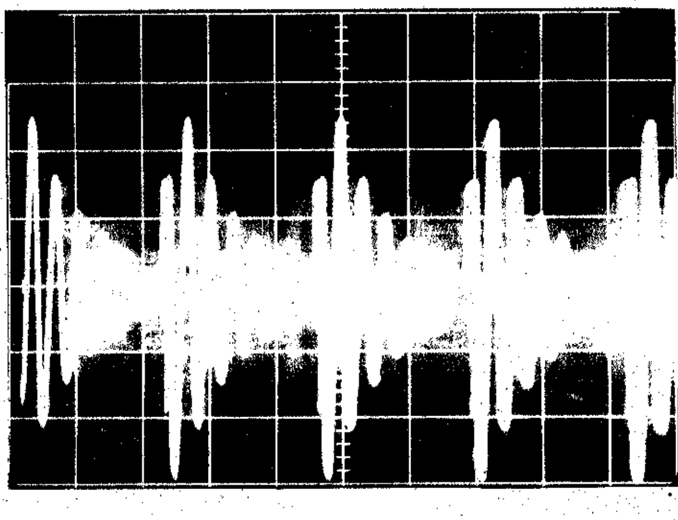
Fig. 11--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 10 cm. in length.











Pressure 600 microns
Current 7 microamps.
Voltage 1500 volts

Oscilloscope settings
1 volt/div.
200 microsec./div.

(a)

Pressure 600 microns
Current 43 microamps.
Voltage 1340 volts

Oscilloscope settings
0.5 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 10 microamps.
Voltage 1430 volts

Oscilloscope settings
1 volt/div.
100 microsec./div.

(c)

Pressure 1200 microns
Current 19 microamps.
Voltage 1395 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

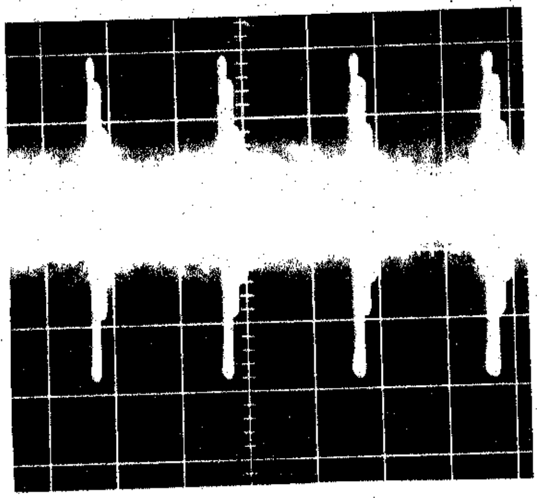
(d)

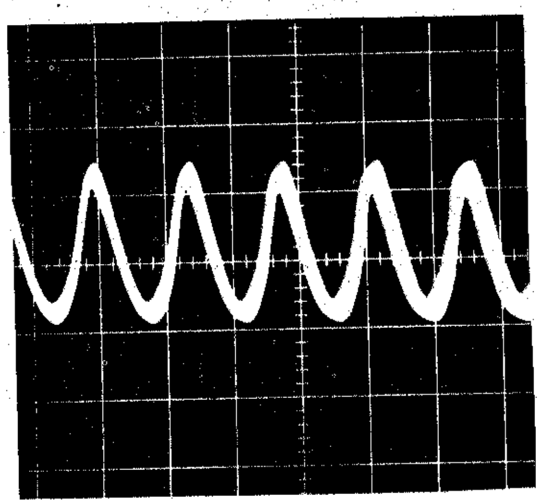
Pressure 1200 microns
Current 20 microamps.
Voltage 1320 volts

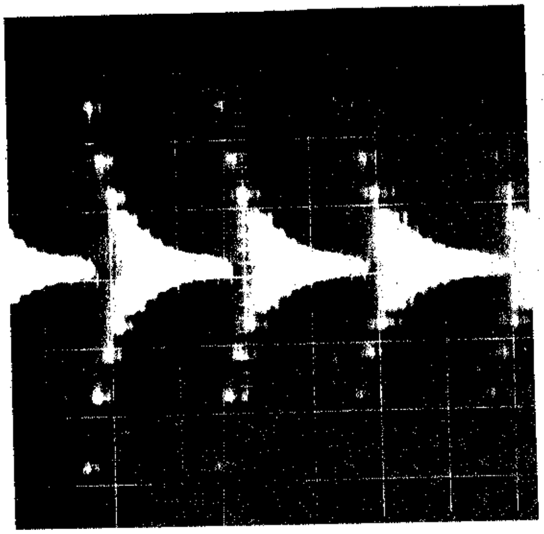
Oscilloscope settings
1 volt/div.
10 microsec./div.

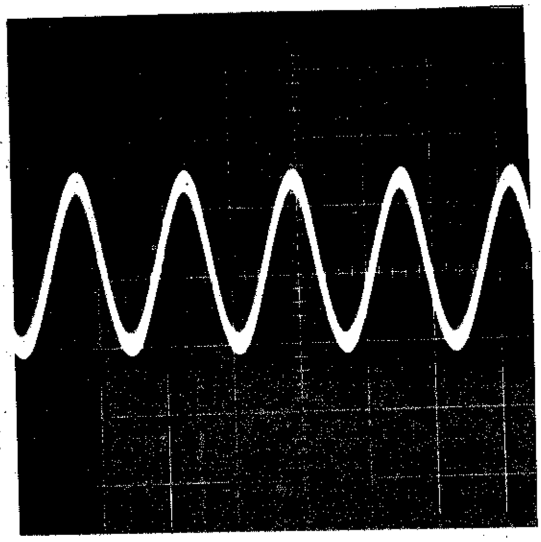
(e)

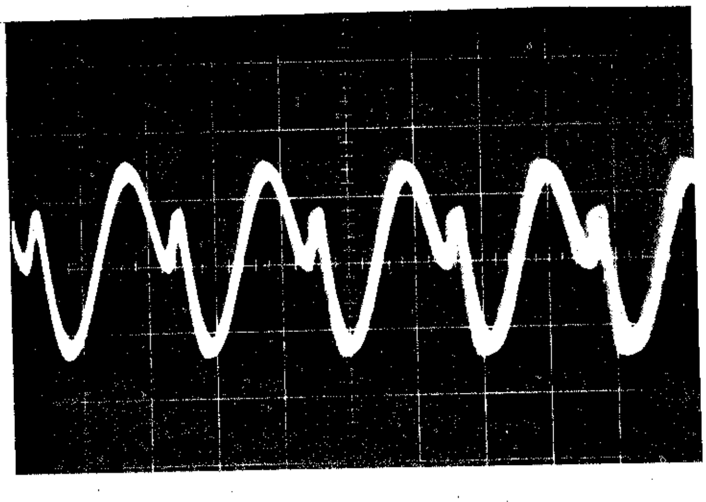
Fig. 12--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 10 cm. in length.











Pressure 300 microns
Current 19 microamps.
Voltage 1120 volts

Oscilloscope settings
0.5 volts/div.
10 microsec./div.

(a)

Pressure 300 microns
Current 29 microamps.
Voltage 1325 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 45 microamps.
Voltage 1660 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(c)

Pressure 600 microns
Current 29 microamps.
Voltage 1470 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

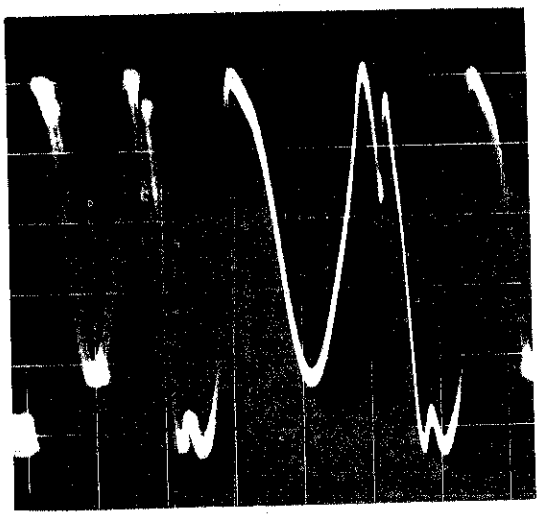
(d)

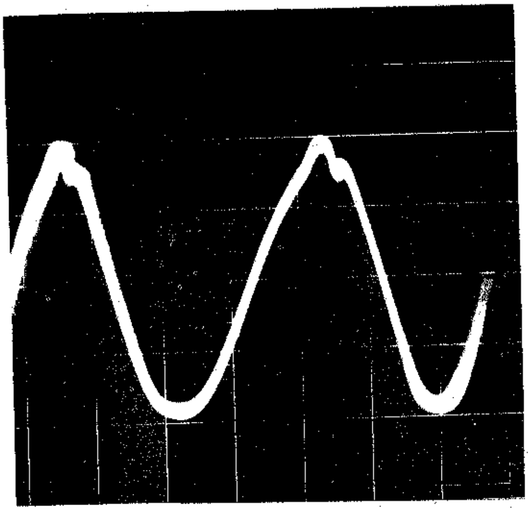
Pressure 600 microns
Current 5 microamps.
Voltage 900 volts

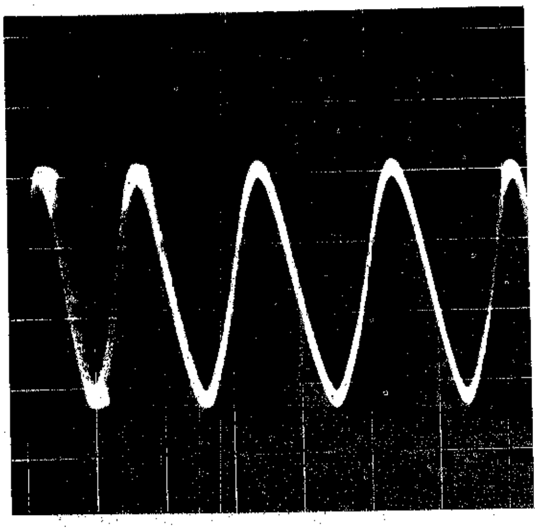
Oscilloscope settings
1 volt/div.
100 microsec./div.

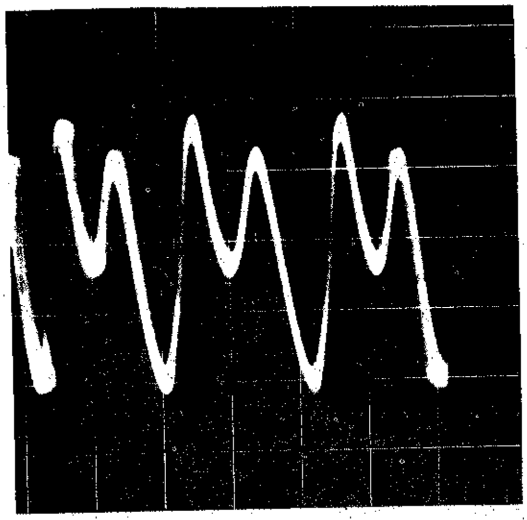
(e)

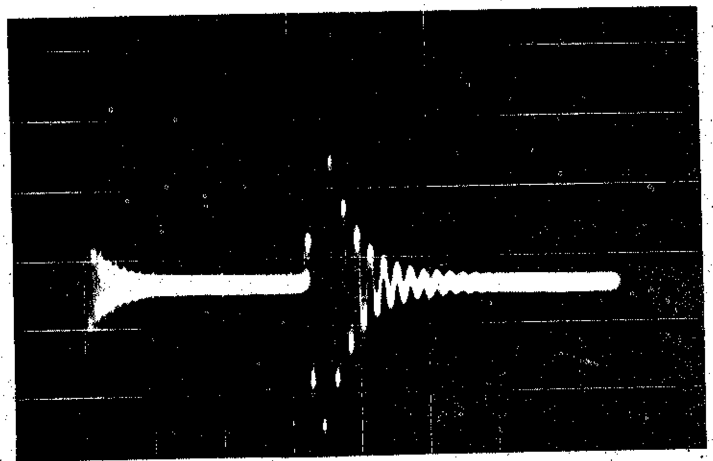
Fig. 13--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 8 cm. in length.











Pressure 900 microns
Current 6 microamps.
Voltage 1155 volts

Oscilloscope settings
0.5 volts/div.
50 microsec./div.

(a)

Pressure 900 microns
Current 22 microamps.
Voltage 1375 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 21 microamps.
Voltage 1465 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(c)

Pressure 1200 microns
Current 15 microamps.
Voltage 1360 volts

Oscilloscope settings
0.5 volts/div.
10 microsec./div.

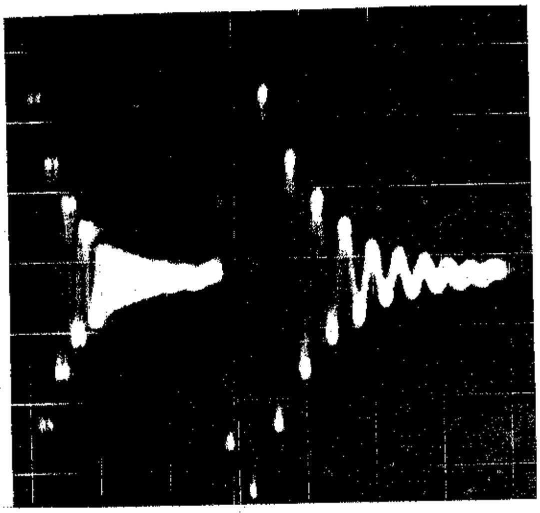
(d)

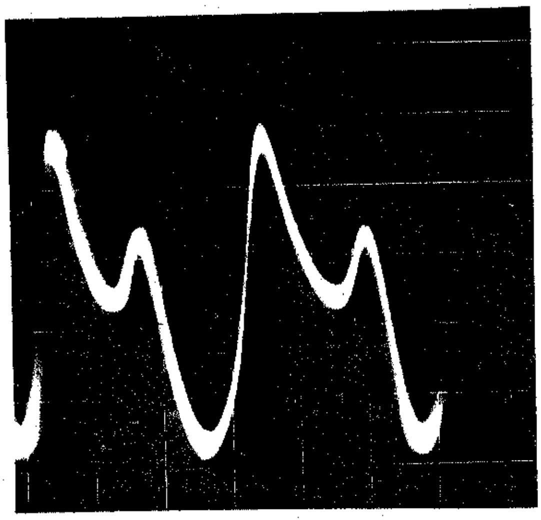
Pressure 1200 microns
Current 7 microamps.
Voltage 1240 volts

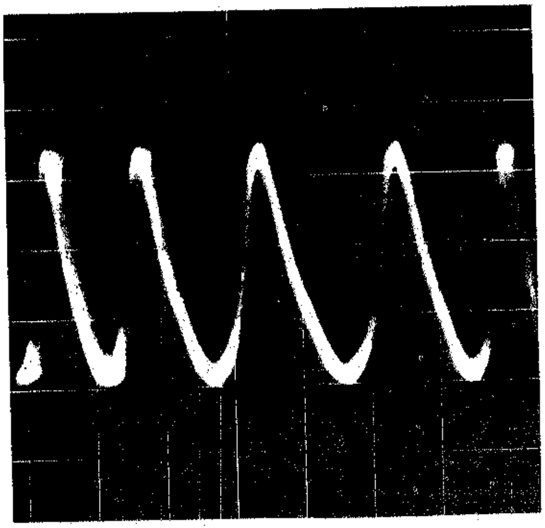
Oscilloscope settings
0.5 volts/div.
50 microsec./div.

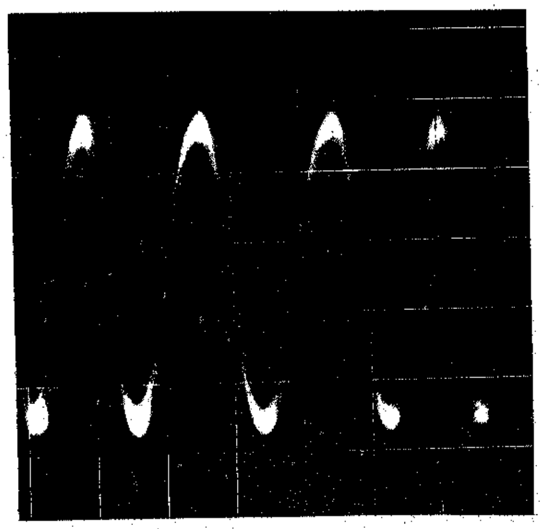
(e)

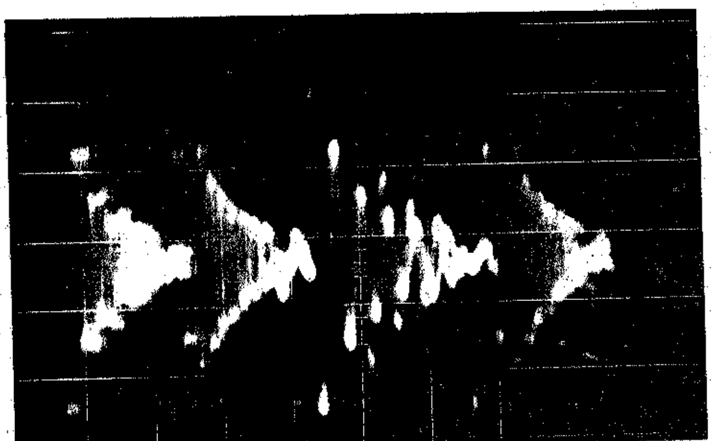
Fig. 14--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 8 cm. in length.











Pressure 300 microns
Current 299 microamps.
Voltage 3550 volts

Oscilloscope settings
5 millivolts/div.
5 microsec./div.

(a)

Pressure 300 microns
Current 189 mocroamps.
Voltage 3550 volts

Oscilloscope settings
5 millivolts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 25 microamps.
Voltage 1150 volts

Oscilloscope settings
50 millivolts/div.
2 microsec./div.

(c)

Pressure 600 microns
Current 18 microamps.
Voltage 810 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

(d)

Pressure 600 microns
Current 15 microamps.
Voltage 785 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

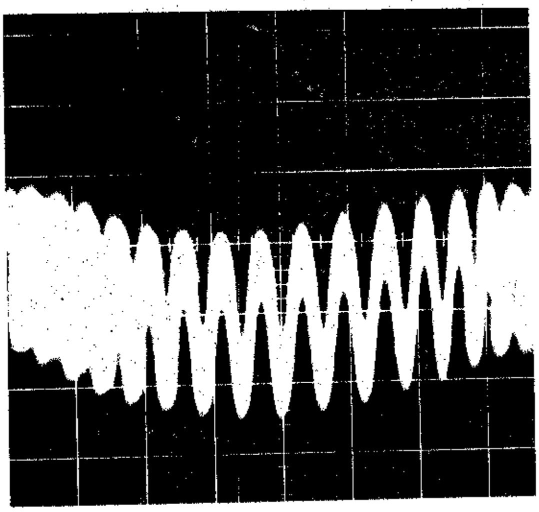
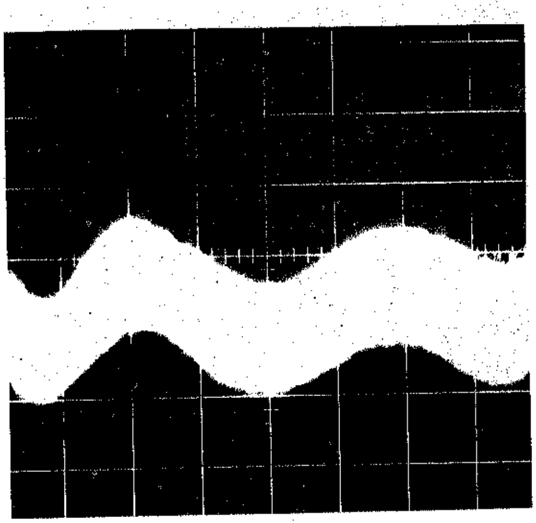
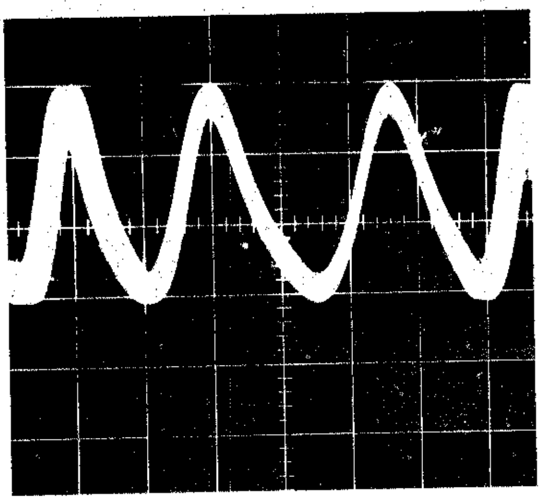
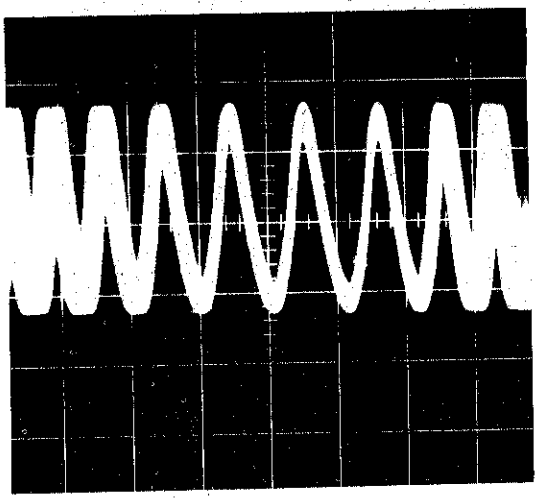
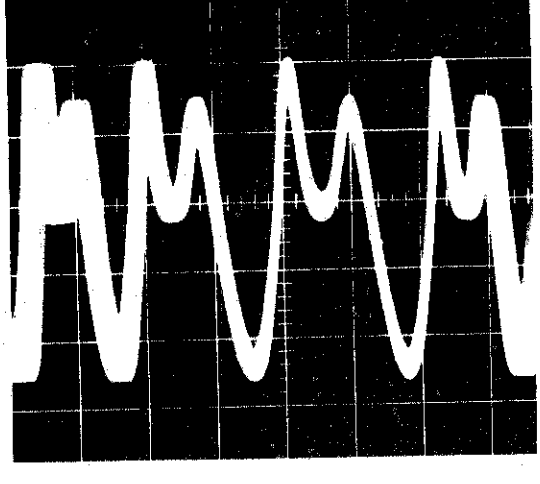
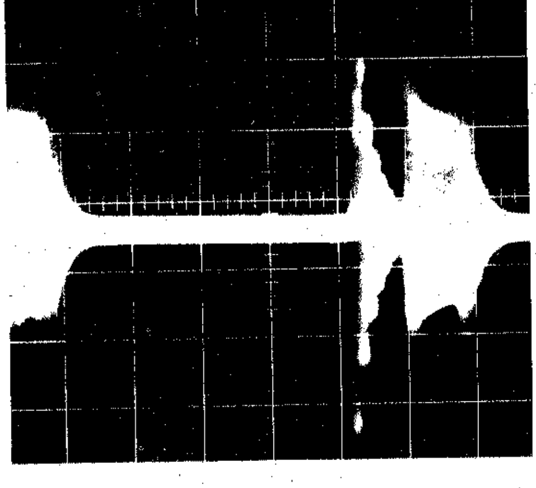
(e)

Pressure 600 microns
Current 6 microamps.
Voltage 830 volts

Oscilloscope settings
2 volts/div.
200 microsec./div.

(f)

Fig. 15--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 6 cm. in length.

Pressure 900 microns
Current 6 microamps.
Voltage 870 volts

Oscilloscope settings
0.2 volts/div.
50 microsec./div.

(a)

Pressure 900 microns
Current 95 microamps.
Voltage 910 volts

Oscilloscope settings
0.2 volts/div.
10 microsec./div.

(b)

Pressure 900 microns
Current 12 microamps.
Voltage 980 volts

Oscilloscope settings
0.5 volts/div.
10 microsec./div.

(c)

Pressure 1200 microns
Current 13 microamps.
Voltage 940 volts

Oscilloscope settings
0.1 volts/div.
10 microsec./div.

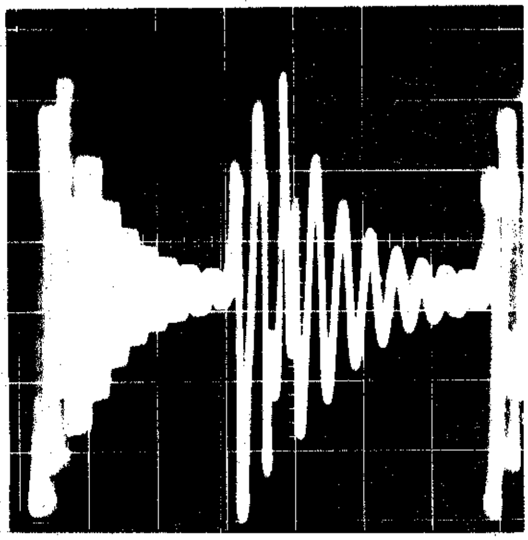
(d)

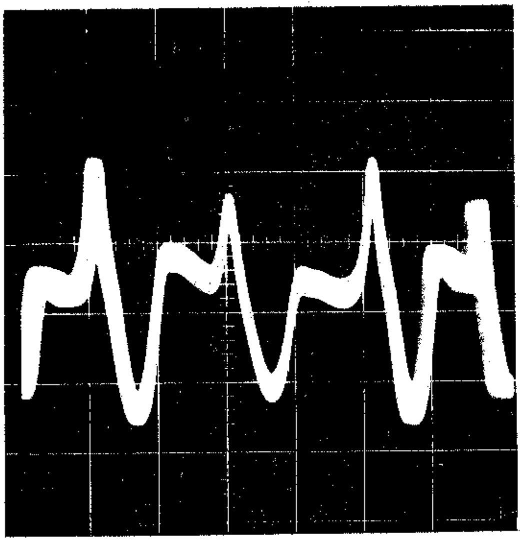
Pressure 1200 microns
Current 15 microamps.
Voltage 1000 volts

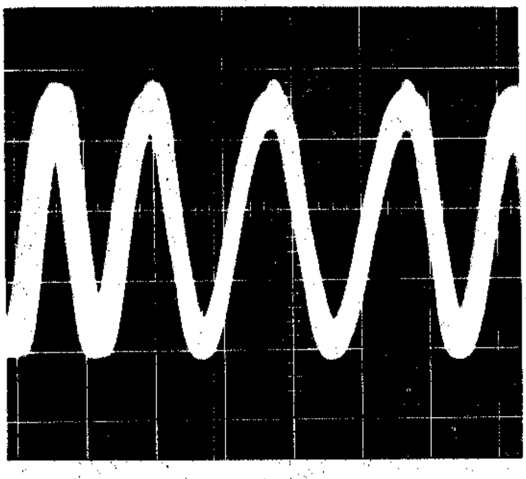
Oscilloscope settings
50 millivolts/div.
5 microsec./div.

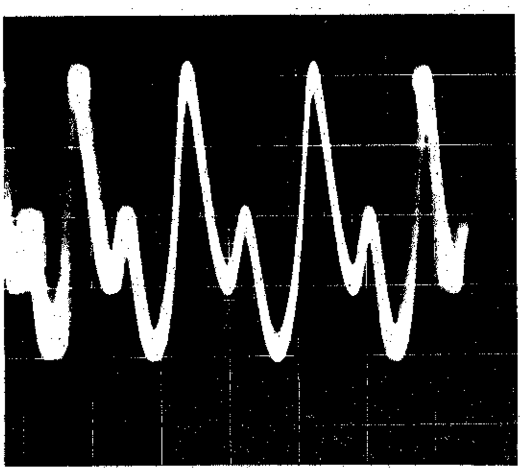
(e)

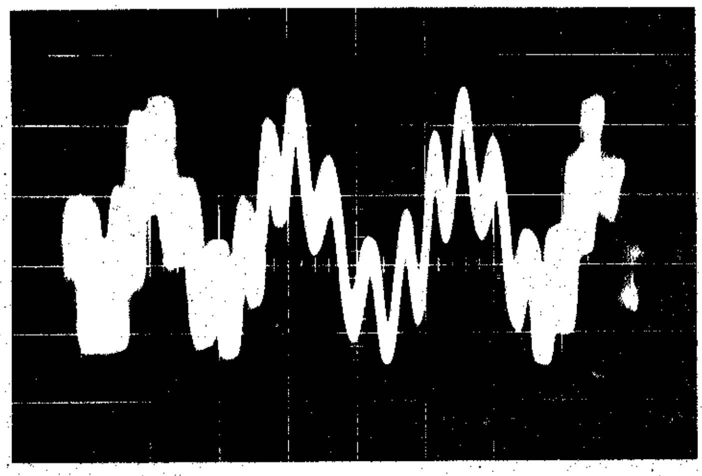
Fig. 16--Plasma oscillations for helium gas in a tube 6 mm. in diameter and 6 cm. in length.











Pressure 300 microns
Current 3 microamps.
Voltage 1550 volts

Oscilloscope settings
2 volts/div.
100 microset./div.

(a)

Pressure 300 microns
Current 8 microamps.
Voltage 1635 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(b)

Pressure 300 microns
Current 103 microamps.
Voltage 1500 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(c)

Pressure 300 microns
Current 179 microamps.
Voltage 2750 volts

Oscilloscope settings
50 millivolts/div.
5 microsec./div.

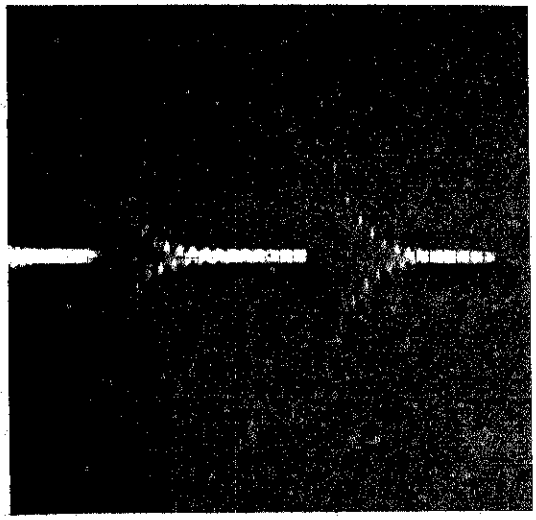
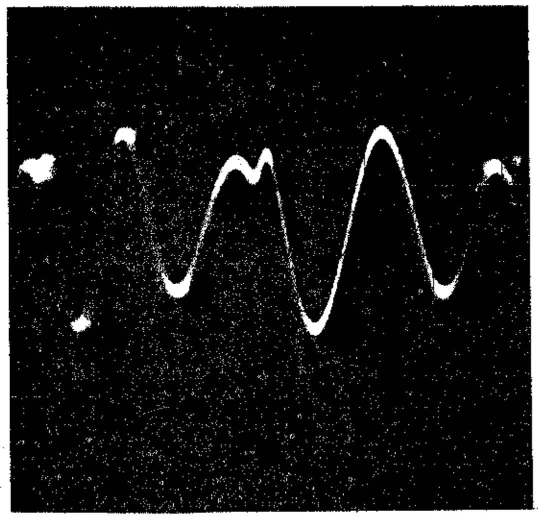
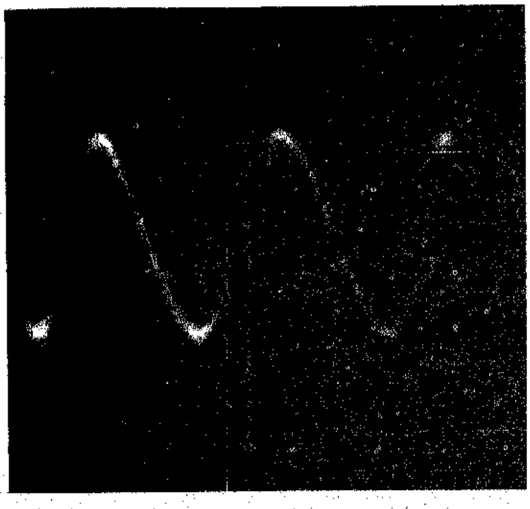
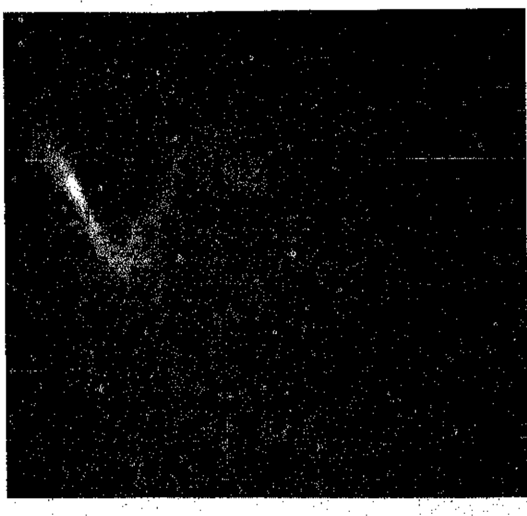
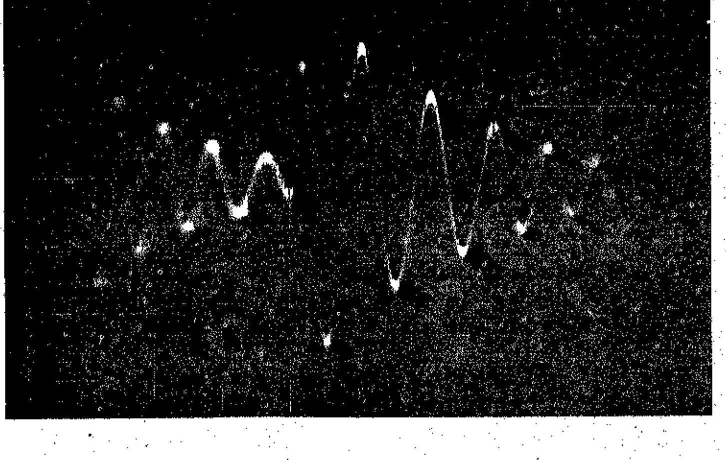
(d)

Pressure 600 microns
Current 3 microamps.
Voltage 1860 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(e)

Fig. 17--Plasma oscillations for helium gas in a tube 5.2 mm. in diameter and 20 cm. in length.

Pressure 600 microns
Current 134 microamps.
Votlage 2500 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(a)

Pressure 600 microns
Current 0 microamps.
Voltage 1860 volts

Oscilloscope settings
1 volt/div.
100 microsec./div.

(b)

Pressure 600 microns
Current 89 microamps.
Voltage 1460 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(c)

Pressure 900 microns
Current 2 microamps.
Voltage 1750 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

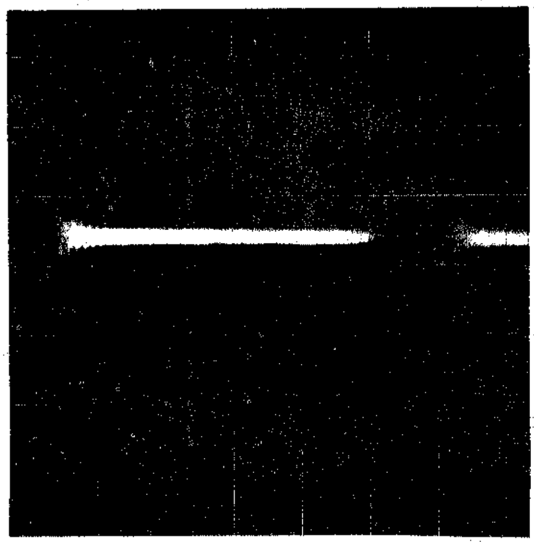
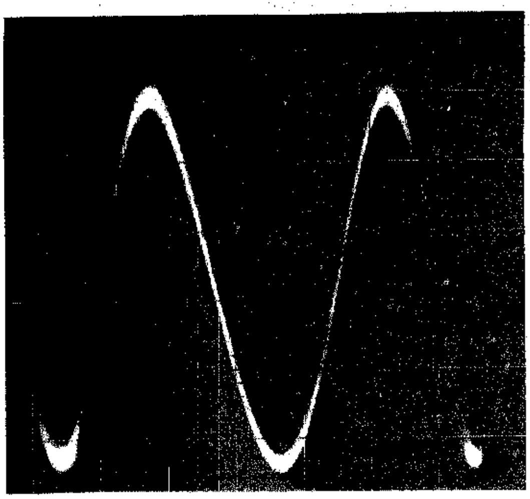
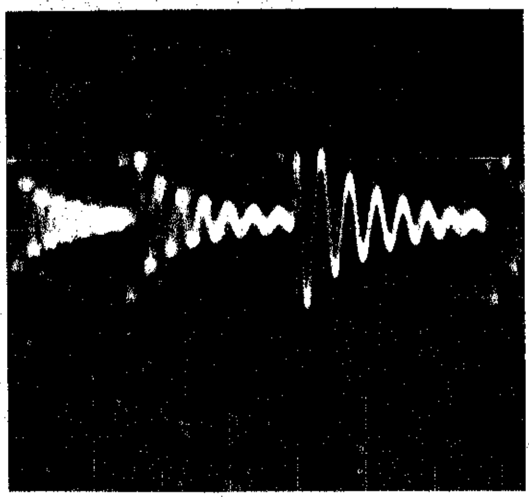
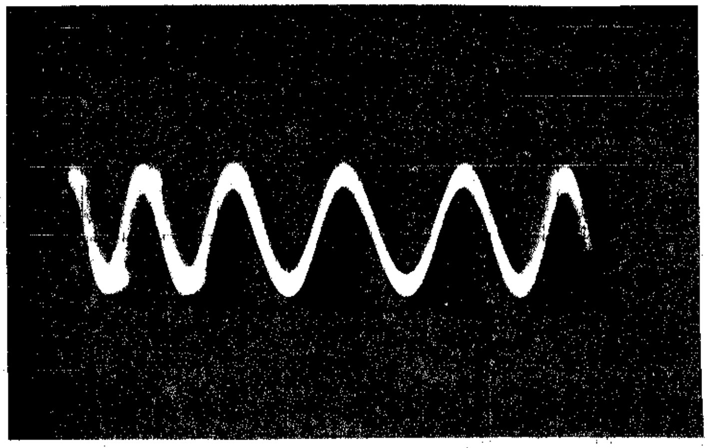
(d)

Pressure 1200 microns
Current 62 microamps.
Voltage 1250 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(e)

Fig. 18--Plasma oscillations for helium gas in a tube 5.2 mm. in diameter and 20 cm. in length.

Pressure 600 microns
Current 135 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(a)

Pressure 600 microns
Current 200 microamps.
Voltage 2550 volts

Oscilloscope settings
20 millivolts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 135 microamps.
Voltage 3250 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

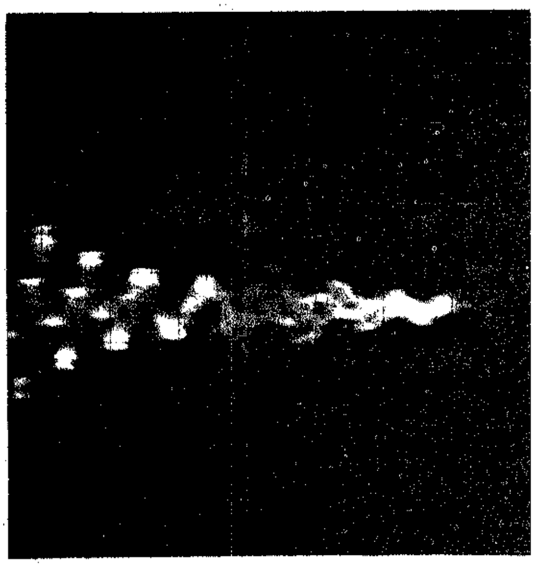
(c)

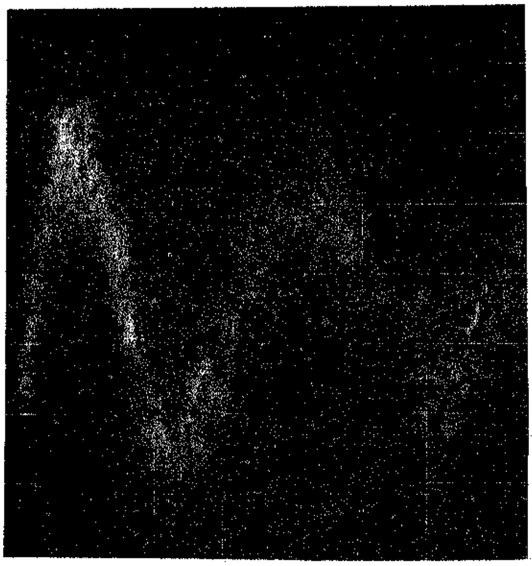
Pressure 900 microns
Current 219 microamps.
Voltage 3050 volts

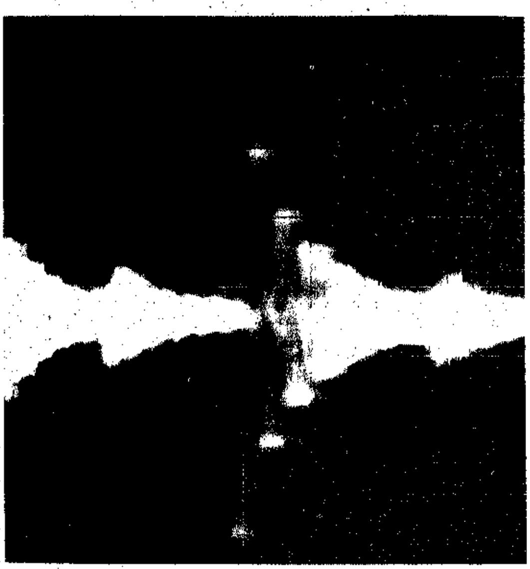
Oscilloscope settings
0.1 volts/div.
2 microsec./div.

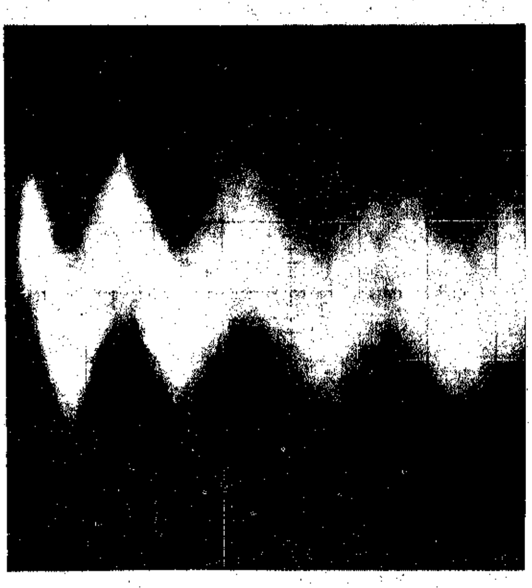
(d)

Fig. 19--Plasma oscillations for helium gas in a tube 3.9 mm. in diameter and 20 cm. in length.









Pressure 1200 microns
Current 136 microamps.
Voltage 2250 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(a)

Pressure 1200 microns
Current 138 microamps.
Voltage 2800 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

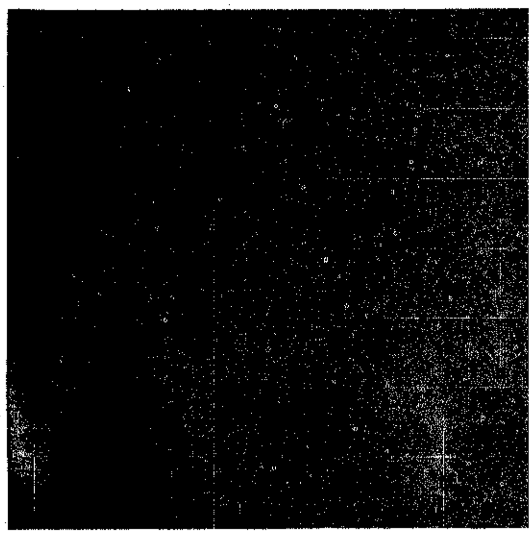
(b)

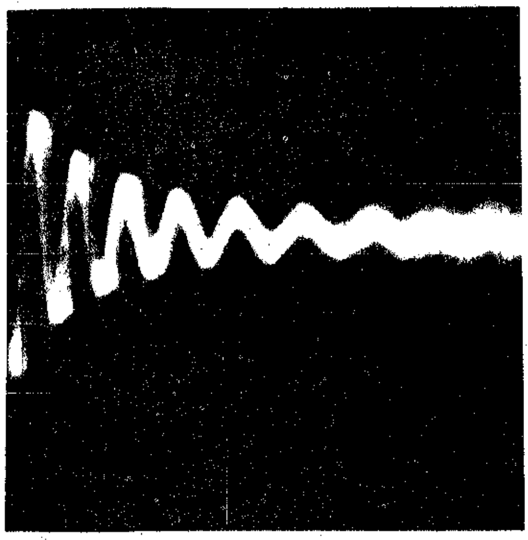
Pressure 1200 microns
Current 239 microamps.
Voltage 2500 volts

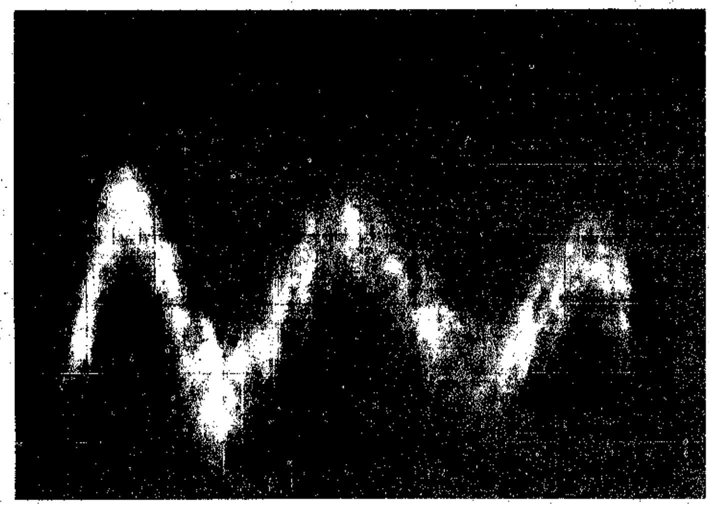
Oscilloscope settings
0.1 volts/div.
5 microsec./div.

(c)

Fig. 20--Plasma oscillations for helium gas in a tube 3.9 mm. in diameter and 20 cm. in length.







Pressure 300 microns
Current 135 microamps.
Voltage 2800 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(a)

Pressure 300 microns
Current 165 microamps.
Voltage 2550 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 171 microamps.
Voltage 2550 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

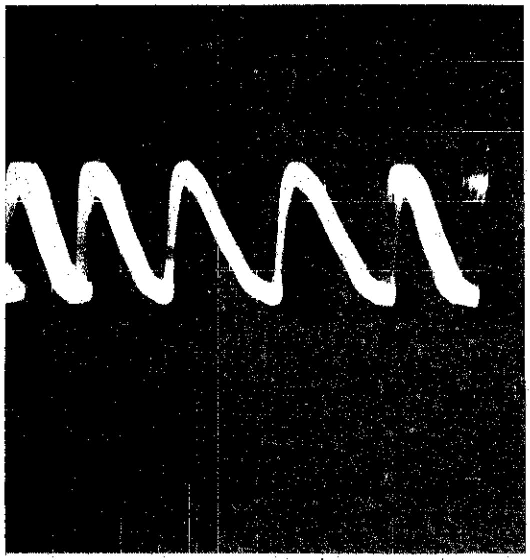
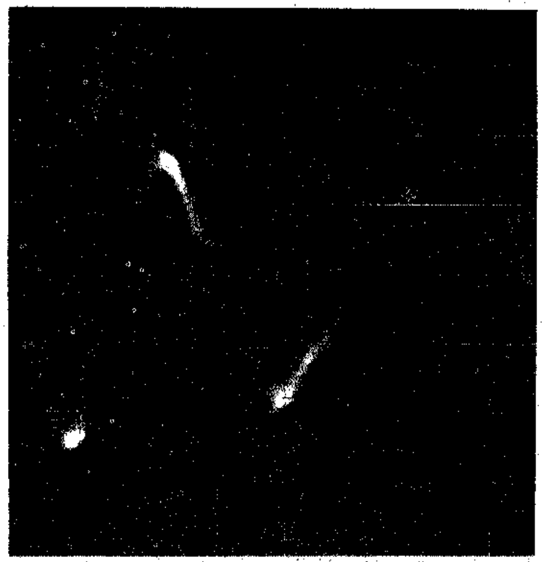
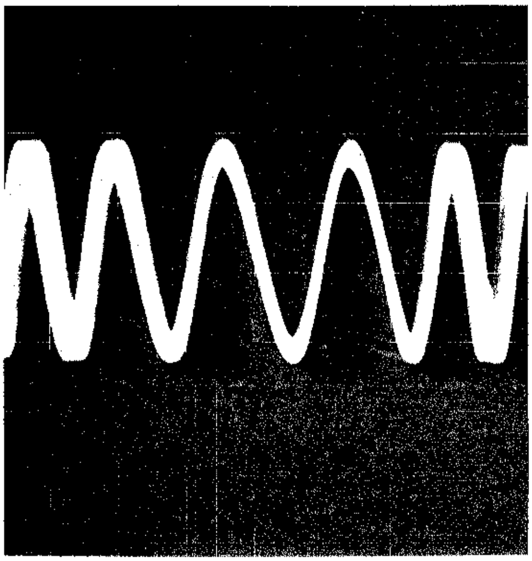
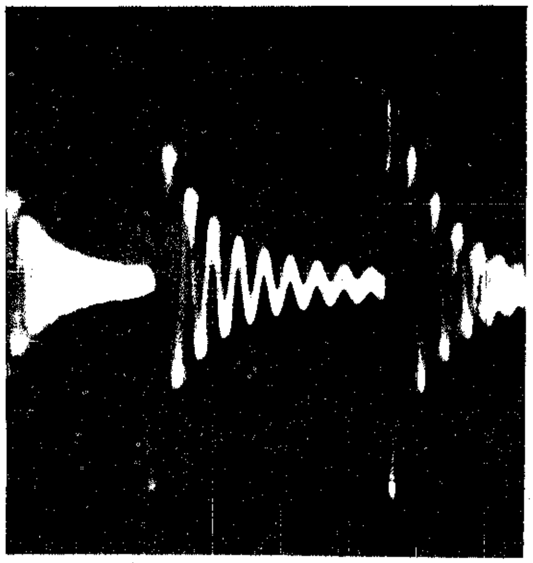
(c)

Pressure 600 microns
Current 26 microamps.
Voltage 2250 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(d)

Fig. 21--Plasma oscillations for helium gas in a tube 3.5 mm. in diameter and 20 cm. in length.

Pressure 600 microns
Current 139 microamps.
Voltage 2550 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(a)

Pressure 600 microns
Current 151 microamps.
Voltage 3250 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

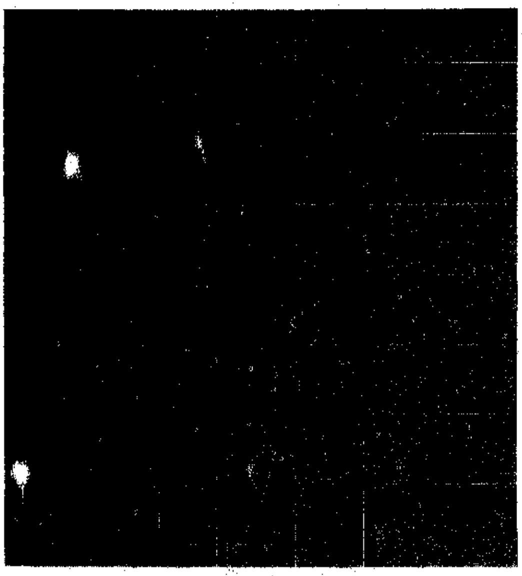
(b)

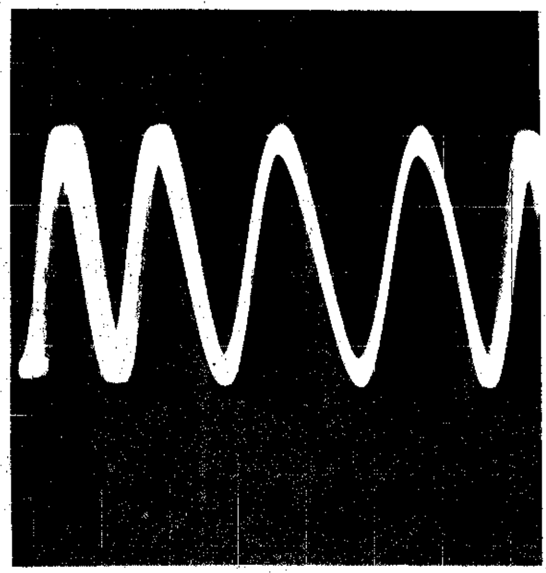
Pressure 900 microns
Current 133 microamps.
Voltage 2550 volts

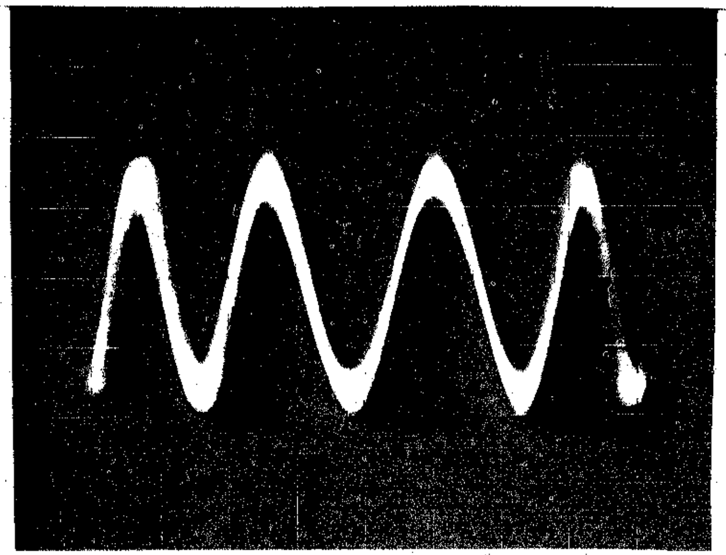
Oscilloscope settings
50 millivolts/div.
2 microsec./div.

(c)

Fig. 22--Plasma oscillations for helium gas in a tube 3.5 mm. in diameter and 20 cm. in length.







Pressure 300 microns
Current 133 microamps.
Voltage 3550 volts

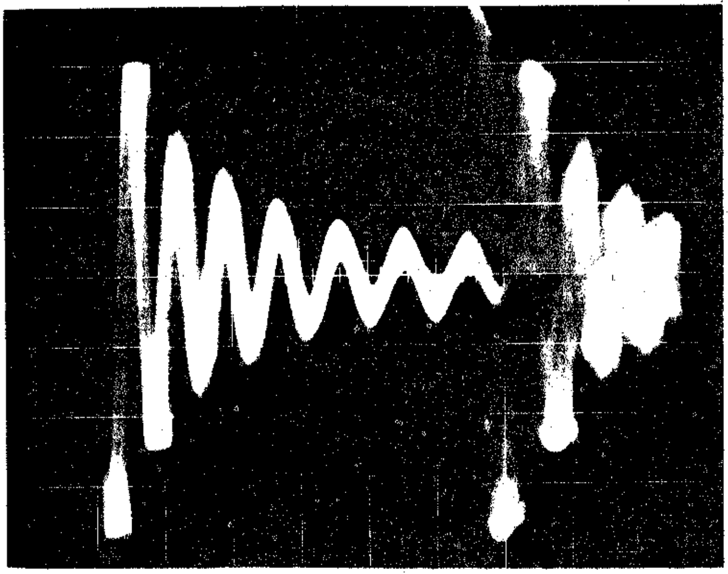
Oscilloscope settings
2 volts/div.
20 microsec./div.

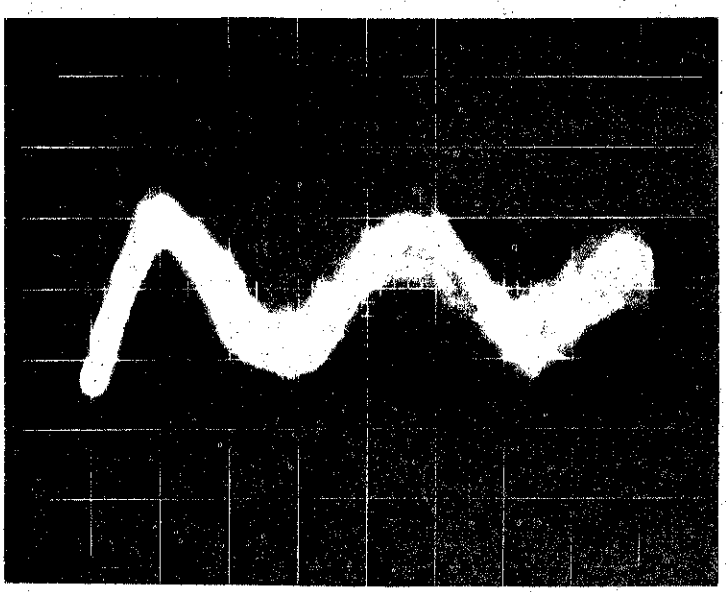
Fig. 23a--Plasma oscillations for helium gas in a tube 2.3 mm. in diameter and 20 cm. in length.

Pressure 300 microns
Current 139 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

Fig. 23b--Plasma oscillations for helium gas in a tube 1.7 mm. in diameter and 20 cm. in length.





Pressure 250 microns
Current 6 microamps.
Voltage 1920 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(a)

Pressure 250 microns
Current 26 microamps.
Voltage 2385 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(b)

Pressure 250 microns
Current 79 microamps.
Voltage 2875 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

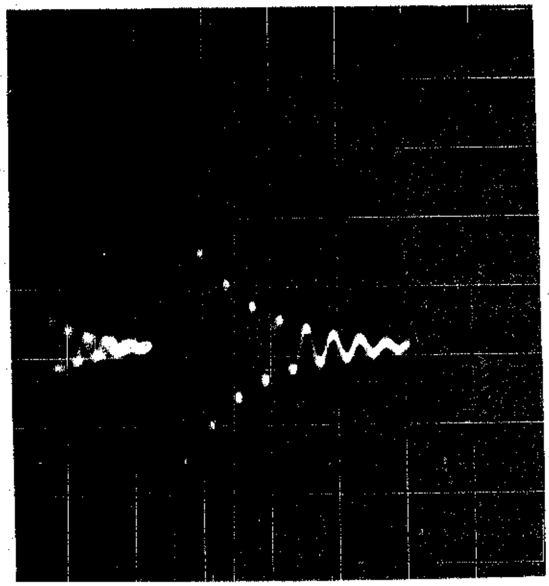
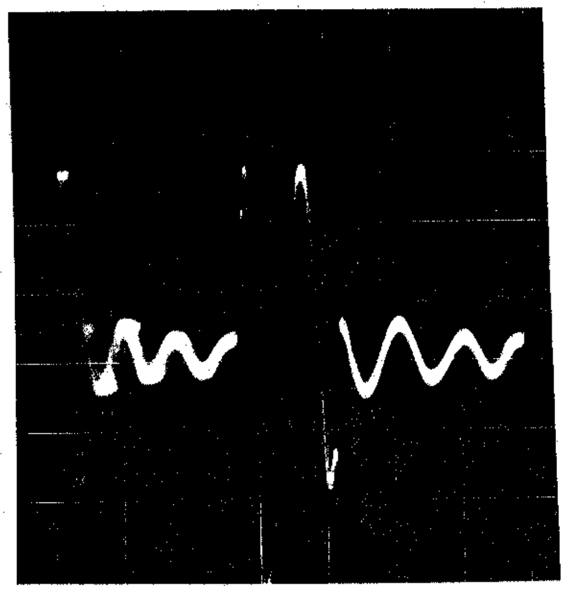
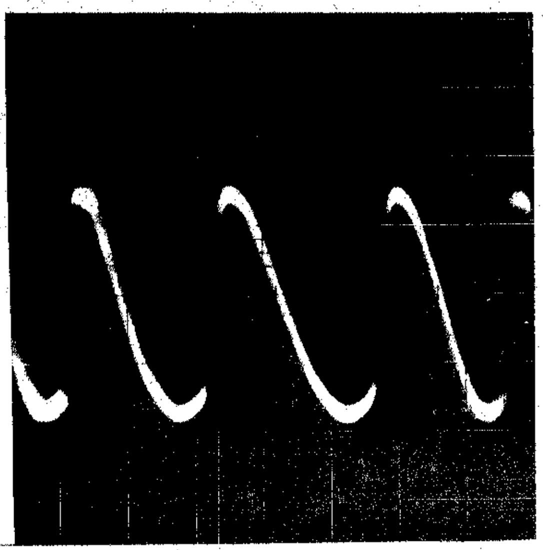
(c)

Pressure 250 microns
Current 39 microamps.
Voltage 2465 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(d)

Fig. 24--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 23 cm. in length.


Pressure 500 microns
Current 9 microamps.
Voltage 1960 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(a)

Pressure 500 microns
Current 59 microamps.
Voltage 2250 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(b)

Pressure 750 microns
Current 70 microamps.
Voltage 2050 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 750 microns
Current 59 microamps.
Voltage 2160 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

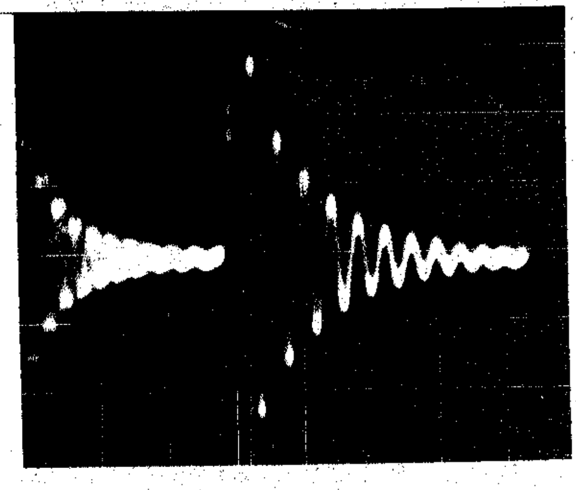
(d)

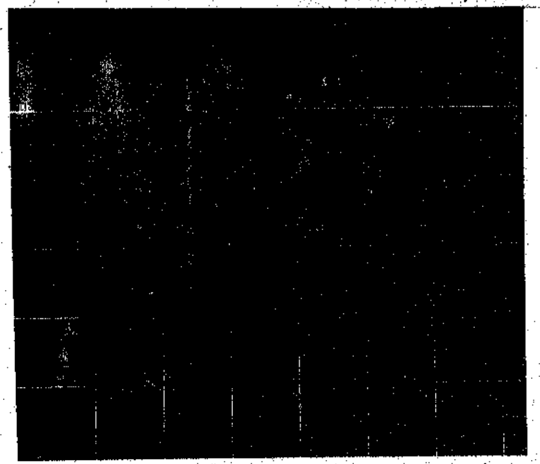
Pressure 1000 microns
Current 59 microamps.
Votlage 2250 volts

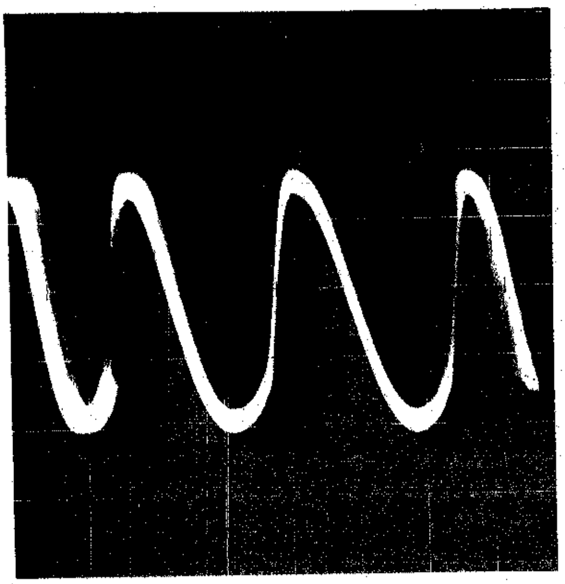
Oscilloscope settings
5 volts/div.
5 microsec./div.

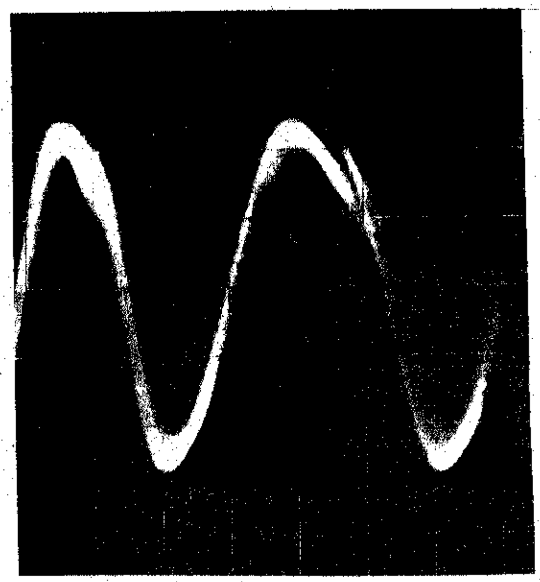
(e)

Fig. 25--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 23 cm. in length.









Pressure 300 microns
Current 21 microamps.
Voltage 1770 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(a)

Pressure 600 microns
Current 99 microamps.
Voltage 1710 volts

Oscilloscope settings
50 millivolts/div.
10 microsec./div.

(b)

Pressure 900 microns
Current 132 microamps.
Voltage 1865 volts

Oscilloscope settings
2 millivolts/div.
20 microsec./div.

(c)

Pressure 900 microns
Current 459 microamps.
Voltage 2800 volts

Oscilloscope settings
5 millivolts/div.
5 microsec./div.

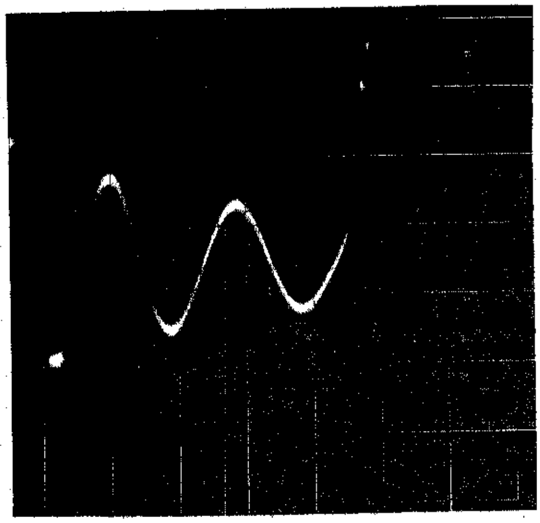
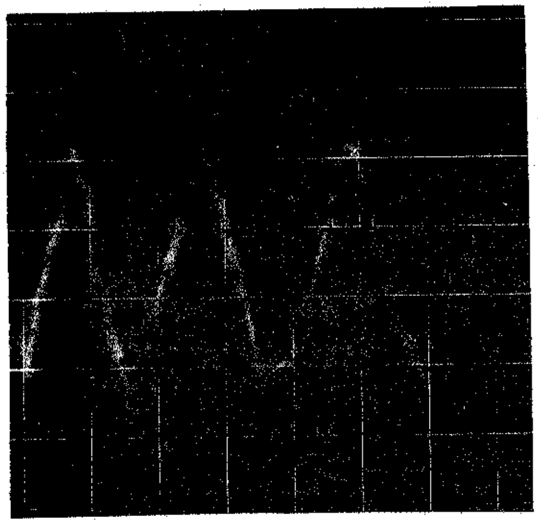
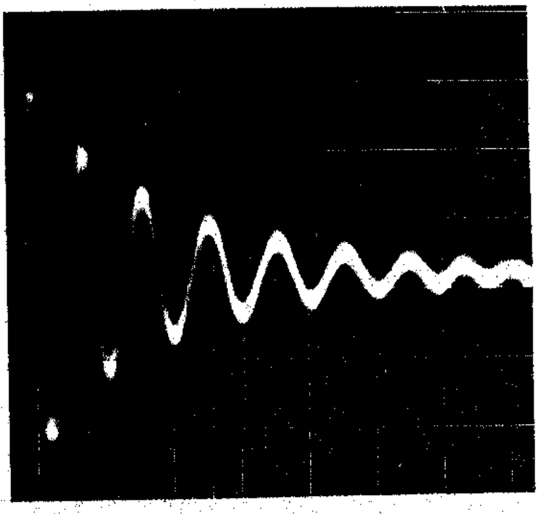
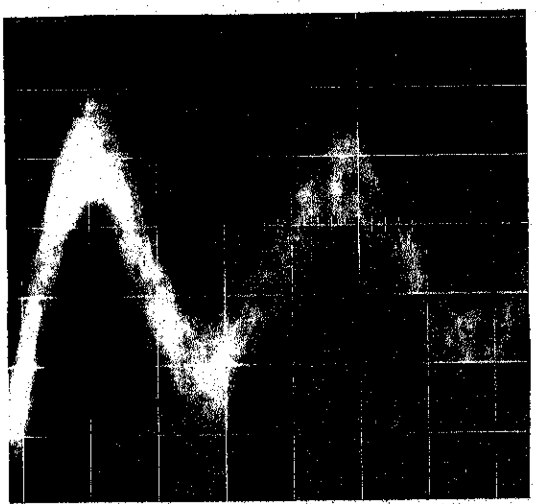
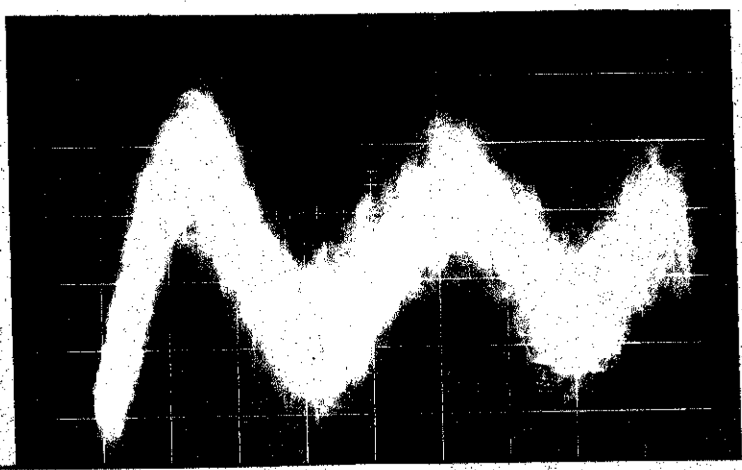
(d)

Pressure 1200 microns
Current 490 microamps.
Voltage 2800 volts

Oscilloscope settings
5 millivolts/div.
5 microsec./div.

(e)

Fig. 26--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 20 cm. in length.

Pressure 300 microns
Current 23 microamps.
Voltage 2355 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(a)

Pressure 300 microns
Current 66 microamps.
Voltage 2555 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(b)

Pressure 300 microns
Current 15 microamps.
Voltage 1675 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

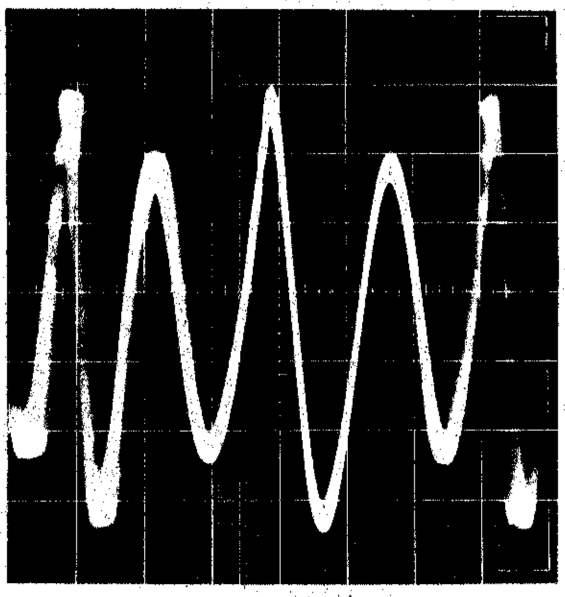
(c)

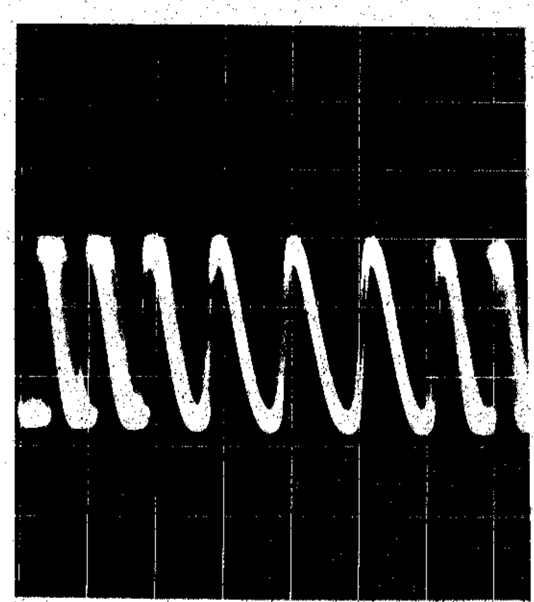
Pressure 600 microns
Current 6 microamps.
Voltage 1300 volts

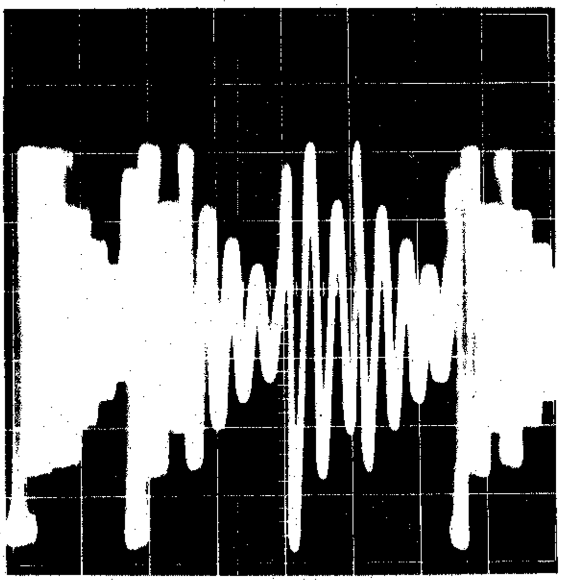
Oscilloscope settings
2 volts/div.
50 microsec./div.

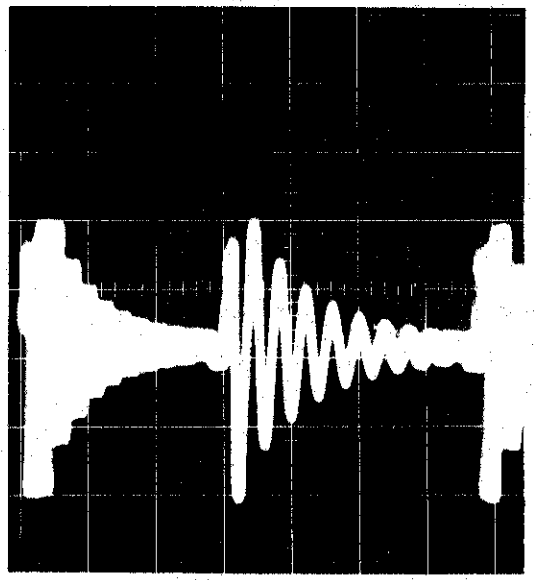
(d)

Fig. 27--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 17 cm. in length.









Pressure 600 microns
Current 41 microamps.
Voltage 2050 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(a)

Pressure 600 microns
Current 57 microamps.
Voltage 1830 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(b)

Pressure 600 microns
Current 89 microamps.
Voltage 2050 volts

Oscilloscope settings
50 millivolts/div.
1 microsec./div.

(c)

Pressure 900 microns
Current 80 microamps.
Voltage 2110 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

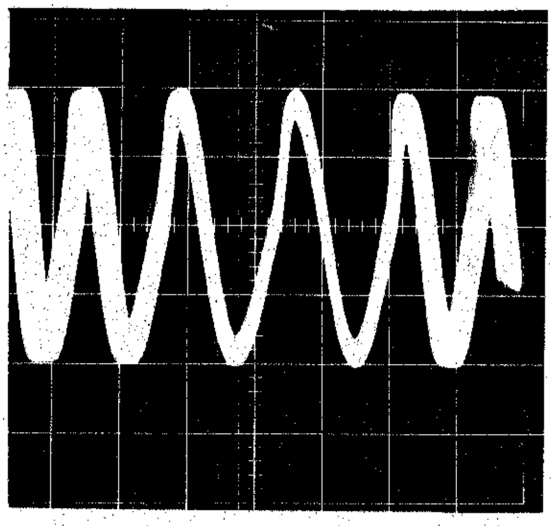
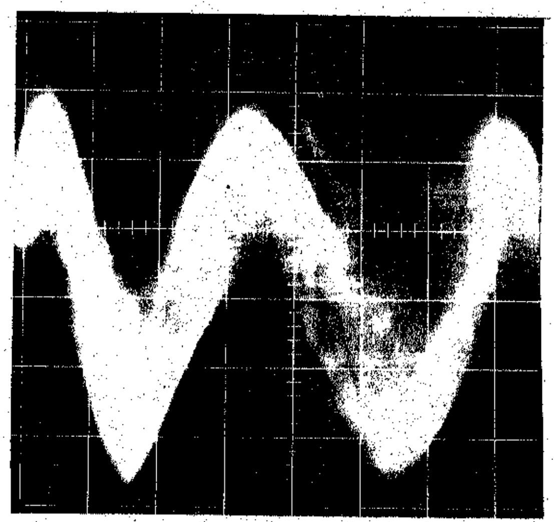
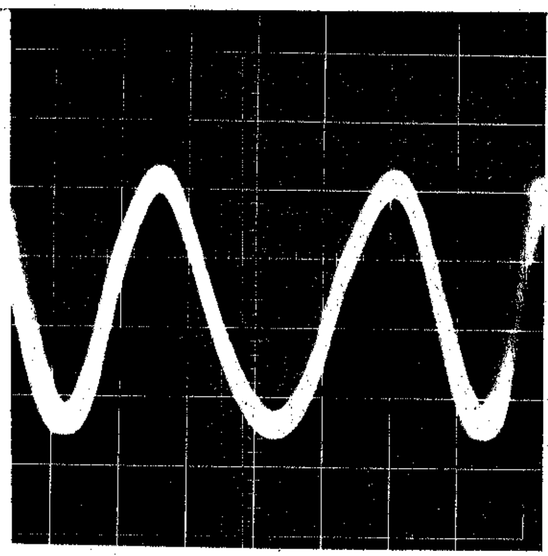
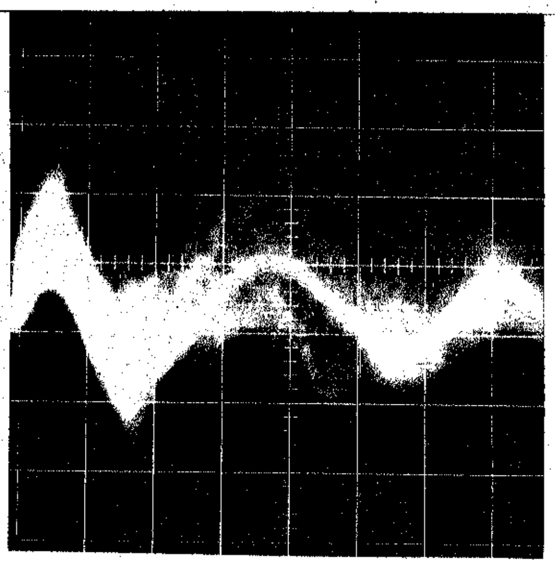
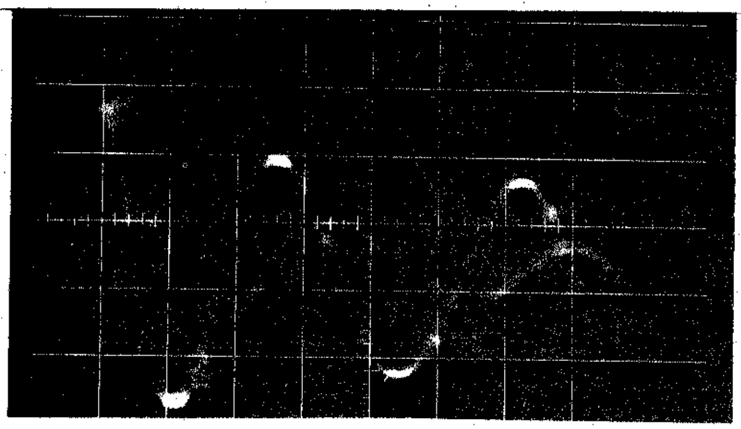
(d)

Pressure 1200 microns
Current 136 microamps.
Voltage 2500 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(e)

Fig. 28--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 17 cm. in length.

Pressure 300 microns
Current 9 microamps.
Votlage 1840 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(a)

Pressure 300 microns
Current 68 microamps.
Voltage 2360 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(b)

Pressure 300 microns
Current 24 microamps.
Voltage 1880 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(c)

Pressure 600 microns
Current 25 microamps.
Voltage 1800 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

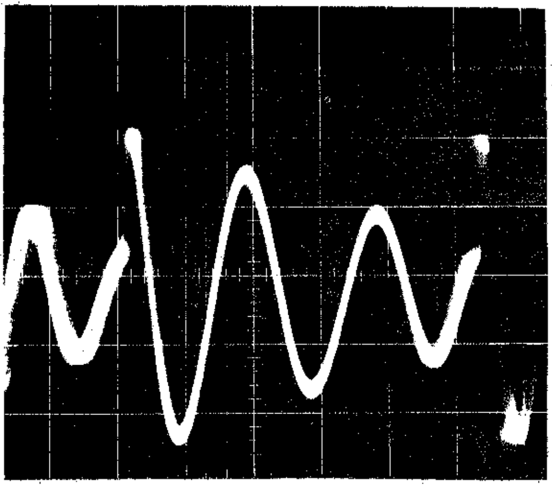
(d)

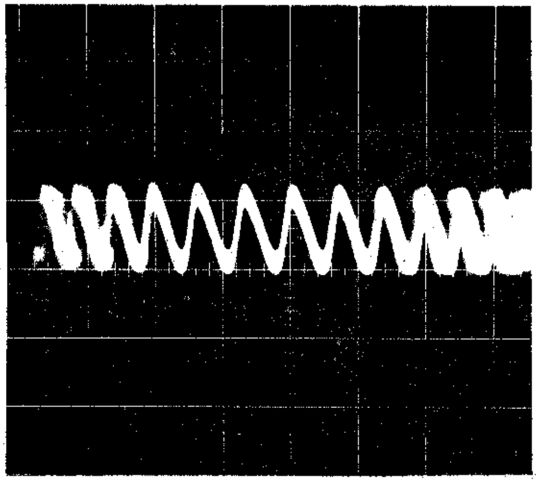
Pressure 600 microns
Current 46 microamps.
Voltage 1915 volts

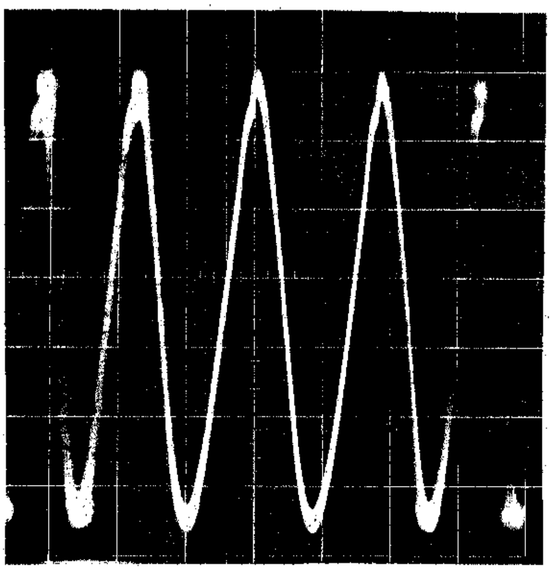
Oscilloscope settings
2 volts/div.
10 microsec./div.

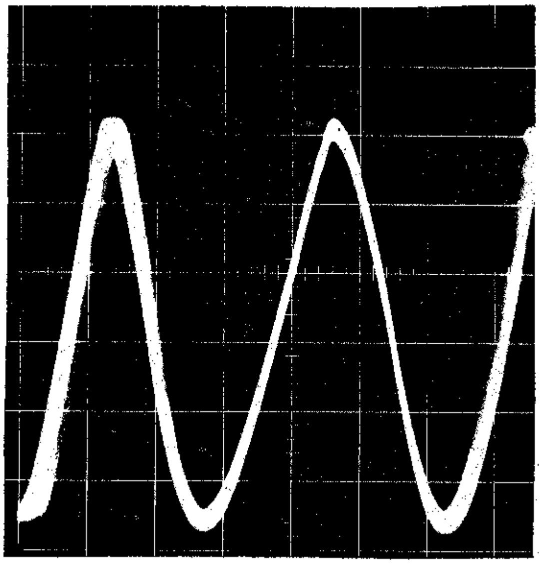
(e)

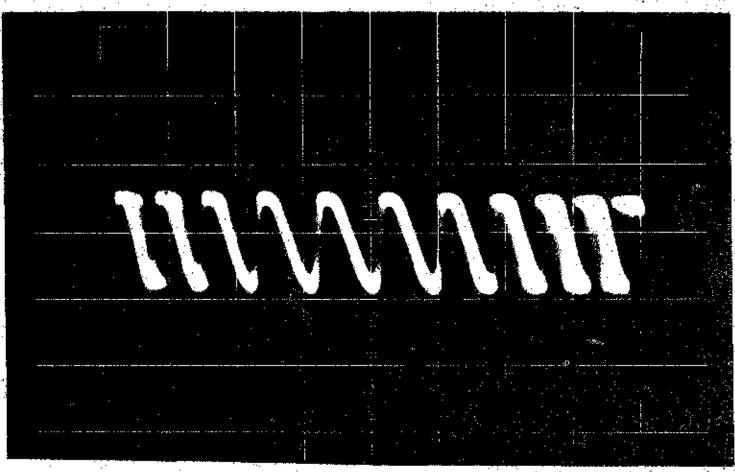
Fig. 29--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 13 cm. in length.











Pressure 600 microns
Current 9 microamps.
Votlage 1390 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(a)

Pressure 900 microns
Current 49 microamps.
Voltage 1415 volts

Oscilloscope settings
0.5 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 41 microamps.
Votlage 1410 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(c)

Pressure 900 microns
Current 32 microamps.
Voltage 1375 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(d)

Pressure 900 microns
Current 24 microamps.
Voltage 1350 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

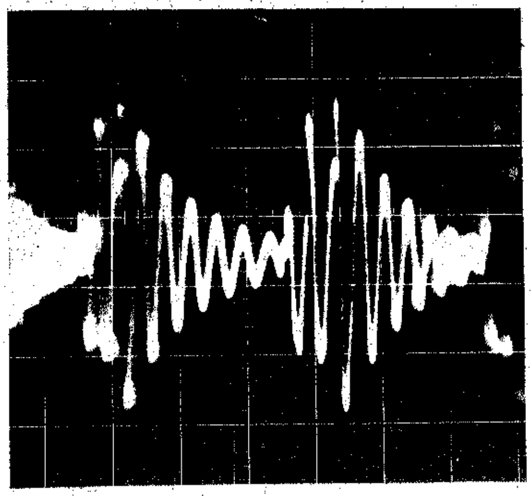
(e)

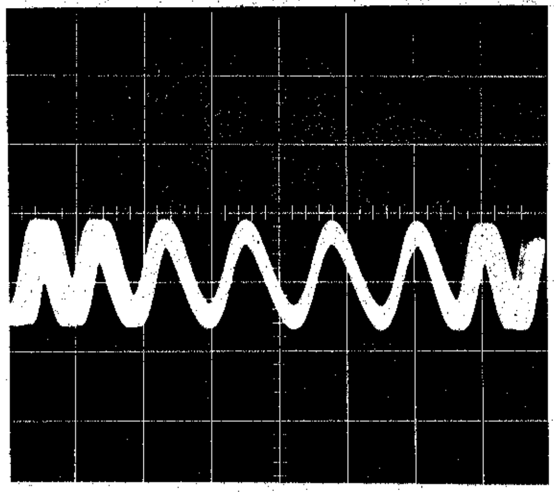
Pressure 900 microns
Current 19 microamps.
Voltage 1455 volts

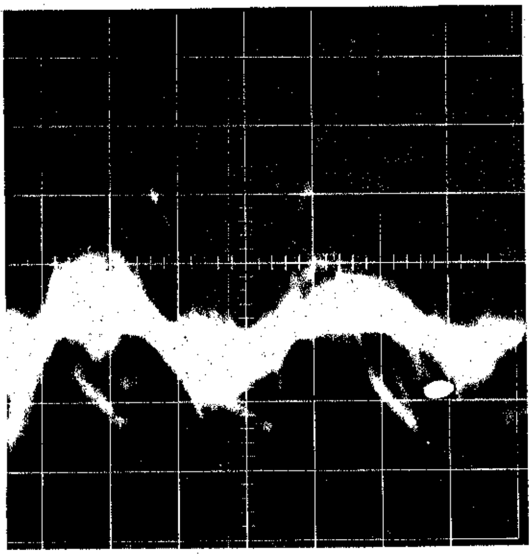
Oscilloscope settings
2 volts/div.
10 microsec./div.

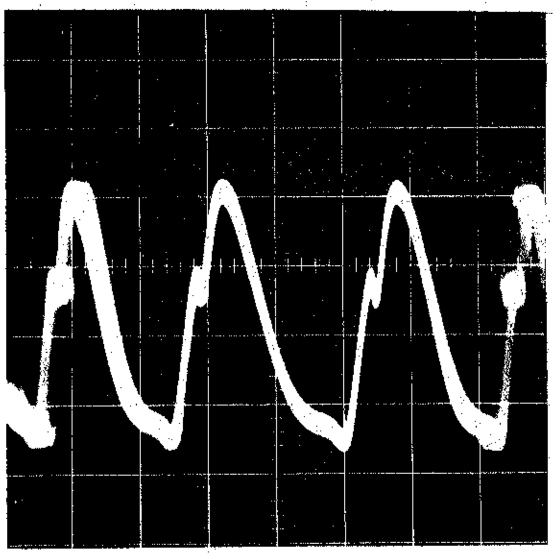
(f)

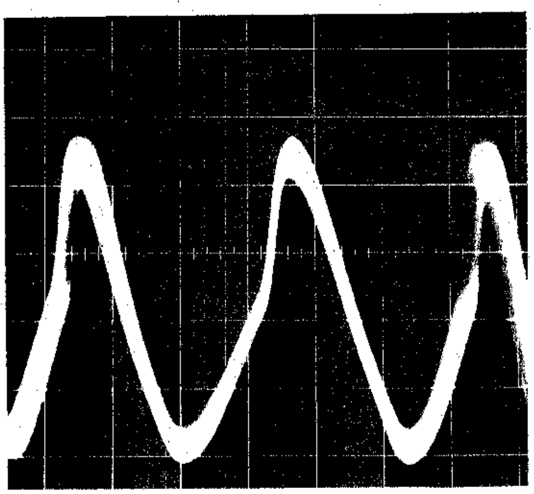
Fig. 30--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 13 cm. in length.

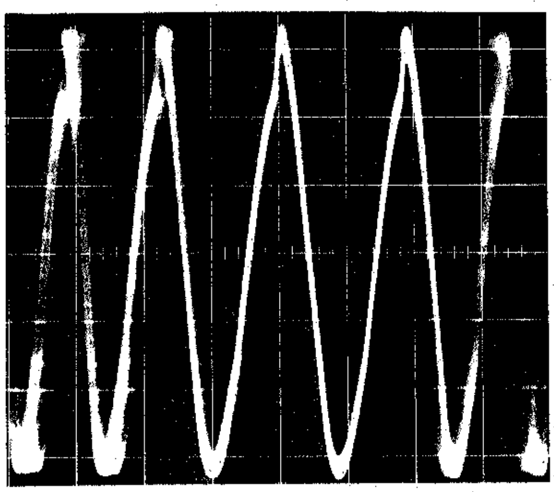












Pressure 900 microns
Current 8 microamps.
Voltage 1370 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(a)

Pressure 900 microns
Current 108 microamps.
Voltage 1815 volts

Oscilloscope settings
10 millivolts/div.
2 microsec./div.

(b)

Pressure 1200 microns
Current 19 microamps.
Voltage 1420 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 1200 microns
Current 119 microamps.
Voltage 1905 volts

Oscilloscope settings
10 millivolts/div.
2 microsec./div.

(d)

Pressure 1200 microns
Current 38 microamps.
Voltage 1490 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

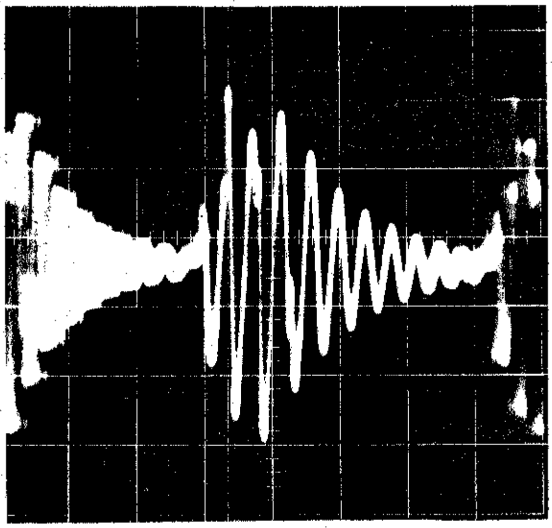
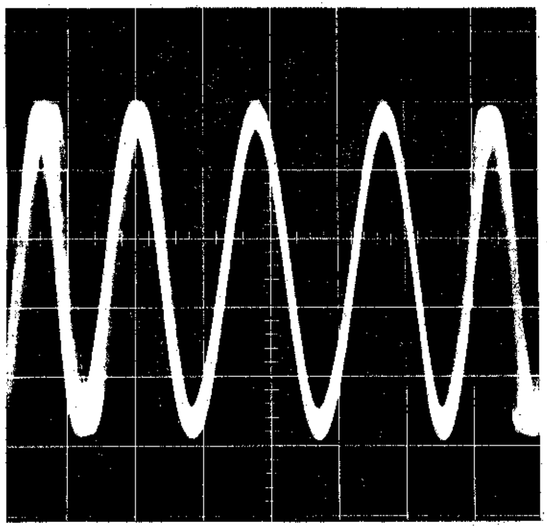
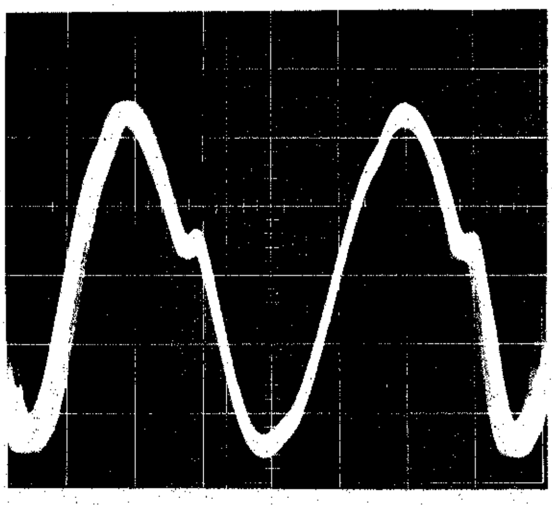
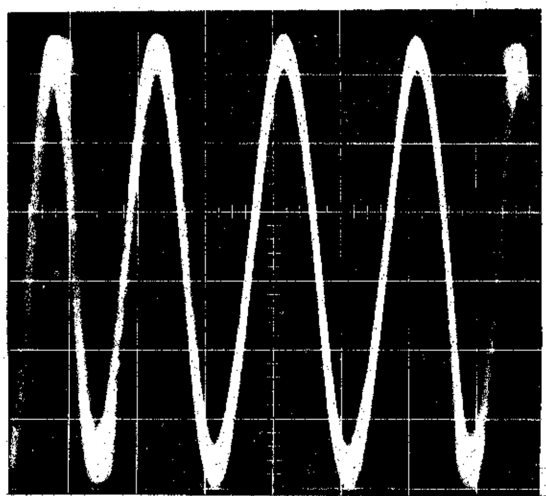
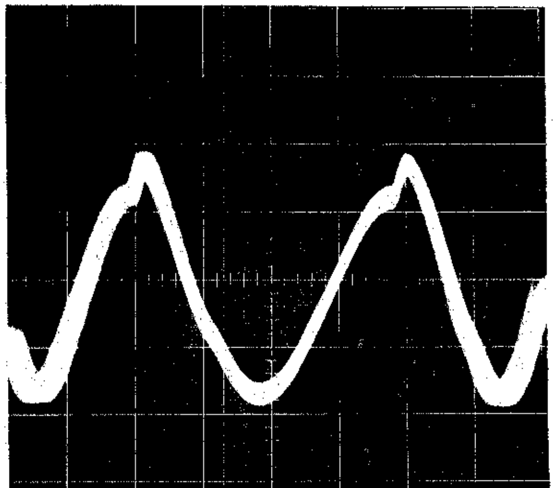
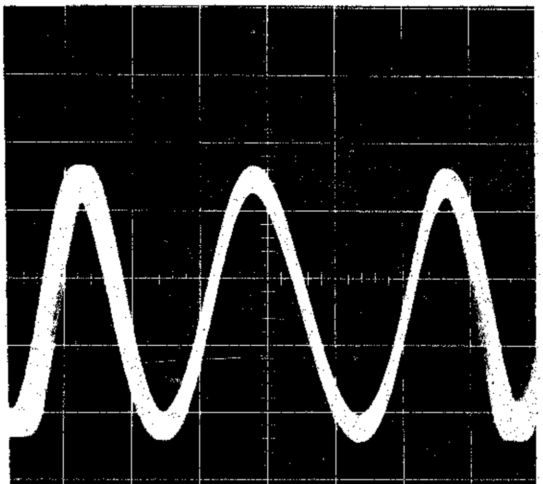
(e)

Pressure 1200 microns
Current 59 microamps.
Voltage 1550 volts

Oscilloscope settings
1 volt/div.
2 microsec./div.

(f)

Fig. 31--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 13 cm. in length.

Pressure 300 microns
Current 6 microamps.
Voltage 1750 volts

Oscilloscope settings
0.5 volts/div.
20 microsec./div.

(a)

Pressure 300 microns
Current 5 microamps.
Voltage 1540 volts

Oscilloscope settings
0.5 volts/div.
20 microsec./div.

(b)

Pressure 300 microns
Current 39 microamps.
Voltage 1145 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 600 microns
Current 113 microamps.
Voltage 1060 volts

Oscilloscope settings
10 millivolts/div.
2 microsec./div.

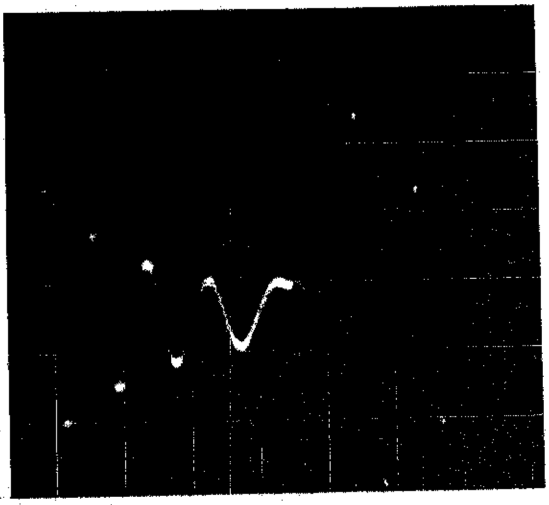
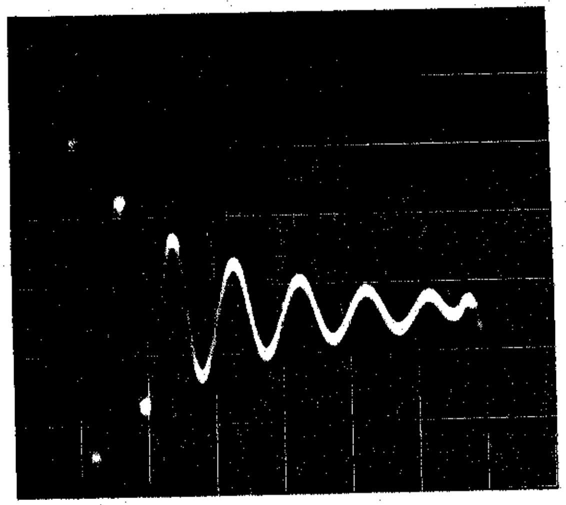
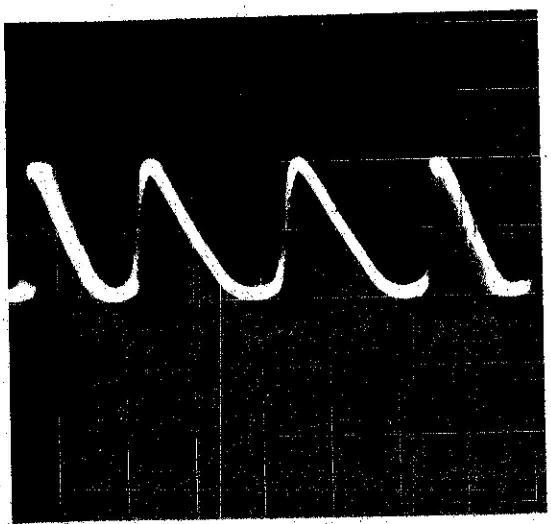
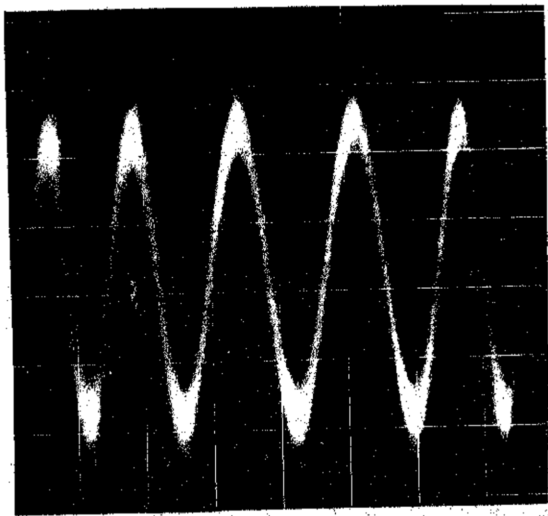
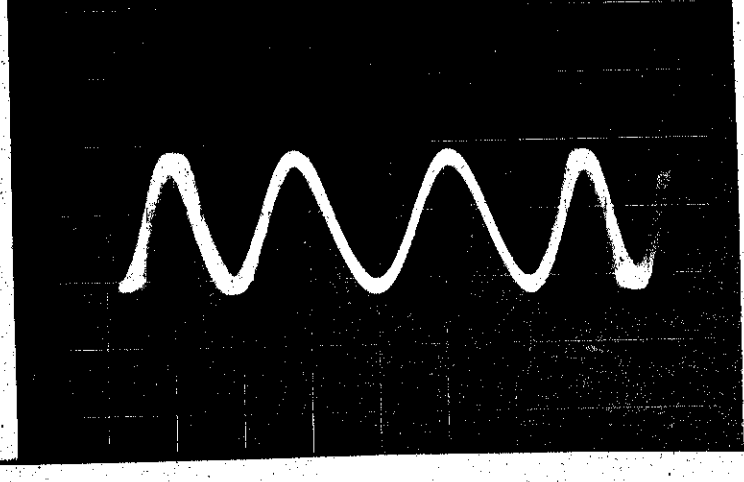
(d)

Pressure 1200 microns
Current 49 microamps.
Voltage 800 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(e)

Fig. 32--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 10 cm. in length.

Pressure 300 microns
Current 19 microamps.
Voltage 1750 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(a)

Pressure 300 microns
Current 11 microamps.
Voltage 1610 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 11 microamps.
Voltage 1495 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

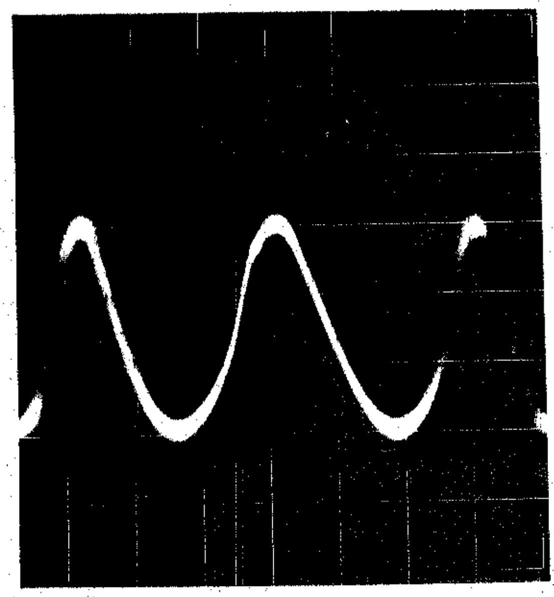
(c)

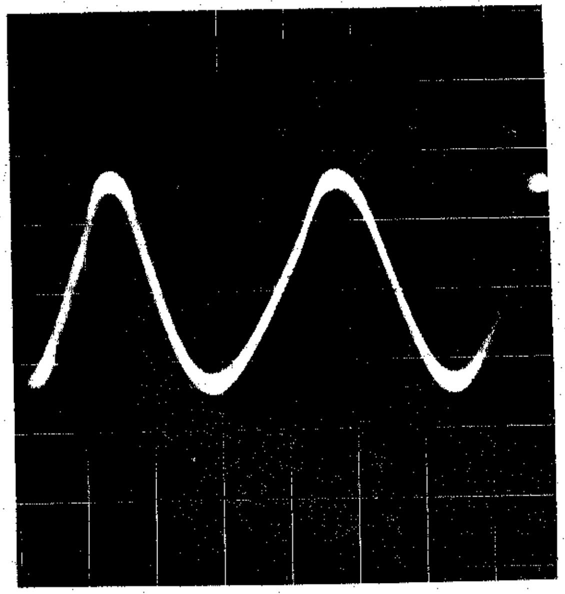
Pressure 600 microns
Current 120 microamps.
Voltage 3050 volts

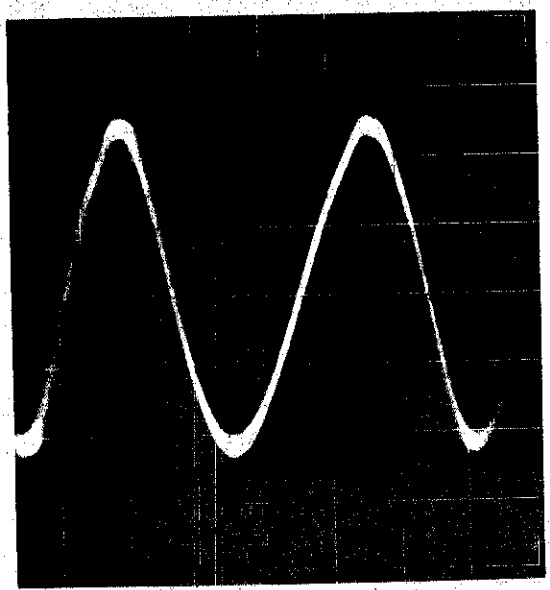
Oscilloscope settings
1 volt/div.
20 microsec./div.

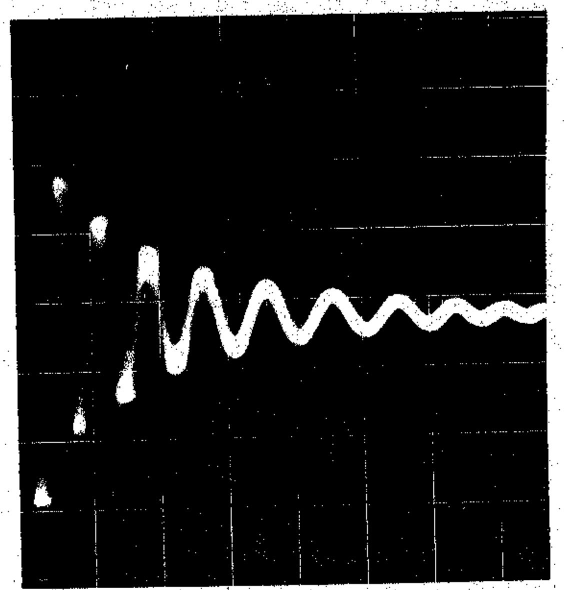
(d)

Fig. 33--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 8 cm. in length.









Pressure 900 microns
Current 2 microamps.
Voltage 1155 volts

Oscilloscope settings
1 volt/div.
100 microsec./div.

(a)

Pressure 900 microns
Current 22 microamps.
Voltage 1350 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(b)

Pressure 1200 microns
Current 31 microamps.
Voltage 1480 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 1200 microns
Current 4 microamps.
Voltage 1070 volts

Oscilloscope settings
1 volt/div.
100 microsec./div.

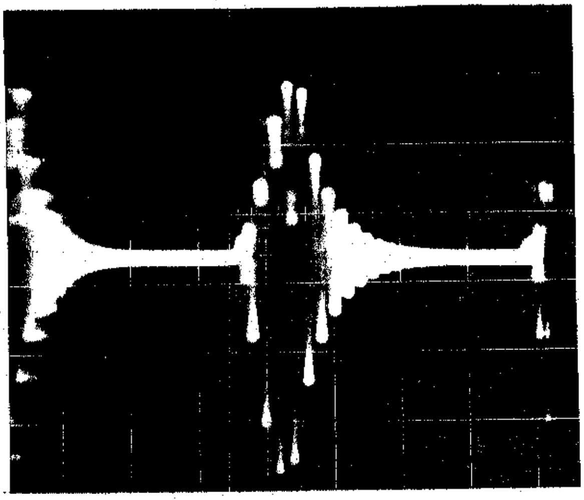
(d)

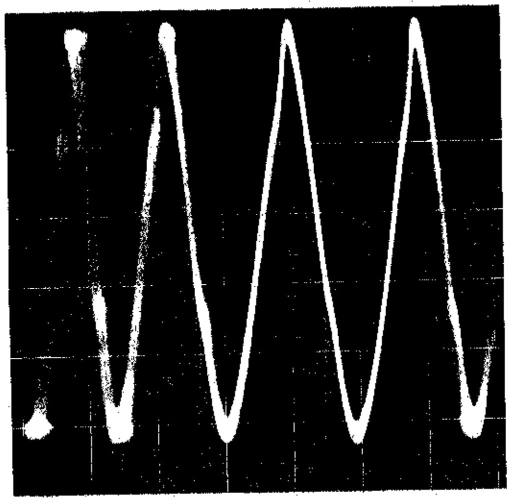
Pressure 1200 microns
Current 4 microamps.
Voltage 1010 volts

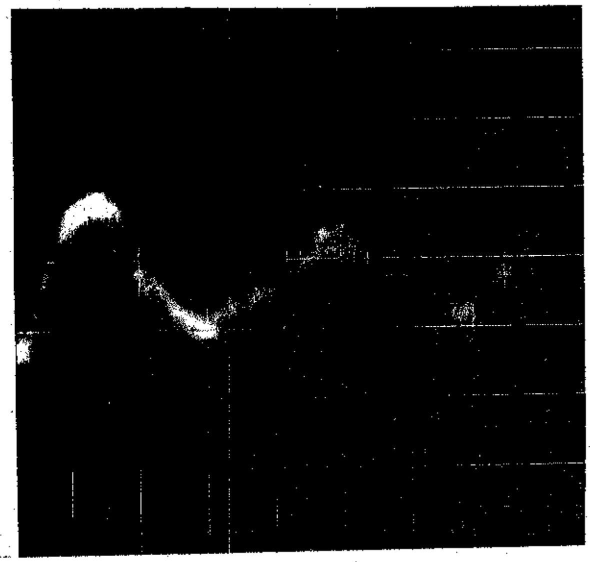
Oscilloscope settings
1 volt/div.
100 microsec./div.

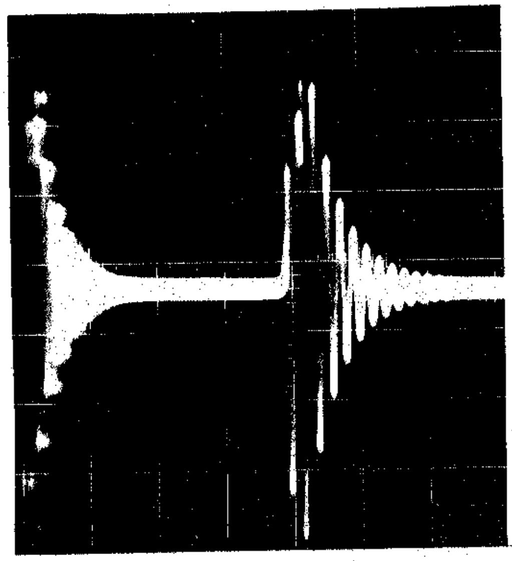
(e)

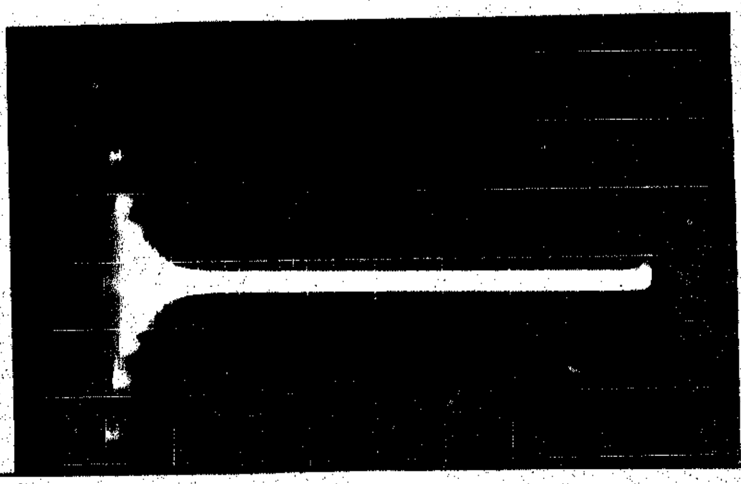
Fig. 34--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 8 cm. in length.











Pressure 900 microns
Current 132 microamps.
Voltage 900 volts

Oscilloscope settings
50 millivolts/div.
10 microsec./div.

(a)

Pressure 900 microns
Current 39 microamps.
Voltage 780 volts

Oscilloscope settings
0.2 volts/div.
10 microsec./div.

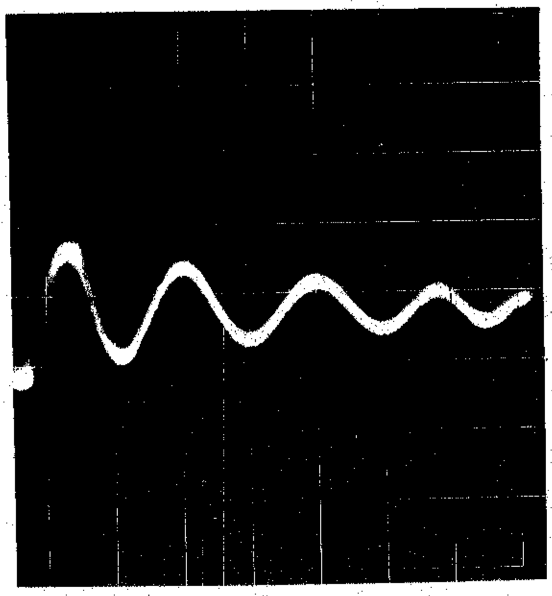
(b)

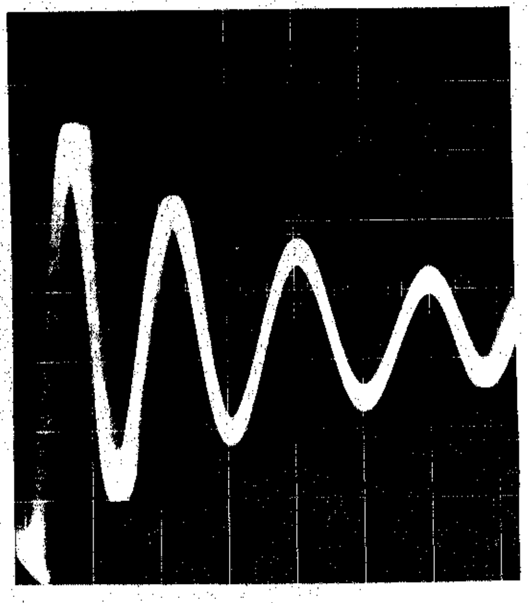
Pressure 1200 microns
Current 205 microamps.
Voltage 1890 volts

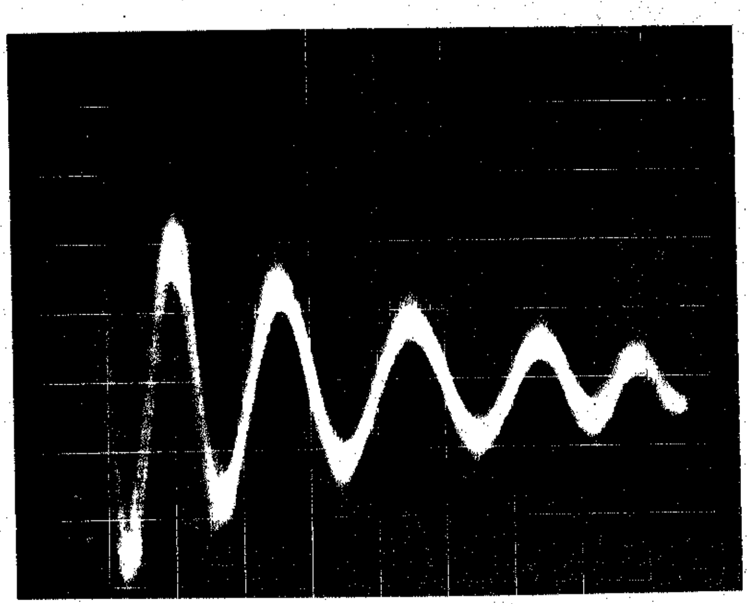
Oscilloscope settings
20 millivolts/div.
10 microsec./div.

(e)

Fig. 35--Plasma oscillations for hydrogen gas in a tube 6 mm. in diameter and 6 cm. in length.







Pressure 300 microns
Current 99 microamps.
Voltage 2550 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(a)

Pressure 600 microns
Current 223 microamps.
Voltage 2500 volts

Oscilloscope settings
50 millivolts/div.
10 microsec./div.

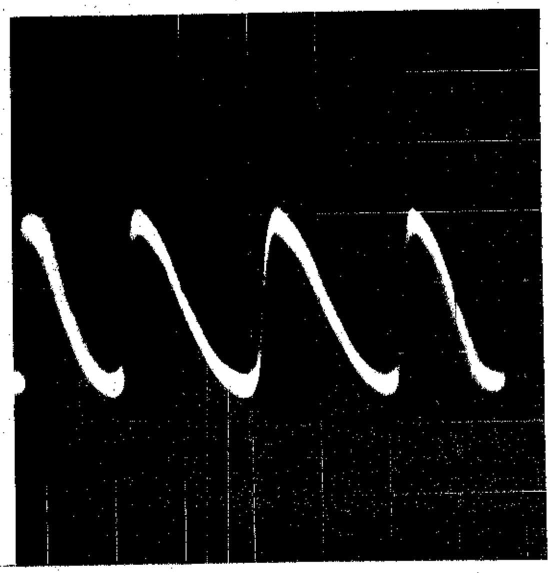
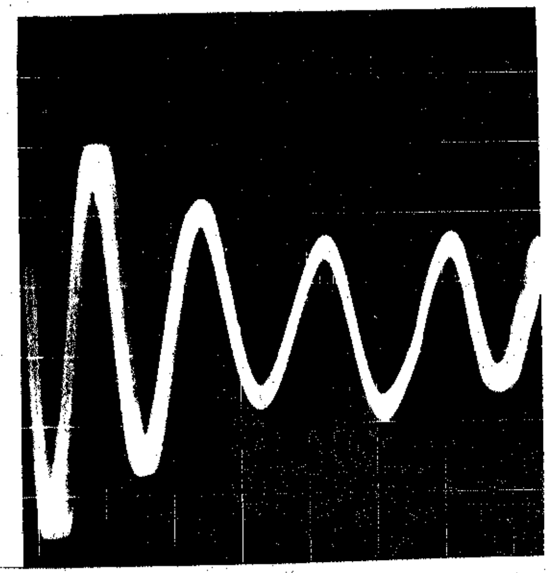
(b)

Pressure 900 microns
Current 129 microamps.
Voltage 2500 volts

Oscilloscope settings
50 millivolts/div.
0.5 microsec./div.

(c)

Fig. 36--Plasma oscillations for hydrogen gas in a tube 5.2 mm. in diameter and 20 cm. in length.


Pressure 600 microns
Current 166 microamps.
Voltage 3250 volts

Oscilloscope settings
2 volts/div.
2 microsec./div.

(a)

Pressure 600 microns
Current 179 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(b)

Pressure 600 microns
Current 110 microamps.
Voltage 3325 volts

Oscilloscope settings
2 volts/div.
2 microsec./div.

(c)

Pressure 900 microns
Current 190 microamps.
Voltage 3500 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

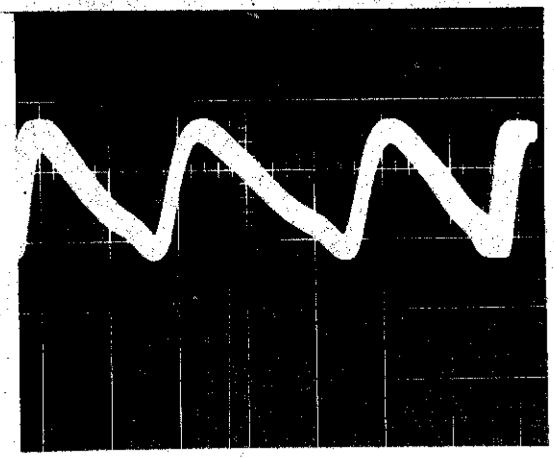
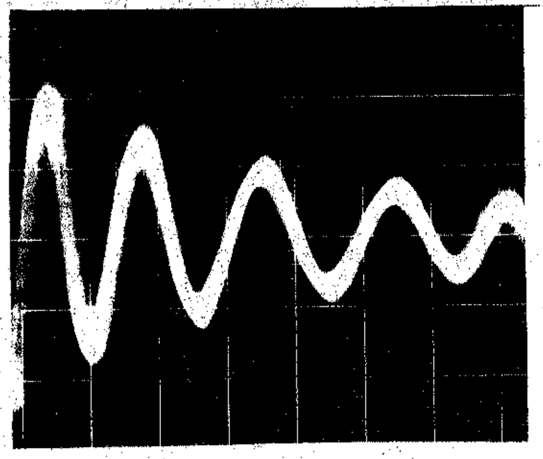
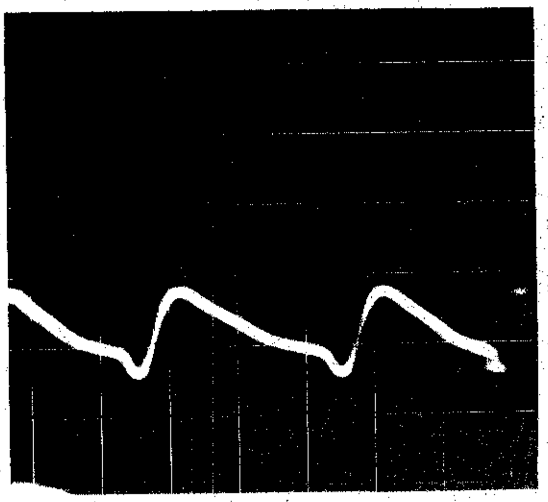
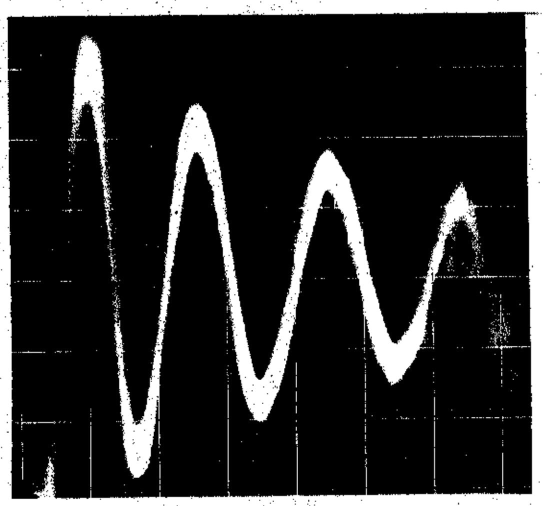
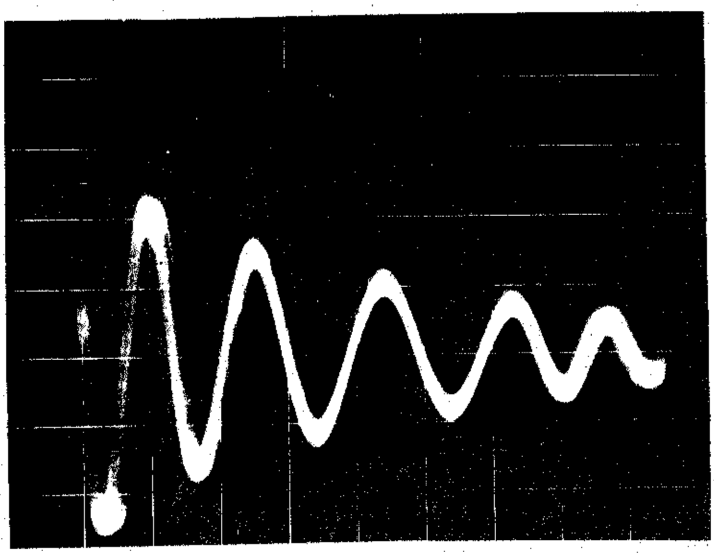
(d)

Pressure 1200 microns
Current 179 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(e)

Fig. 37--Plasma oscillations for hydrogen gas in a tube 3.9 mm. in diameter and 20 cm. in length.

Pressure 600 microns
Current 129 microamps.
Voltage 2800 volts

Oscilloscope settings
1 volt/div.
2 microsec./div.

(a)

Pressure 900 microns
Current 129 microamps.
Voltage 2800 volts

Oscilloscope settings
1 volt/div.
2 microsec./div.

(b)

Pressure 900 microns
Current 129 microamps.
Voltage 2800 volts

Oscilloscope settings
1 volt/div.
2 microsec./div.

(c)

Pressure 900 microns
Current 199 microamps.
Voltage 3050 volts

Oscilloscope settings
50 millivolts/div.
2 microsec./div.

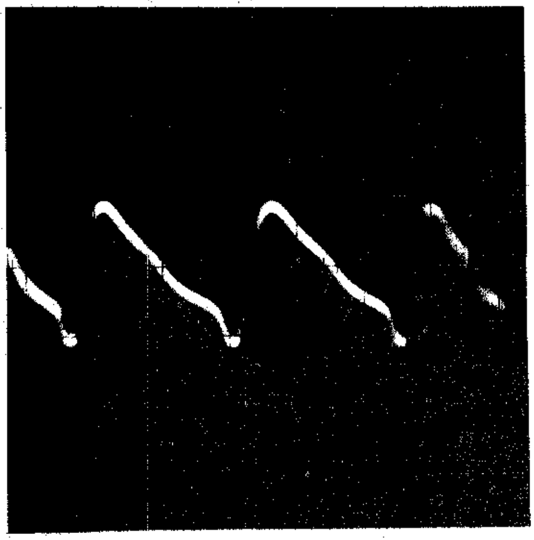
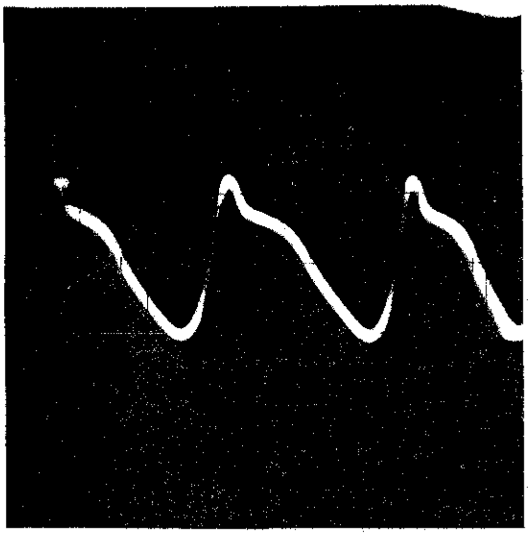
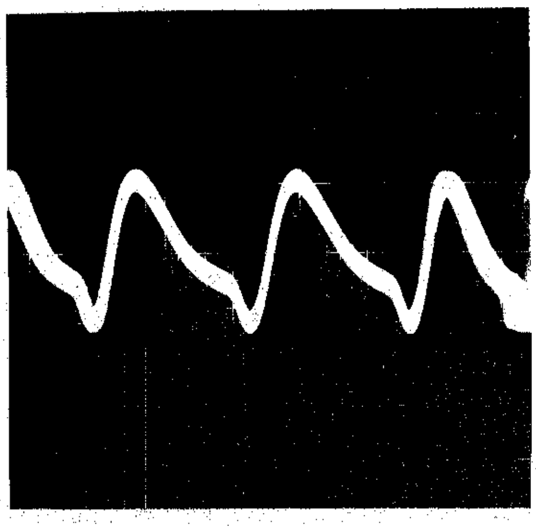
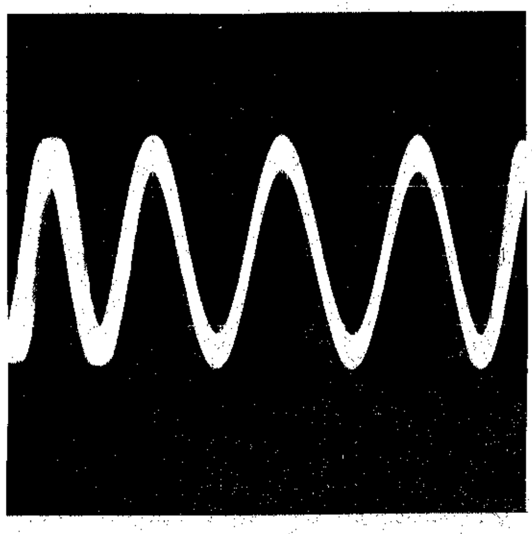
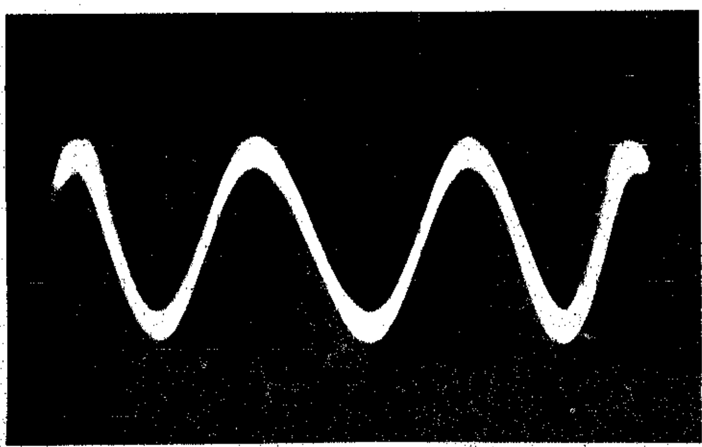
(d)

Pressure 1200 microns
Current 129 microamps.
Voltage 3300 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(e)

Fig. 38--Plasma oscillations for hydrogen gas in a tube 3.5 mm. in diameter and 20 cm. in length.

Pressure 600 microns
Current 0 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
20 microsec./div.

(a)

Pressure 900 microns
Current 129 microamps.
Voltage 3050 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(b)

Pressure 1050 microns
Current 99 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(c)

Pressure 1200 microns
Current 134 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(d)

Pressure 1400 microns
Current 69 microamps.
Voltage 3350 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

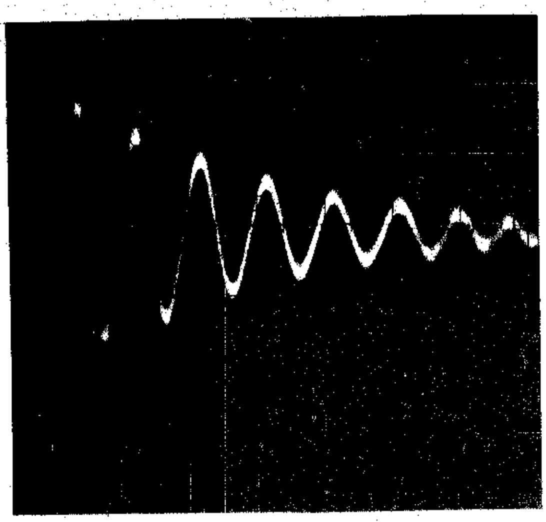
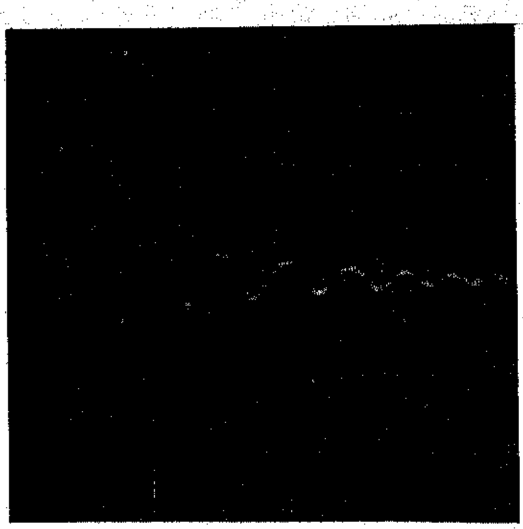
(e)

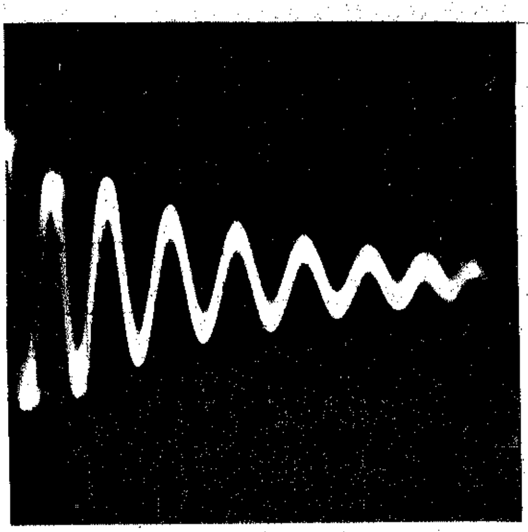
Pressure 1500 microns
Current 129 microamps.
Voltage 3350 volts

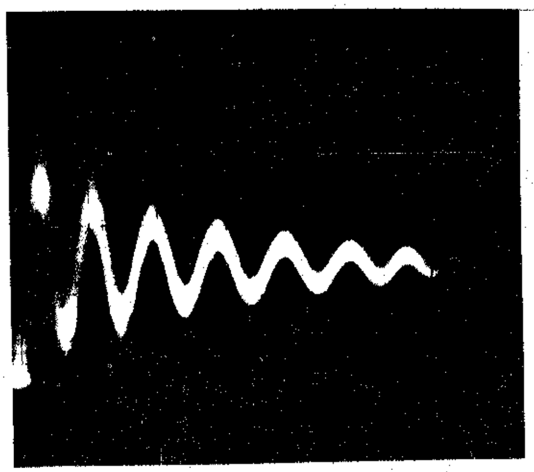
Oscilloscope settings
2 volts/div.
20 microsec./div.

(f)

Fig. 39--Plasma oscillations for hydrogen gas in a tube 2.3 mm. in diameter and 20 cm. in length.





Pressure 300 microns
Current 70 microamps.
Voltage 3550 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(a)

Pressure 300 microns
Current 20 microamps.
Voltage 2455 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(b)

Pressure 600 microns
Current 60 microamps.
Voltage 3050 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(c)

Pressure 600 microns
Current 9 microamps.
Voltage 2010 volts

Oscilloscope settings
5 volts/div.
50 microamps.

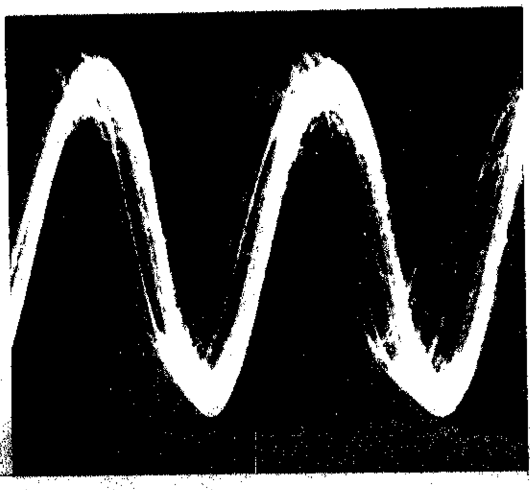
(d)

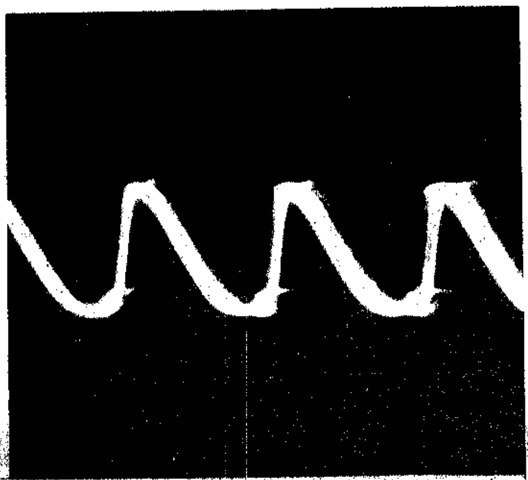
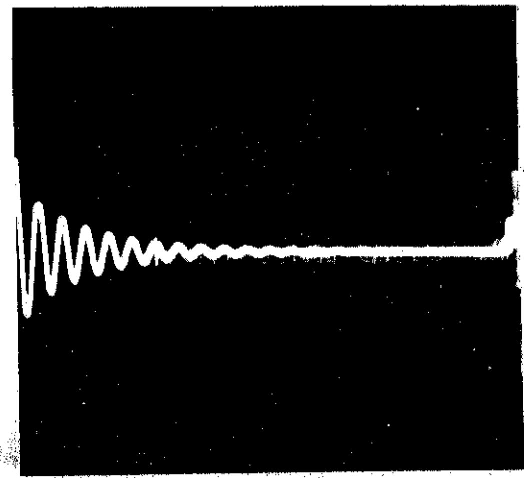
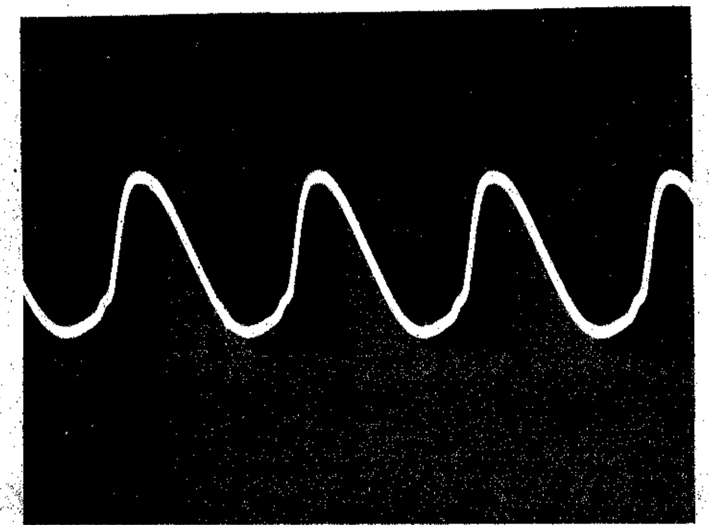
Pressure 900 microns
Current 50 microamps.
Voltage 2600 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(e)

Fig. 40--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 23 cm. in length.



Pressure 900 microns
Current 0 microamps.
Voltage 1905 volts

Oscilloscope settings
5 volts/div.
2 microsec./div.

(a)

Pressure 900 microns
Current 0 microamps.
Voltage 1905 volts

Oscilloscope settings
5 volts/div.
500 microsec./div.

(b)

Pressure 900 microns
Current 129 microamps.
Voltage 2800 volts

Oscilloscope settings
0.02 volts/div.
2 microsec./div.

(c)

Pressure 1200 microns
Current 89 microamps.
Voltage 1500 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

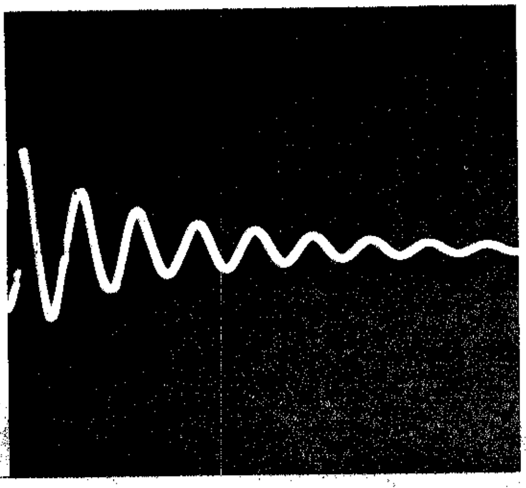
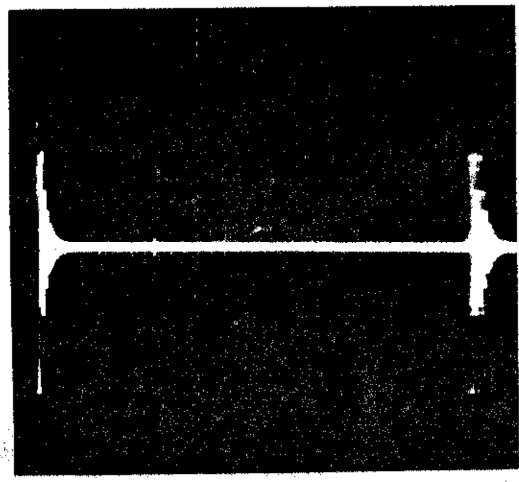
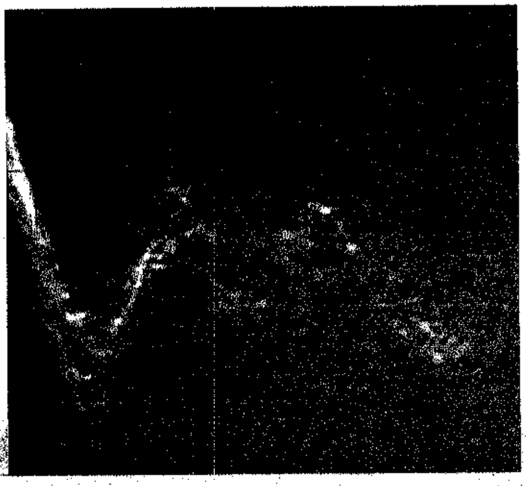
(d)

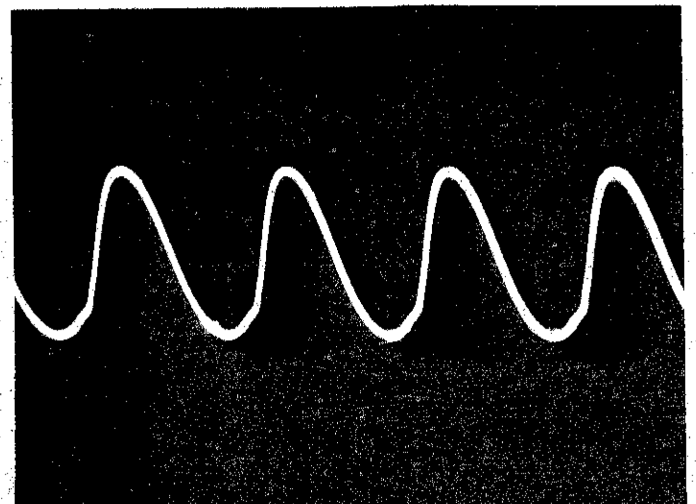
Pressure 1200 microns
Current 79 microamps.
Voltage 2800 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(e)

Fig. 41--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 23 cm. in length.



Pressure 300 microns
Current 10 microamps.
Voltage 2190 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(a)

Pressure 600 microns
Current 100 microamps.
Voltage 1880 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(b)

Pressure 600 microns
Current 75 microamps.
Votlage 1900 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 900 microns
Current 90 microamps.
Voltage 2750 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(d)

Pressure 900 microns
Current 80 microamps.
Voltage 2500 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

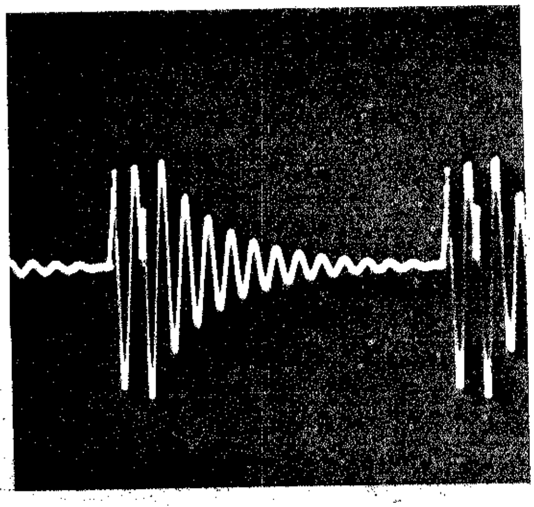
(e)

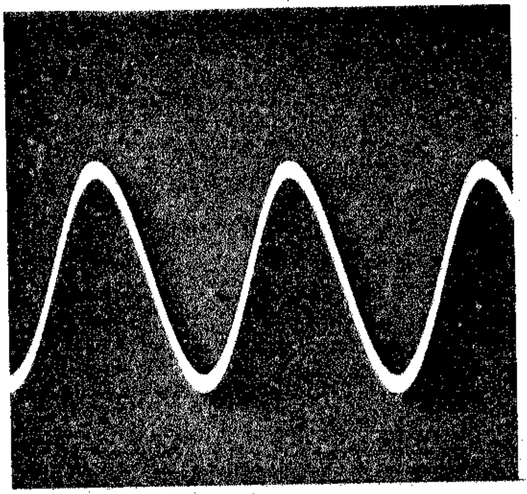
Pressure 900 microns
Current 40 microamps.
Voltage 2030 volts

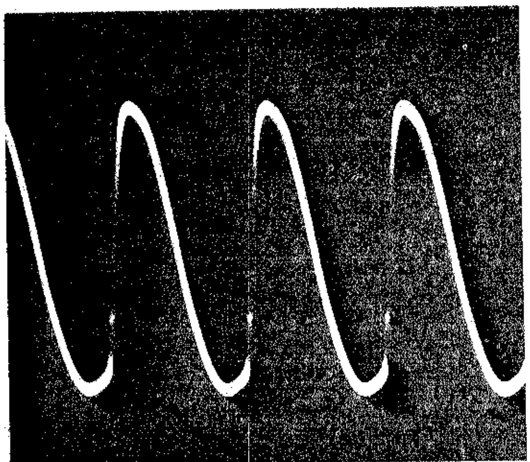
Oscilloscope settings
5 volts/div.
5 microsec./div.

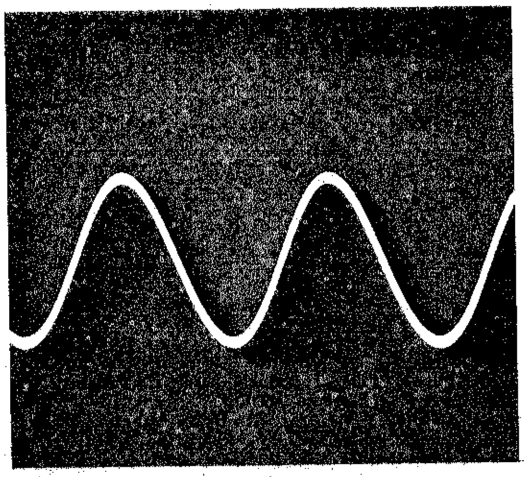
(f)

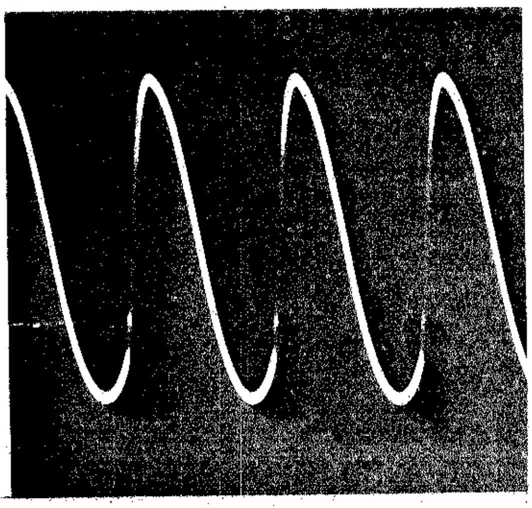
Fig. 42--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 20 cm. in length.

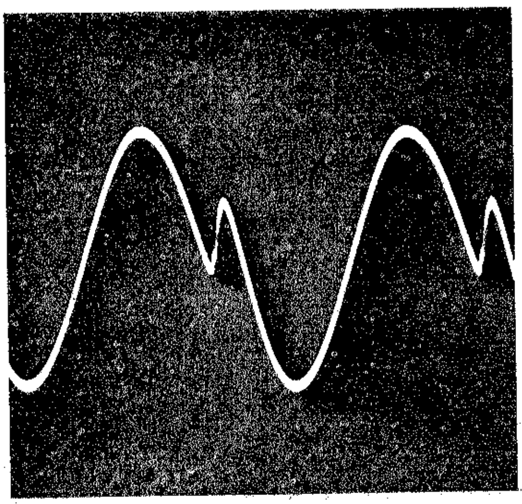












Pressure 900 microns
Current 0 microamps.
Voltage 1585 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(a)

Pressure 1200 microns
Current 90 microamps.
Voltage 2180 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(b)

Pressure 1200 microns
Current 79 microamps.
Voltage 2150 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 1200 microns
Current 41 microamps.
Voltage 2020 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

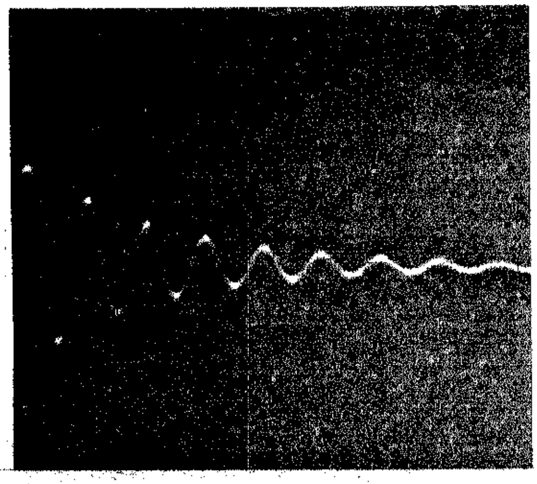
(d)

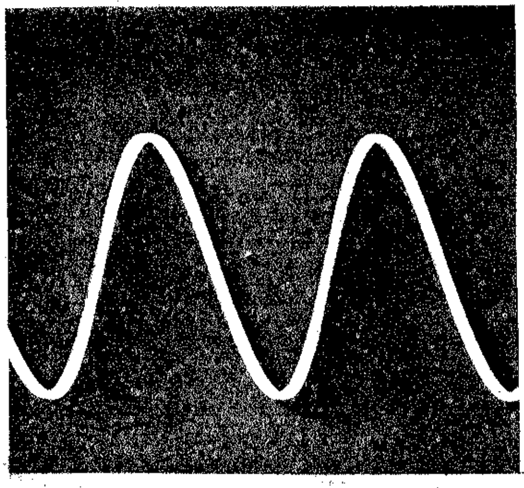
Pressure 1200 microns
Current 40 microamps.
Voltage 1990 volts

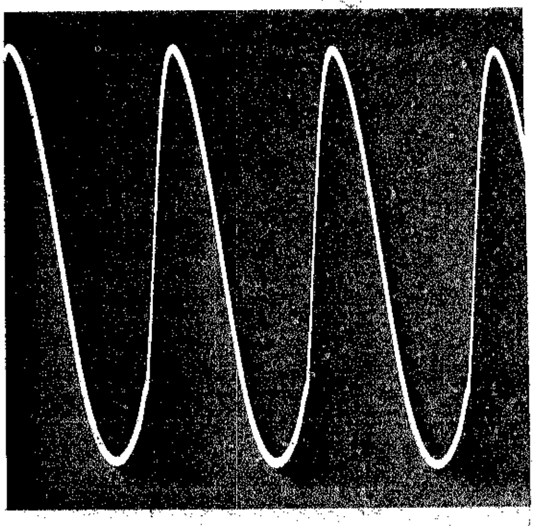
Oscilloscope settings
2 volts/div.
10 microsec./div.

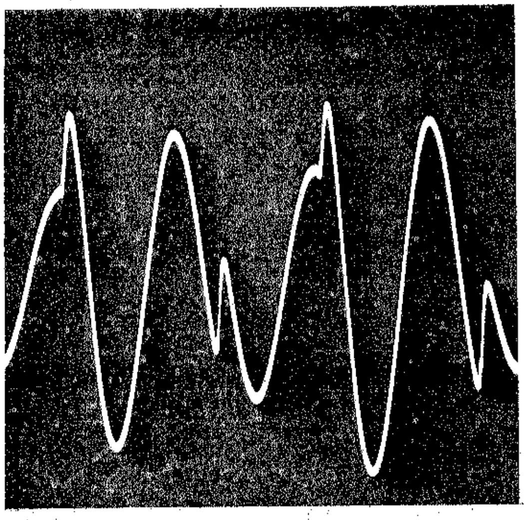
(e)

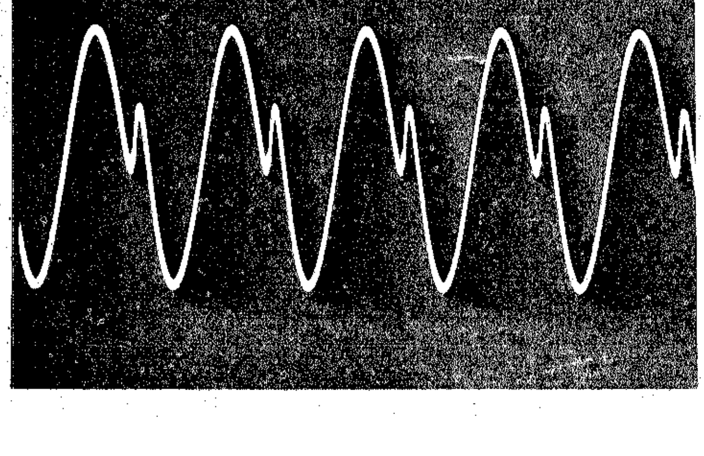
Fig. 43--Plasma oscillations for deuterium in a tube 6 mm. in diameter and 20 cm. in length.











Pressure 300 microns
Current 40 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(a)

Pressure 300 microns
Current 77 microamps.
Voltage 2880 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 20 microamps.
Voltage 2130 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(c)

Pressure 300 microns
Current 90 microamps.
Voltage 3510 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

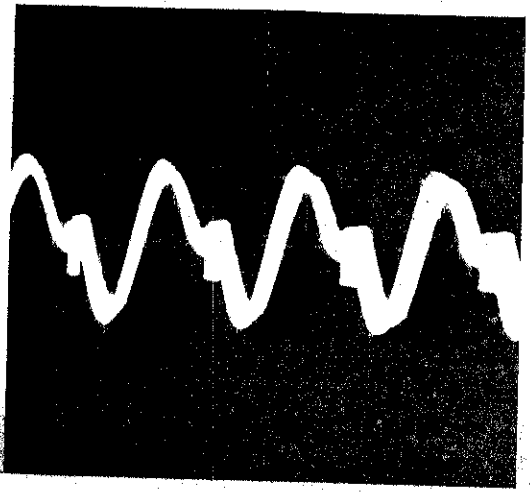
(d)

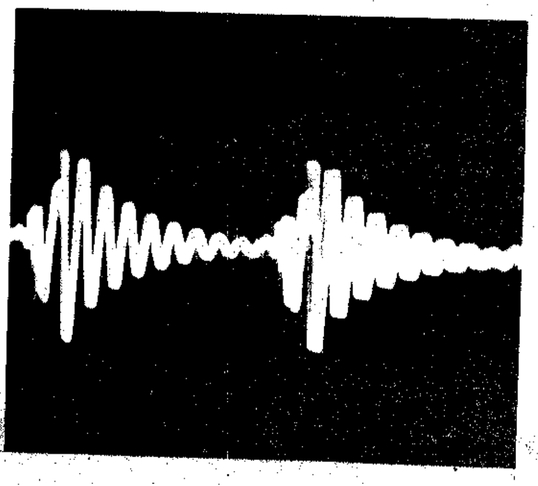
Pressure 300 microns
Current 139 microamps.
Voltage 1800 volts

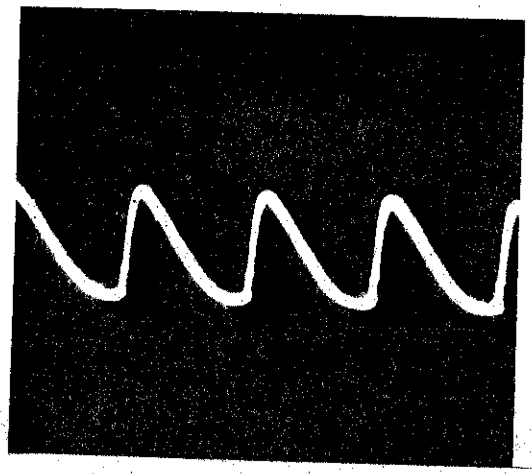
Oscilloscope settings
0.02 volts/div.
5 microsec./div.

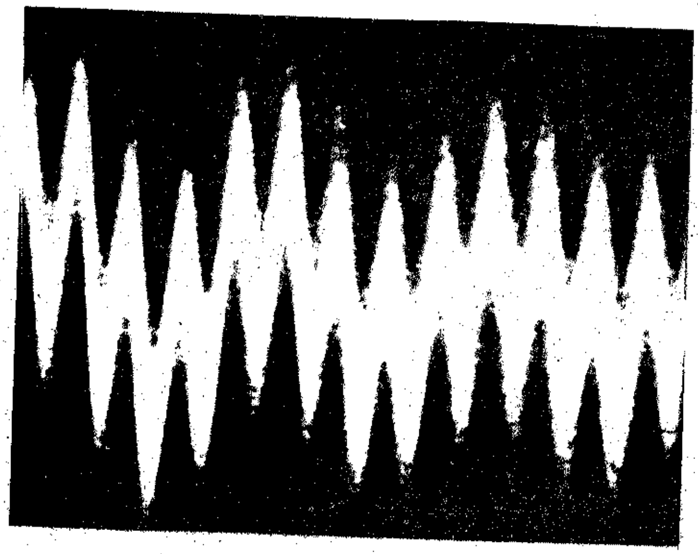
(e)

Fig. 44--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 17 cm. in length.









Pressure 600 microns
Current 60 microamps.
Voltage 2590 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(a)

Pressure 600 microns
Current 30 microamps.
Voltage 2200 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 31 microamps.
Voltage 2500 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(c)

Pressure 900 microns
Current 49 microamps.
Voltage 2330 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

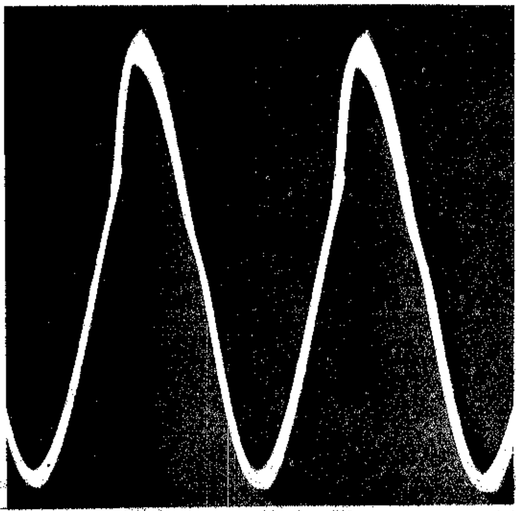
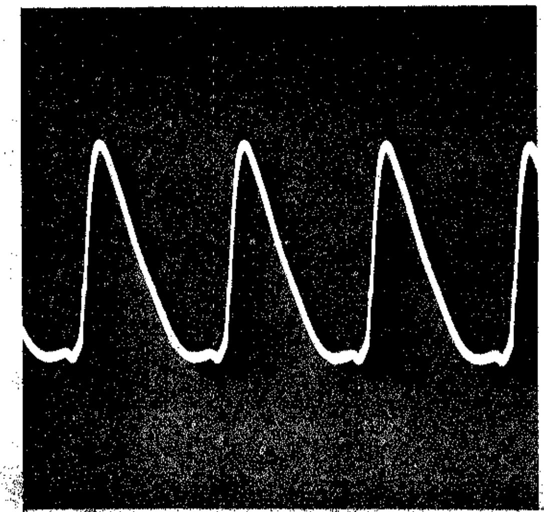
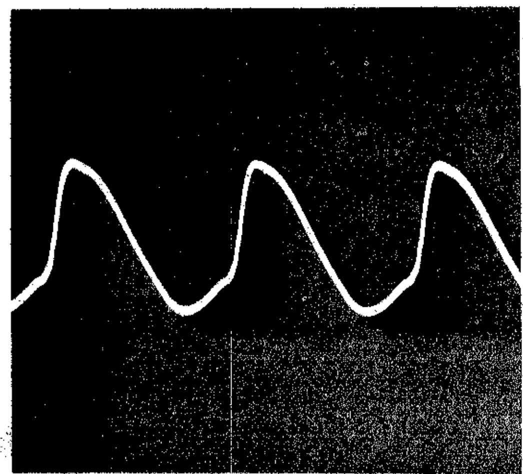
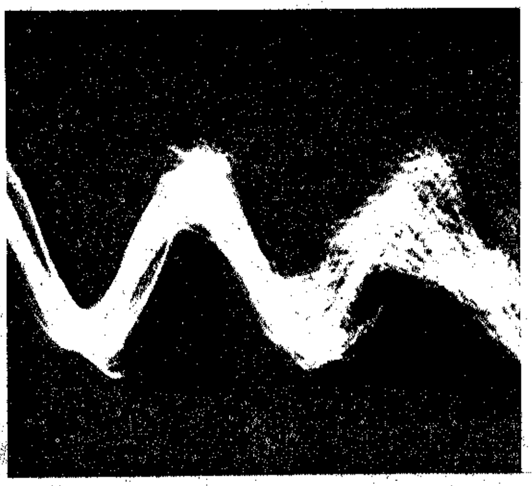
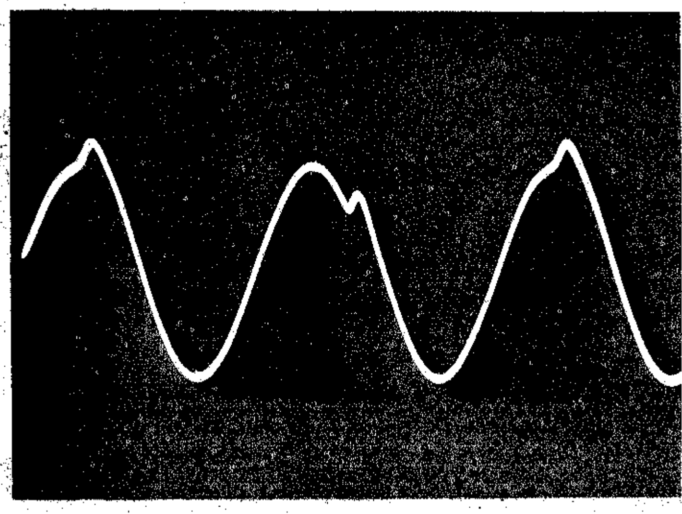
(d)

Pressure 1200 microns
Current 40 microamps.
Voltage 1695 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(e)

Fig. 45--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 17 cm. in length.

Pressure 300 microns
Current 79 microamps.
Voltage 2500 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(a)

Pressure 300 microns
Current 3 microamps.
Voltage 1275 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(b)

Pressure 300 microns
Current 29 microamps.
Voltage 1550 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 300 microns
Current 76 microamps.
Voltage 2300 volts

Oscilloscope settings
2 volts/div.
2 microsec./div.

(d)

Pressure 300 microns
Current 30 microamps.
Voltage 1530 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

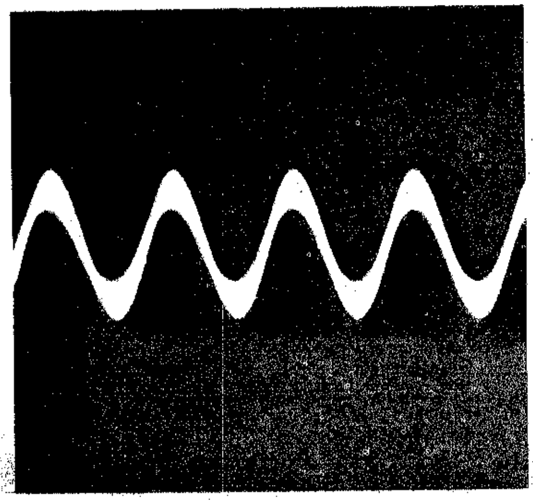
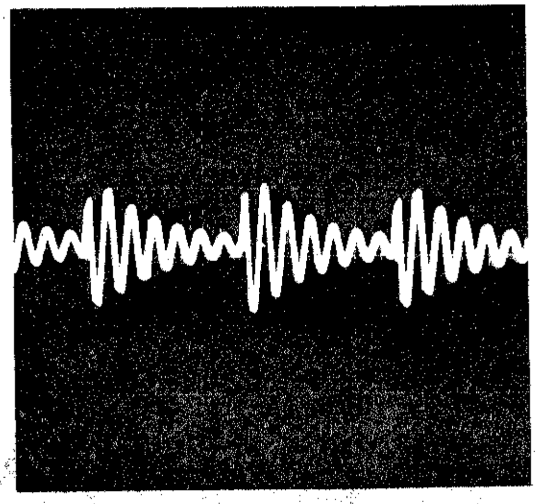
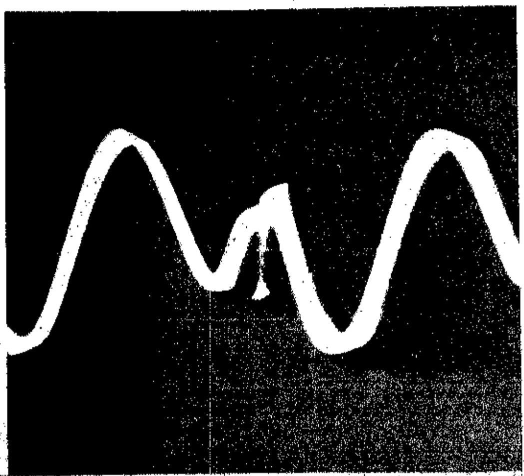
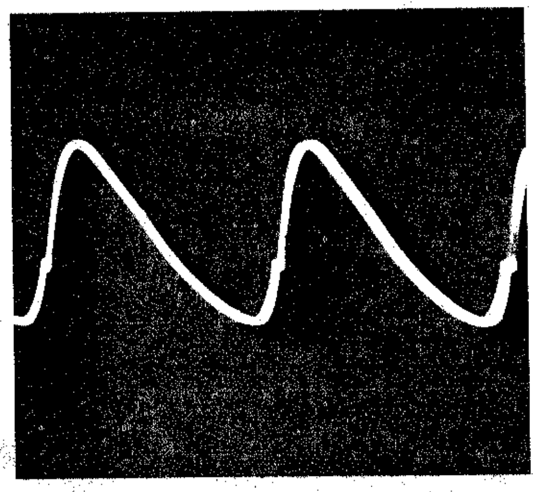
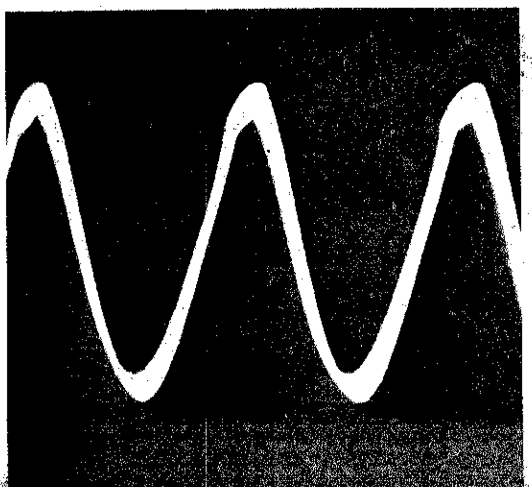
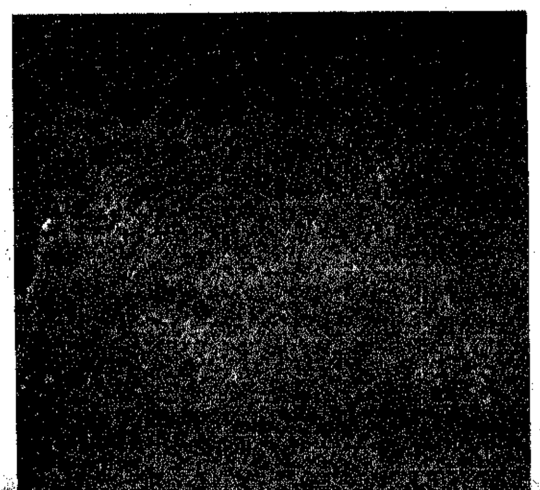
(e)

Pressure 300 microns
Current 180 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(f)

Fig. 46--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 13 cm. in length.

Pressure 600 microns
Current 70 microamps.
Voltage 2765 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(a)

Pressure 600 microns
Current 40 microamps.
Voltage 2230 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 600 microns
Current 0 microamps.
Voltage 1535 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(c)

Pressure 600 microns
Current 6 microamps.
Voltage 1840 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(d)

Pressure 900 microns
Current 70 microamps.
Voltage 2260 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

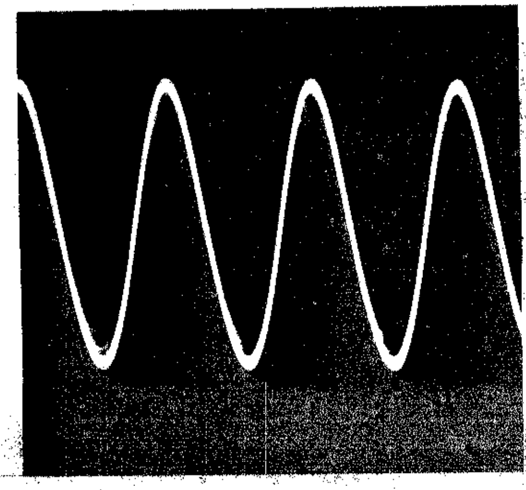
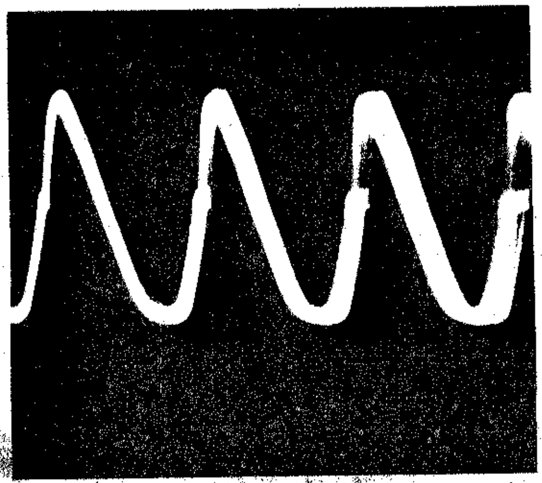
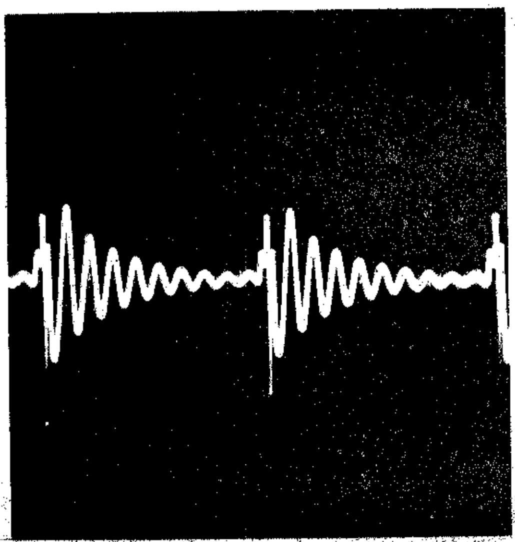
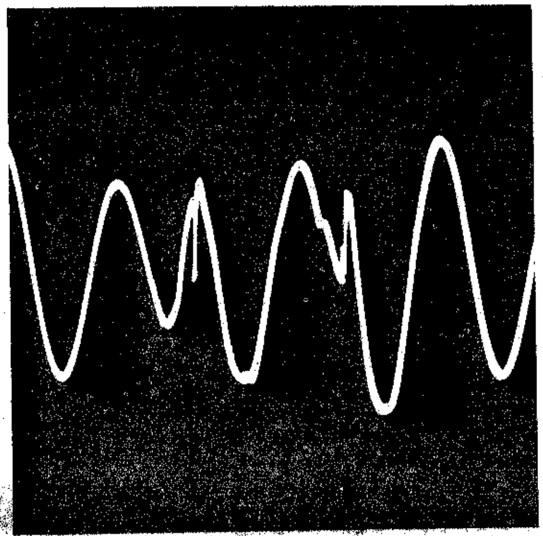
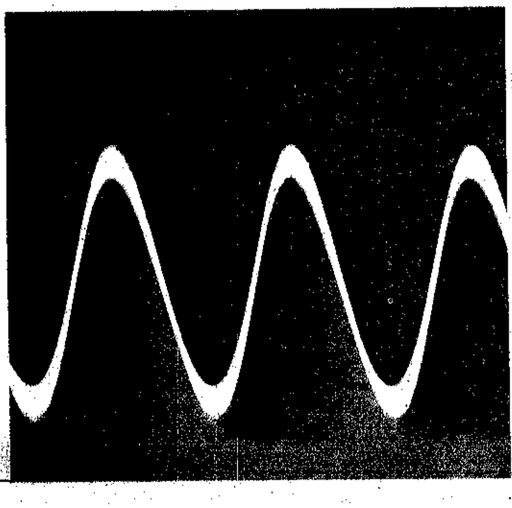
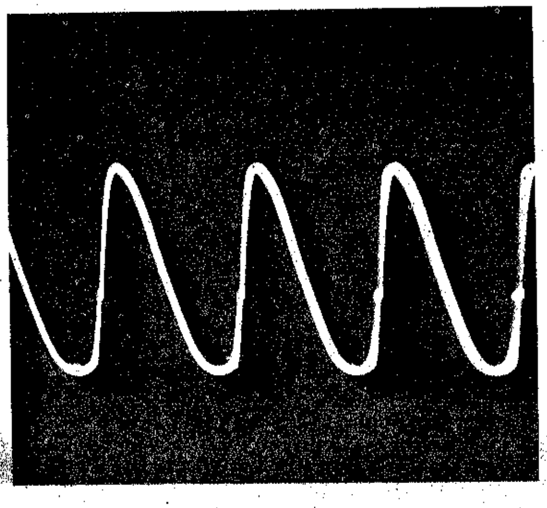
(e)

Pressure 900 microns
Current 50 microamps.
Voltage 1945 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(f)

Fig. 47--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 13 cm. in length.

Pressure 900 microns
Current 350 microamps.
Voltage 3550 volts

Oscilloscope settings
0.01 volts/div.
5 microsec./div.

(a)

Pressure 900 microns
Current 0 microamps.
Voltage 1450 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(b)

Pressure 900 microns
Current 20 microamps.
Voltage 1595 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 1200 microns
Current 70 microamps.
Voltage 1810 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(d)

Pressure 1200 microns
Current 40 microamps.
Voltage 1670 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

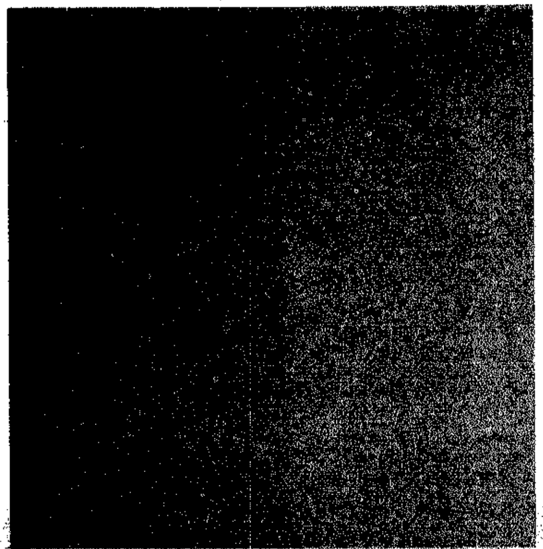
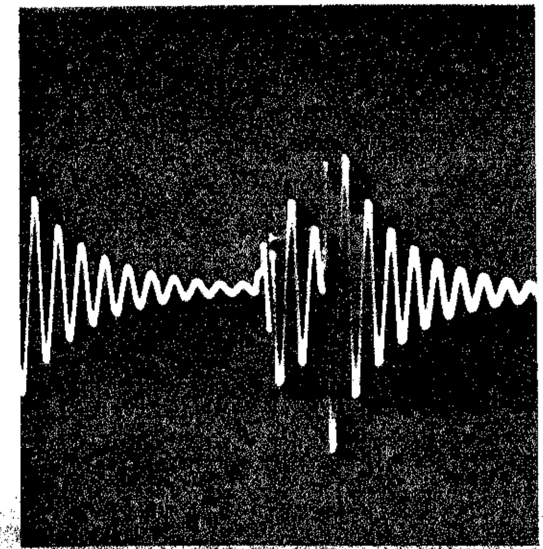
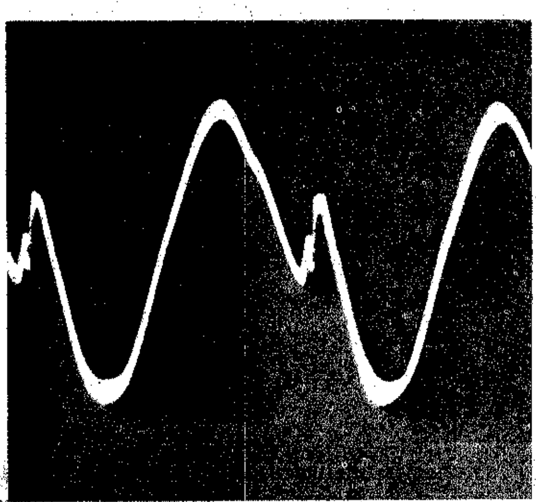
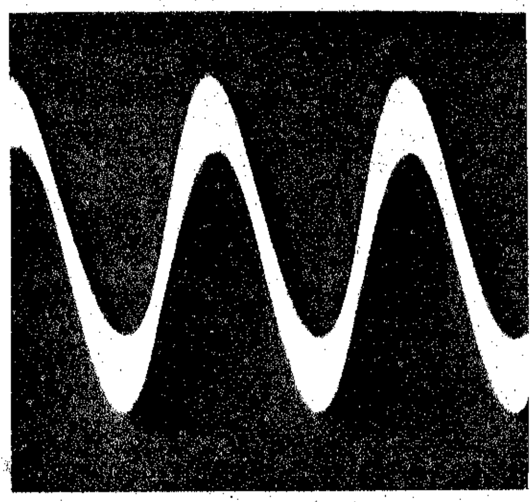
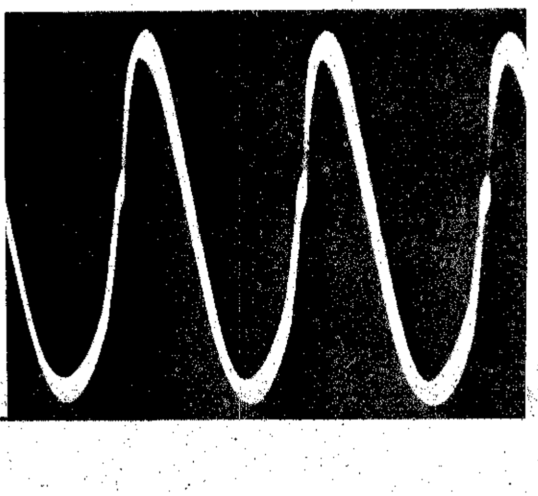
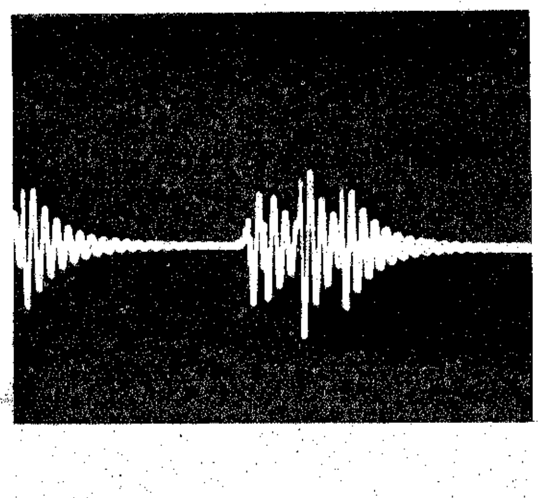
(e)

Pressure 1200 microns
Current 10 microamps.
Voltage 1490 volts

Oscilloscope settings
5 volts/div.
100 microsec./div.

(f)

Fig. 48--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 13 cm. in length.

Pressure 300 microns
Current 0 microamps.
Voltage 1055 volts

Oscilloscope settings
1 volt/div.
50 microsec./div.

(a)

Pressure 300 microns
Current 34 microamps.
Voltage 1780 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 42 microamps.
Voltage 1780 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(c)

Pressure 300 microns
Current 59 microamps.
Voltage 2190 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(d)

Pressure 600 microns
Current 39 microamps.
Voltage 1665 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

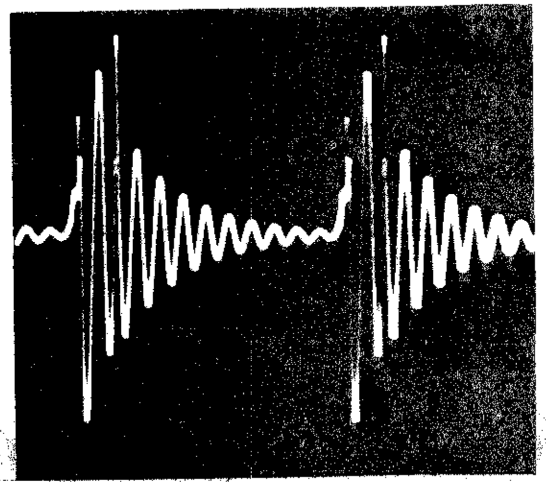
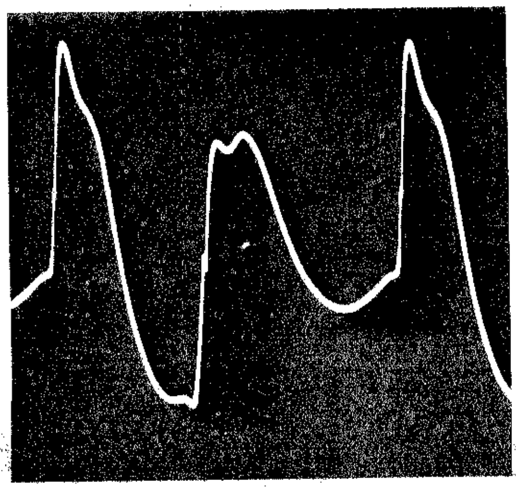
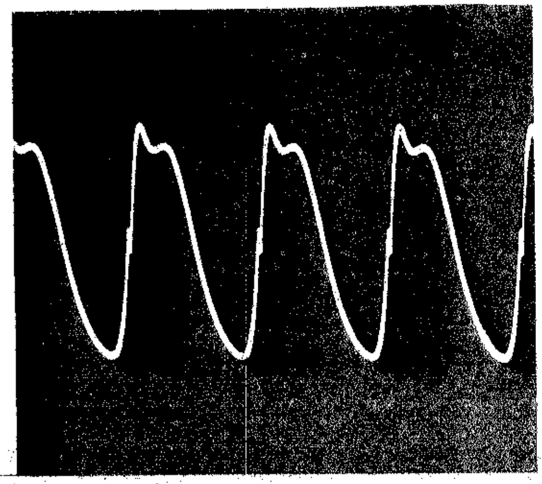
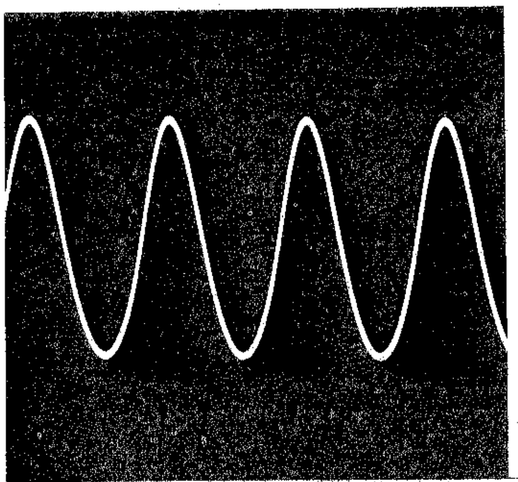
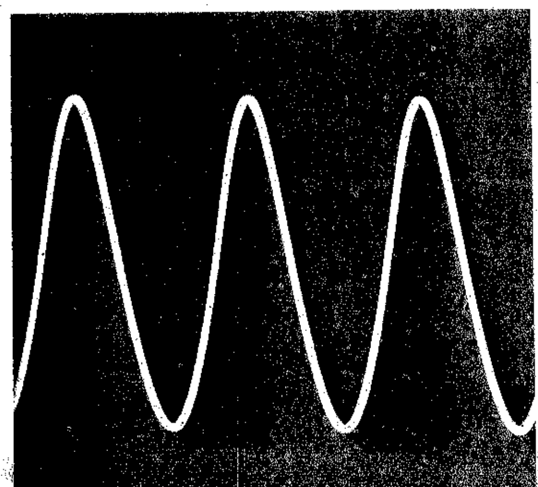
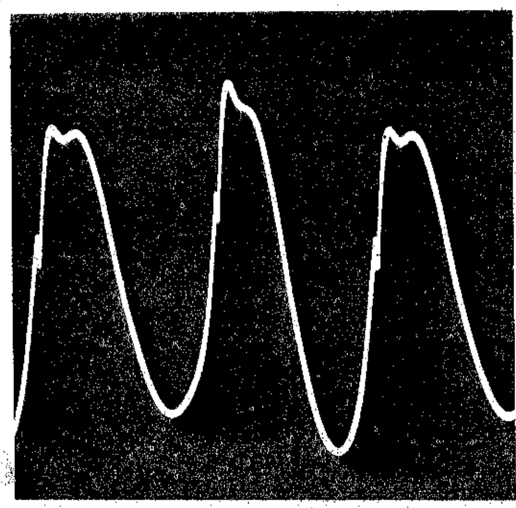
(e)

Pressure 600 microns
Current 34 microamps.
Voltage 1470 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(f)

Fig. 49--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 10 cm. in length.

Pressure 600 microns
Current 10 microamps.
Voltage 1120 volts

Oscilloscope settings
0.2 volts/div.
50 microsec./div.

(a)

Pressure 900 microns
Current 30 microamps.
Voltage 1640 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 39 microamps.
Voltage 1680 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(c)

Pressure 900 microns
Current 26 microamps.
Voltage 1510 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

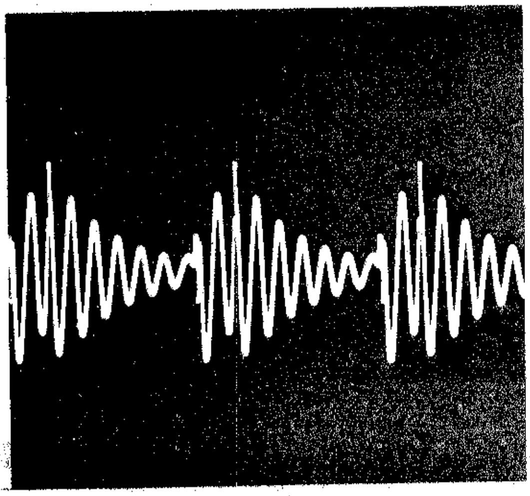
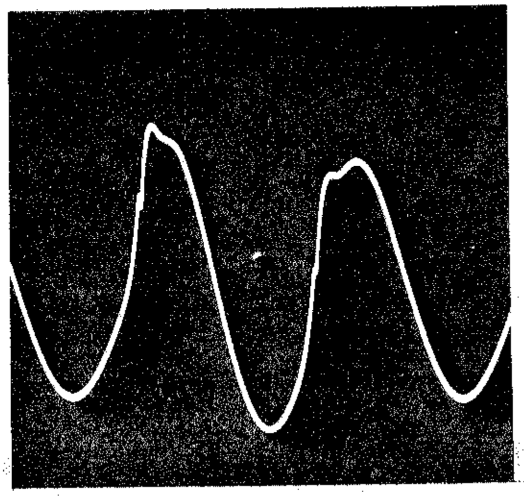
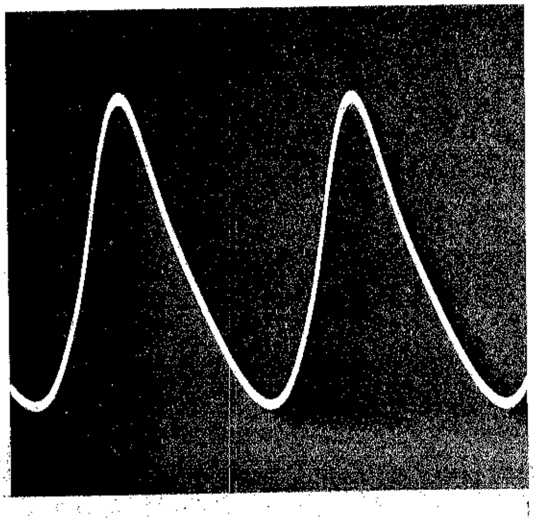
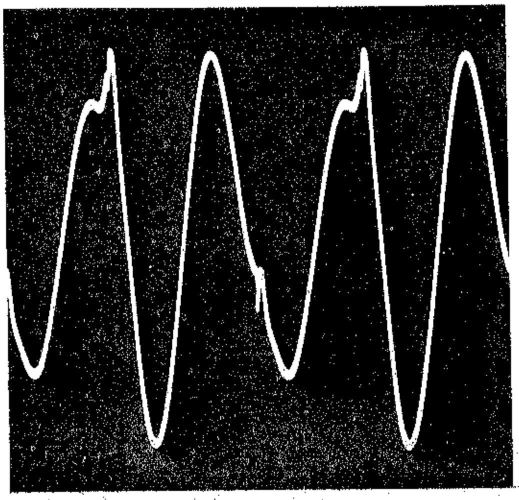
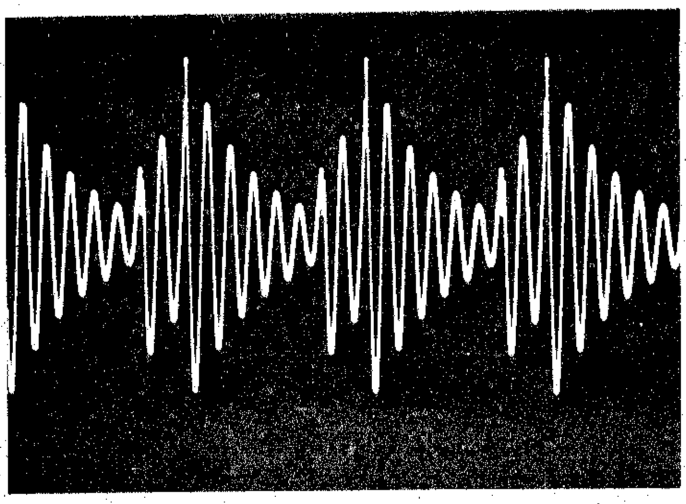
(d)

Pressure 900 microns
Current 10 microamps.
Voltage 1250 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(e)

Fig. 50--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 10 cm. in length.

Pressure 1200 microns
Current 24 microamps.
Voltage 1500 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(a)

Pressure 1200 microns
Current 26 microamps.
Voltage 1580 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(b)

Pressure 1200 microns
Current 10 microamps.
Voltage 1290 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(c)

Pressure 1200 microns
Current 20 microamps.
Voltage 1415 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

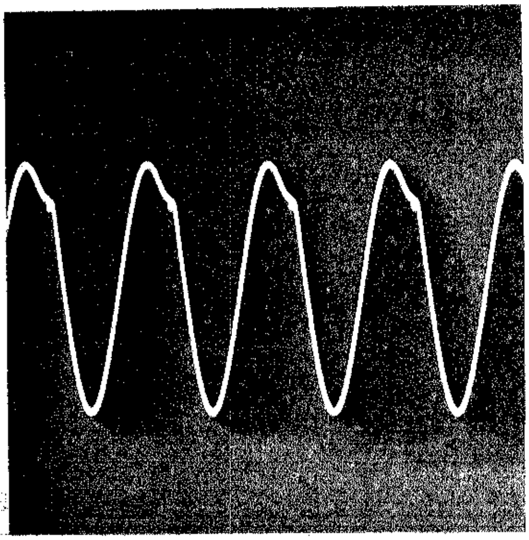
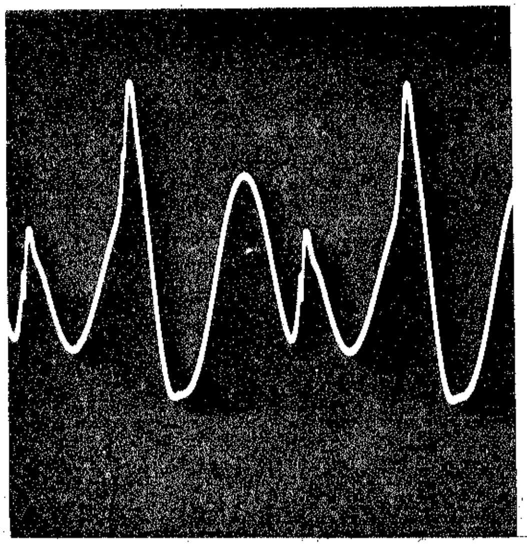
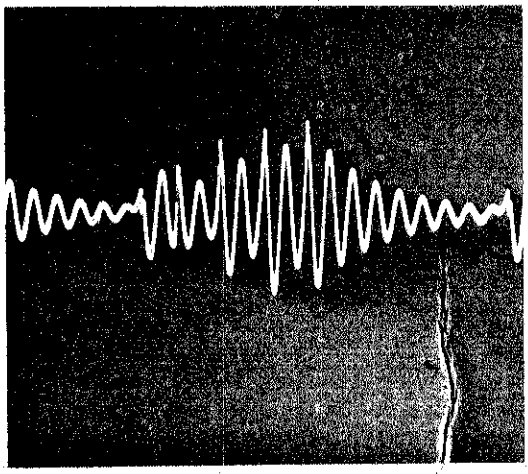
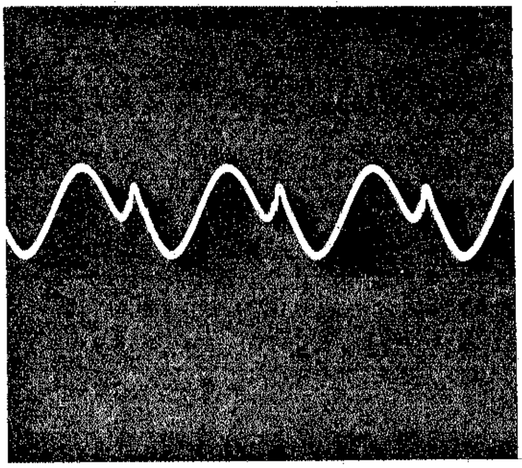
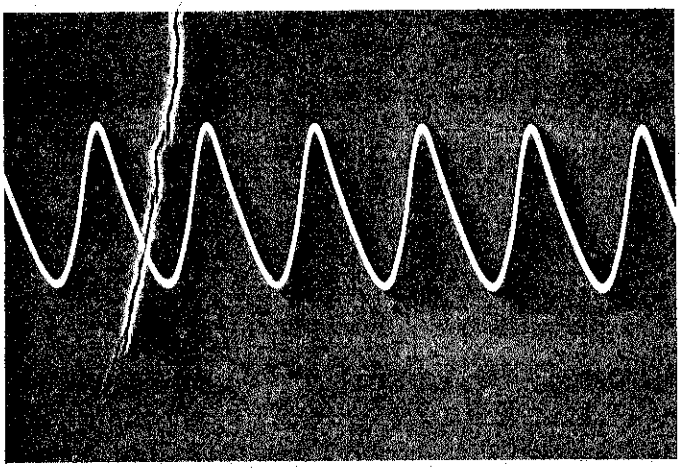
(d)

Pressure 1200 microns
Current 35 microamps.
Voltage 1660 volts

Oscilloscope settings
0.5 volts/div.
5 microsec./div.

(e)

Fig. 51--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 10 cm. in length.

Pressure 300 microns
Current 20 microamps.
Voltage 2095 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(a)

Pressure 300 microns
Current 18 microamps.
Voltage 1750 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(b)

Pressure 300 microns
Current 10 microamps.
Voltage 1250 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(c)

Pressure 300 microns
Current 0 microamps.
Voltage 1125 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(d)

Pressure 300 microns
Current 0 microamps.
Voltage 860 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

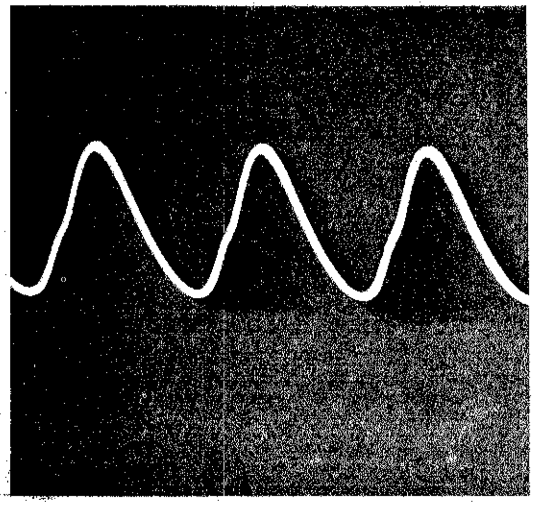
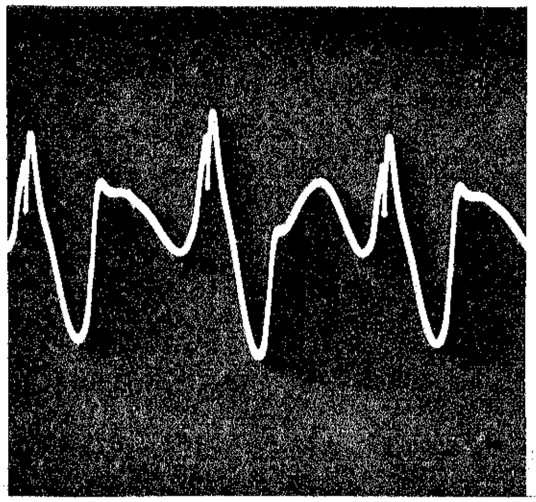
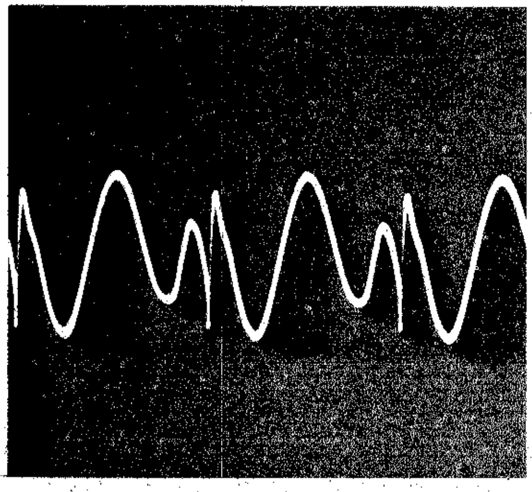
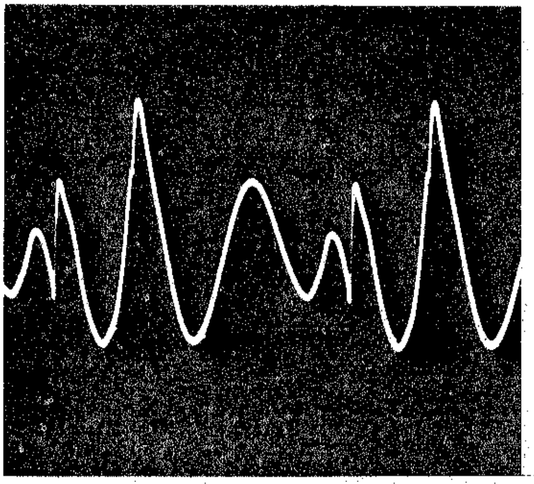
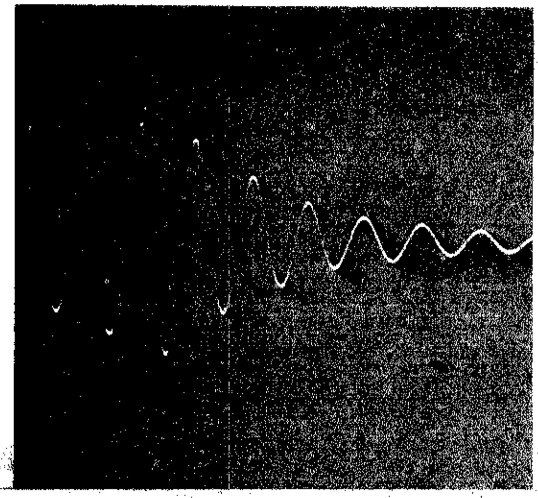
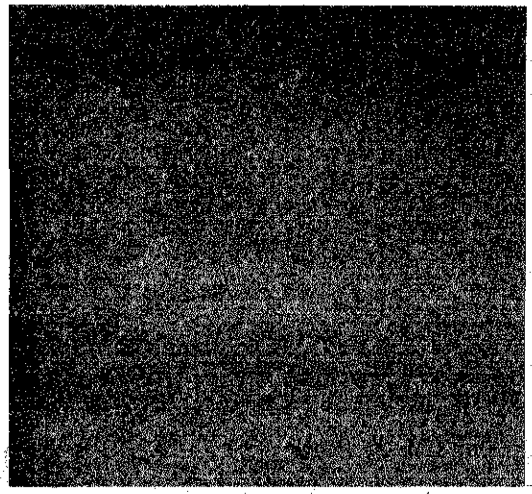
(e)

Pressure 300 microns
Current 124 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

(f)

Fig. 52--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 8 cm. in length.

Pressure 600 microns
Current 29 microamps.
Voltage 1880 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(a)

Pressure 600 microns
Current 10 microamps.
Voltage 1540 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(b)

Pressure 600 microns
Current 0 microamps.
Voltage 1370 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(c)

Pressure 600 microns
Current 6 microamps.
Voltage 1280 volts

Oscilloscope settings
2 volts/div.
50 microsec./div.

(d)

Pressure 600 microns
Current 212 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
10 microsec./div.

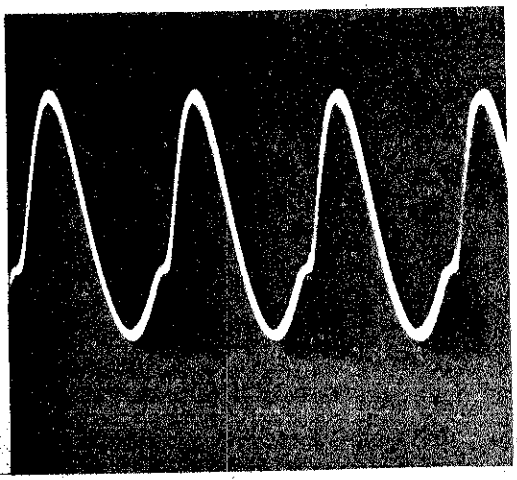
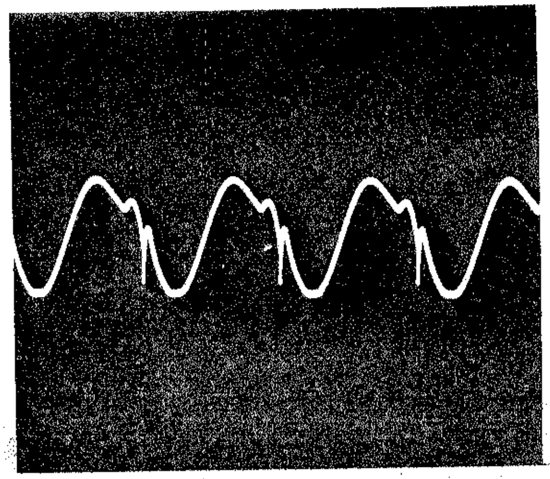
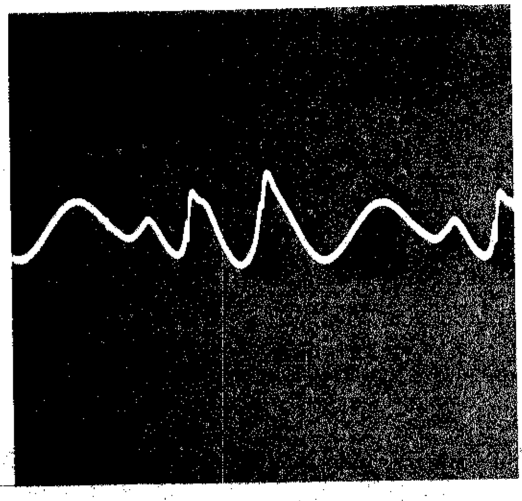
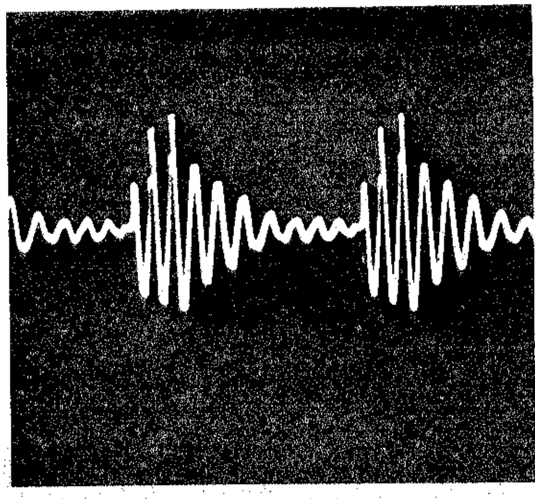
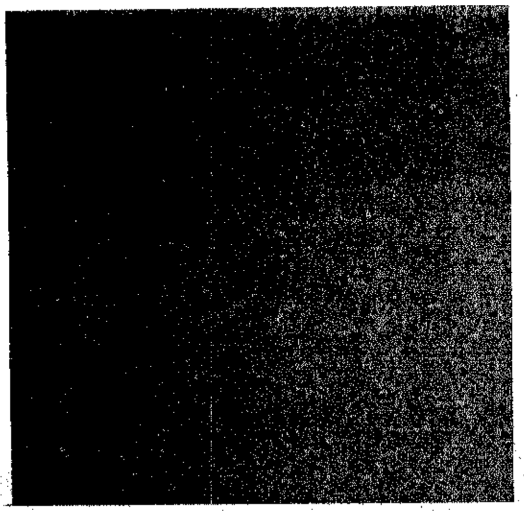
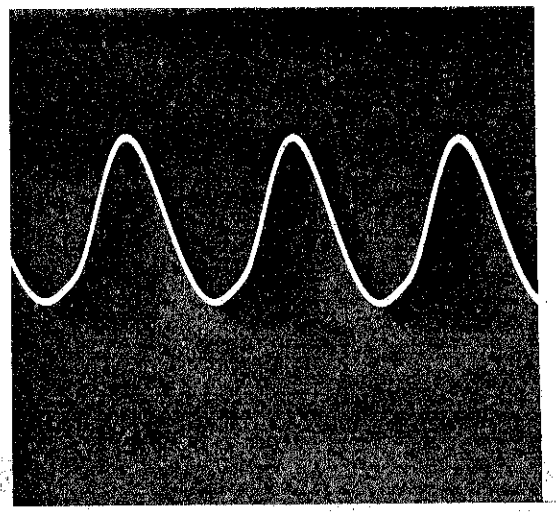
(e)

Pressure 900 microns
Current 29 microamps.
Voltage 1870 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(f)

Fig. 53--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 8 cm. in length.

Pressure 900 microns
Current 16 microamps.
Voltage 1600 volts

Oscilloscope settings
0.5 volts/div.
5 microsec./div.

(a)

Pressure 900 microns
Current 10 microamps.
Voltage 1340 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(b)

Pressure 900 microns
Current 10 microamps.
Voltage 1400 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(c)

Pressure 900 microns
Current 10 microamps.
Voltage 1270 volts

Oscilloscope settings
1 volt/div.
20 microsec./div.

(d)

Pressure 1200 microns
Current 20 microamps.
Voltage 1345 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

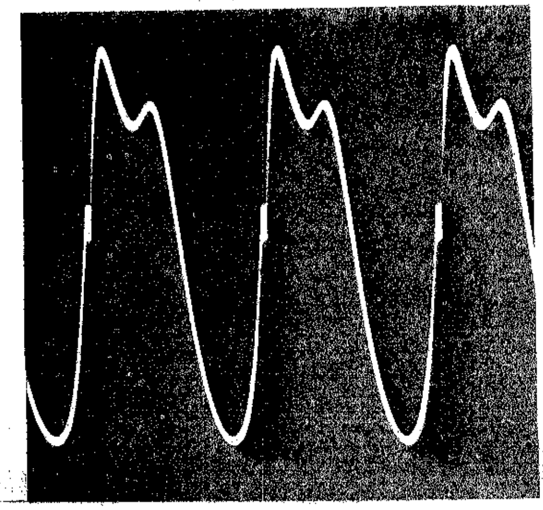
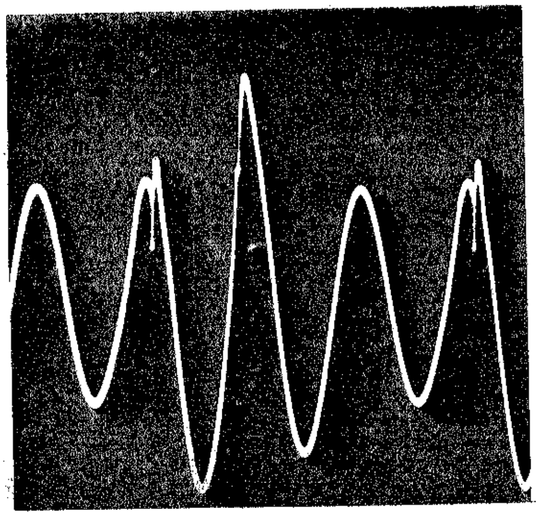
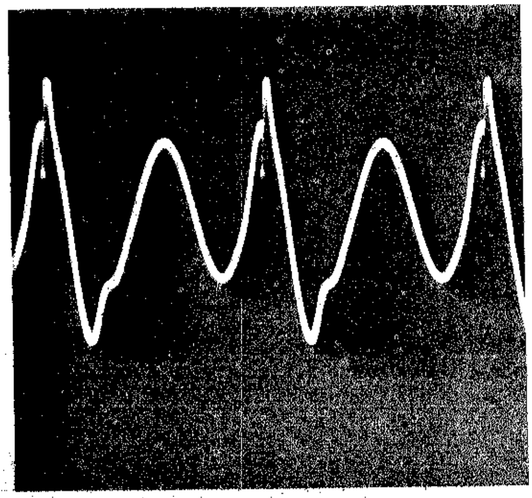
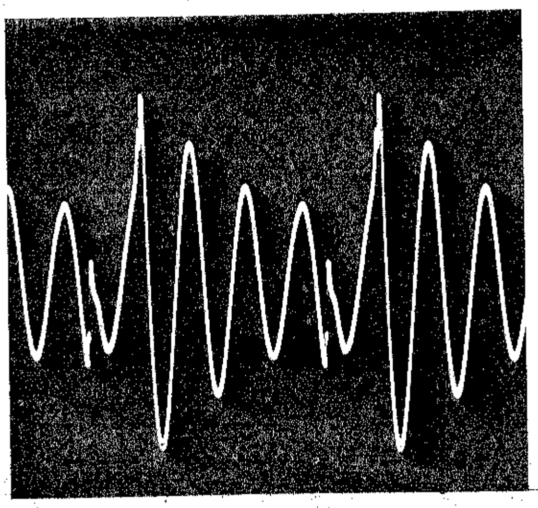
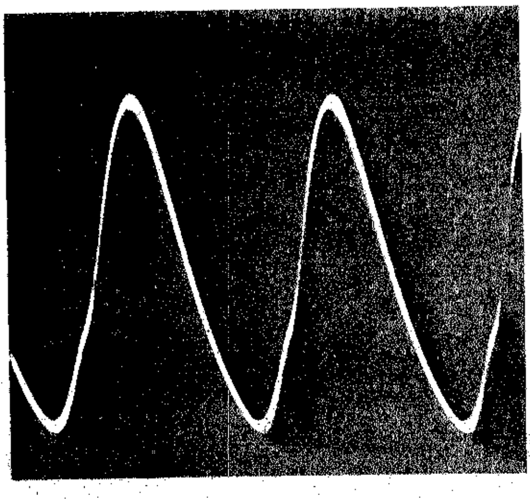
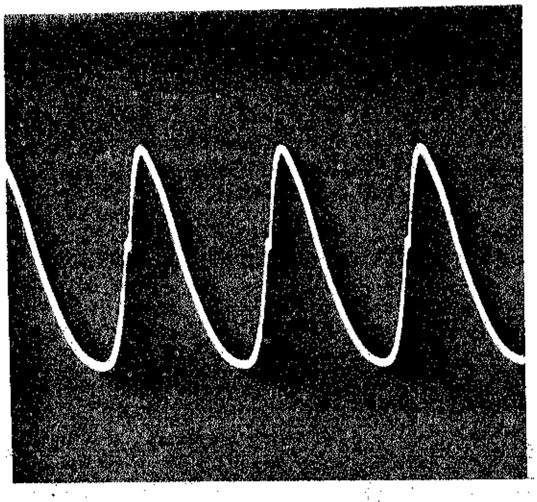
(e)

Pressure 1200 microns
Current 10 microamps.
Voltage 1240 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

(f)

Fig. 54--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 8 cm. in length.

Pressure 300 microns
Current 20 microamps.
Voltage 1860 volts

Oscilloscope settings
0.05 volts/div.
2 microsec./div.

(a)

Pressure 300 microns
Current 14 microamps.
Voltage 1325 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 10 microamps.
Voltage 1210 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(c)

Pressure 300 microns
Current 6 microamps.
Voltage 1140 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(d)

Pressure 600 microns
Current 30 microamps.
Voltage 1570 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

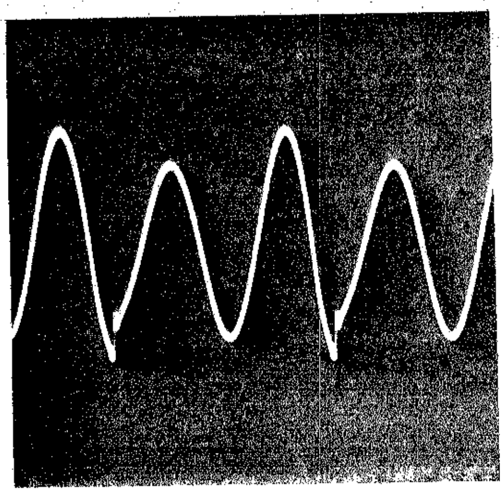
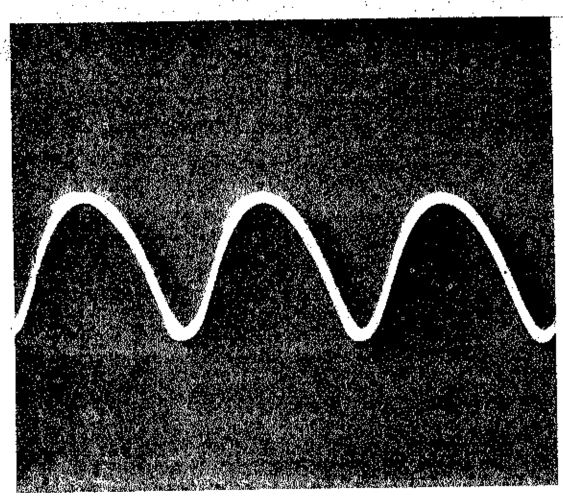
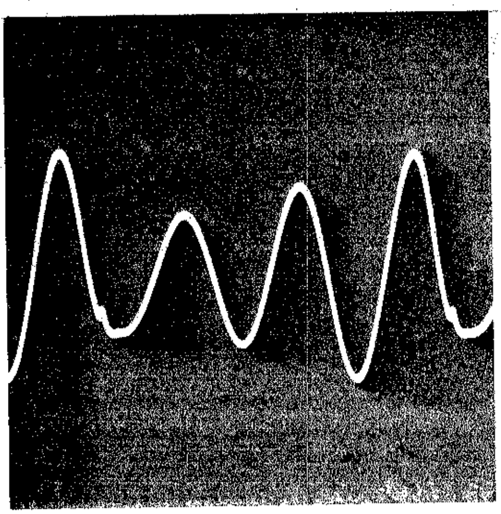
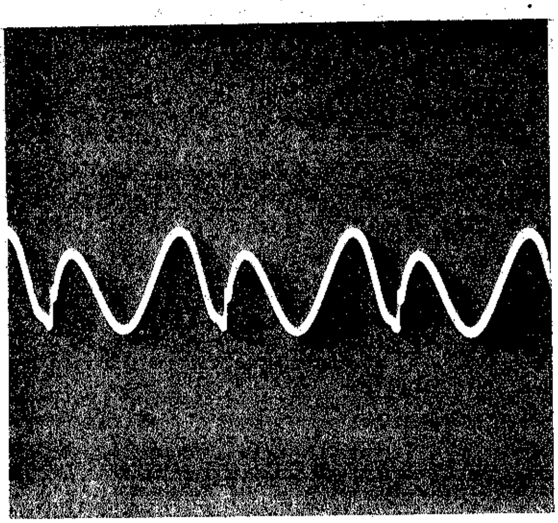
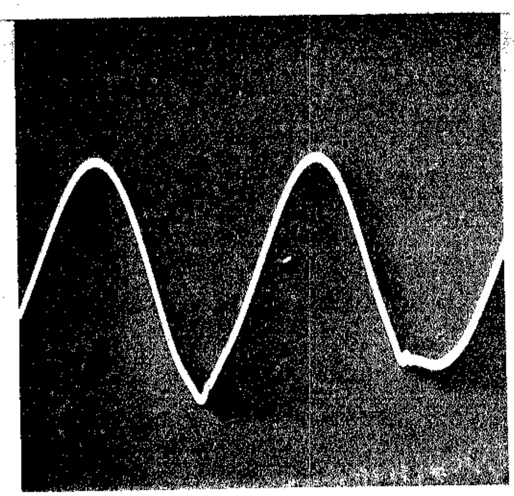
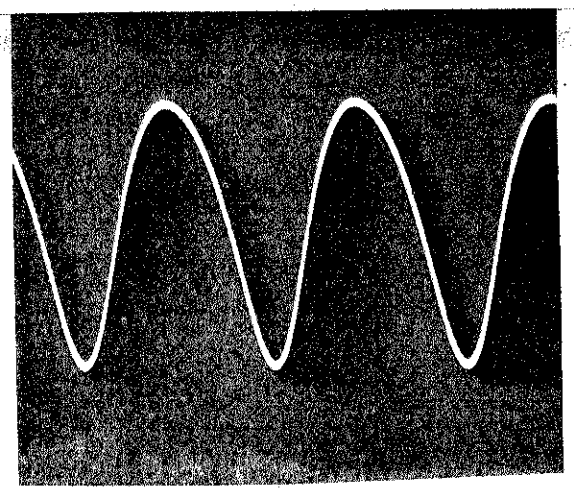
(e)

Pressure 600 microns
Current 10 microamps.
Voltage 1305 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(f)

Fig. 55--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 6 cm. in length.

Pressure 600 microns
Current 2 microamps.
Voltage 1140 volts

Oscilloscope settings
1 volt/div.
20 microsec./div.

(a)

Pressure 900 microns
Current 10 microamps.
Voltage 1240 volts

Oscilloscope settings
0.5 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 19 microamps.
Voltage 1365 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(c)

Pressure 900 microns
Current 10 microamps.
Voltage 1175 volts

Oscilloscope settings
0.5 volts/div.
5 microsec./div.

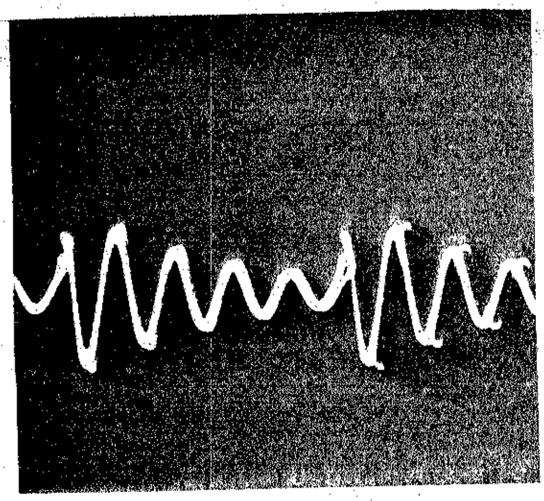
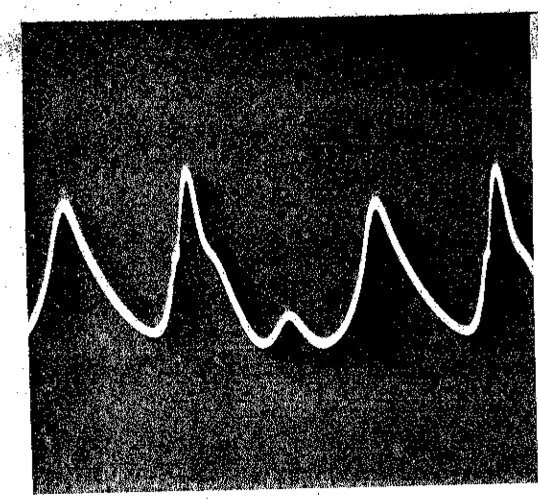
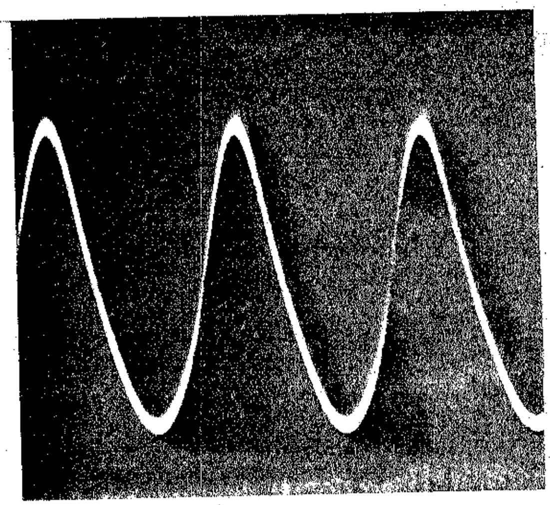
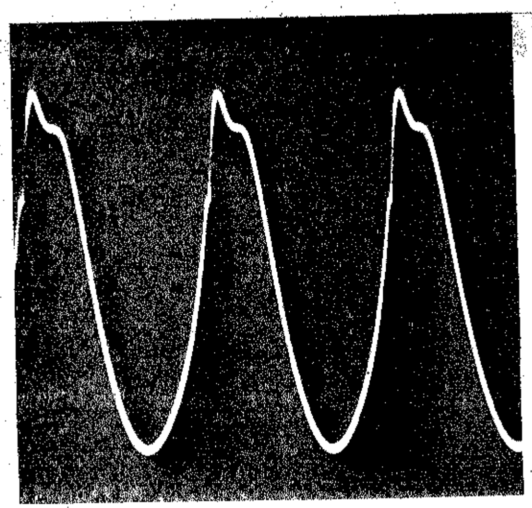
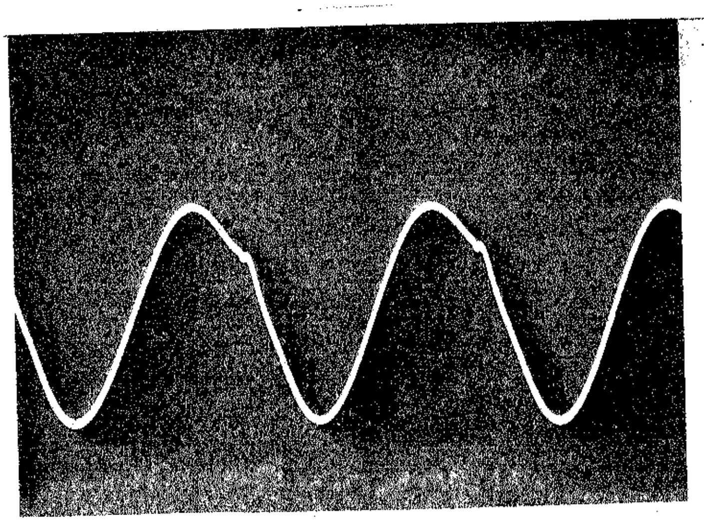
(d)

Pressure 900 microns
Current 0 microamps.
Voltage 1100 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(e)

Fig. 56--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 6 cm. in length.

Pressure 900 microns
Current 4 microamps.
Voltage 970 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(a)

Pressure 1200 microns
Current 10 microamps.
Voltage 1290 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(b)

Pressure 1200 microns
Current 10 microamps.
Voltage 1130 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 1200 microns
Current 1 microamp.
Voltage 955 volts

Oscilloscope settings
0.5 volts/div.
10 microsec./div.

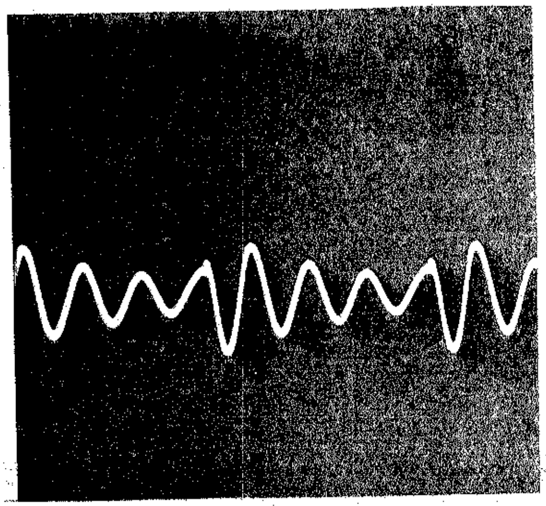
(d)

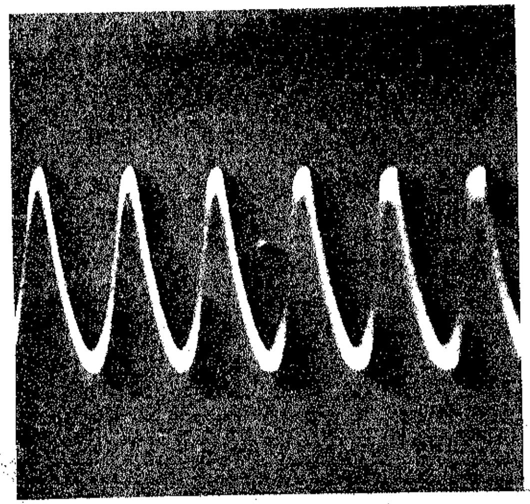
Pressure 1200 microns
Current 3 microamps.
Voltage 1000 volts

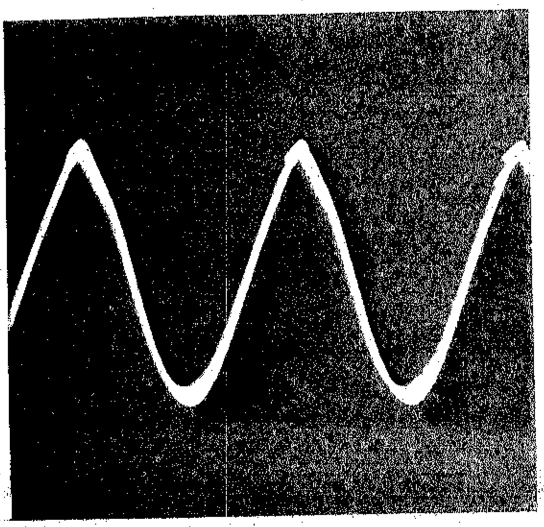
Oscilloscope settings
2 volts/div.
20 microsec./div.

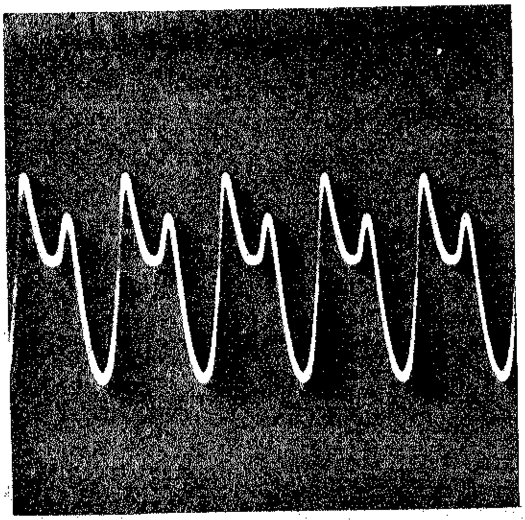
(e)

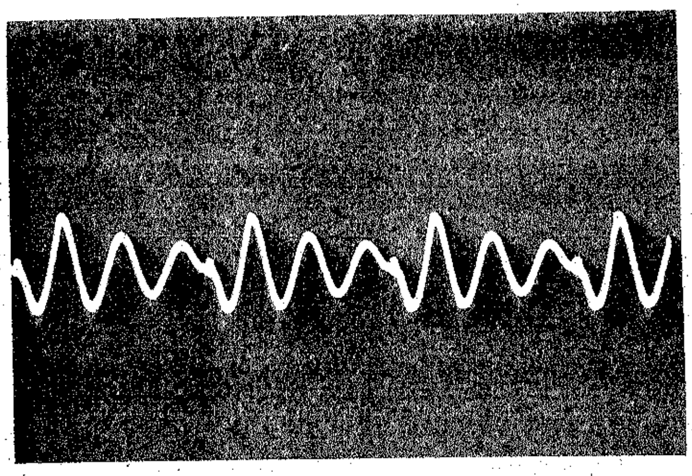
Fig. 57--Plasma oscillations for deuterium gas in a tube 6 mm. in diameter and 6 cm. in length.











Pressure 300 microns
Current 140 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(a)

Pressure 300 microns
Current 0 microamps.
Voltage 1270 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(b)

Pressure 600 microns
Current 119 microamps.
Voltage 1375 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

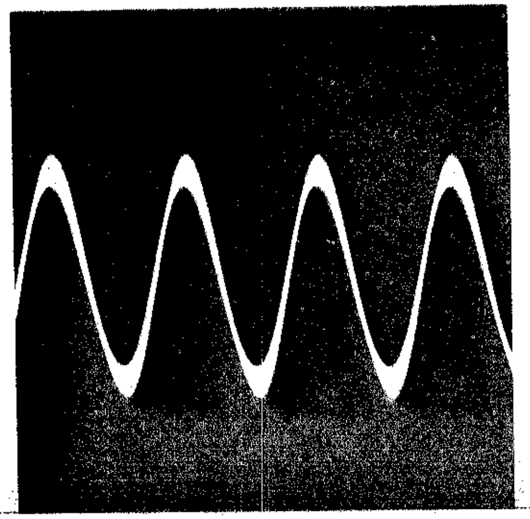
(c)

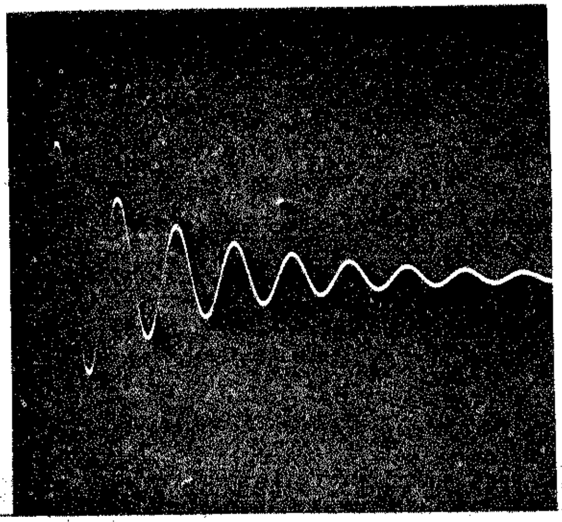
Pressure 600 microns
Current 0 microamps.
Voltage 1300 volts

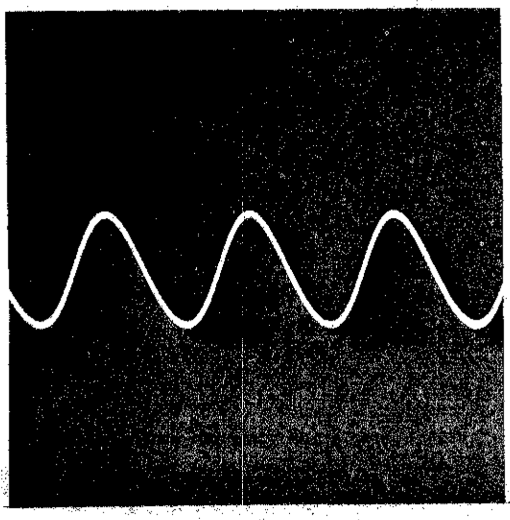
Oscilloscope settings
2 volts/div.
20 microsec./div.

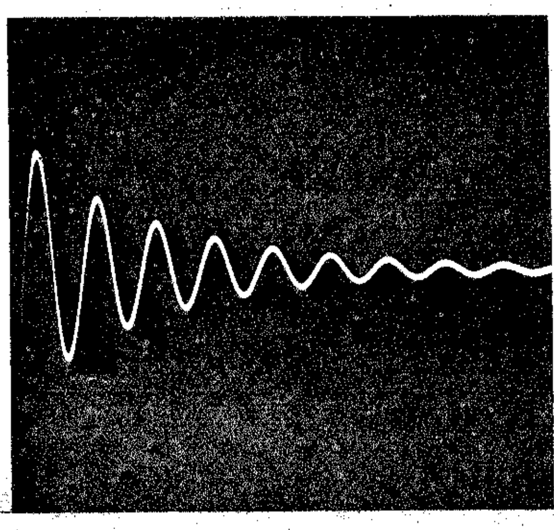
(d)

Fig. 58--Plasma oscillations for deuterium gas in a tube 5.2 mm. in diameter and 20 cm. in length.









Pressure 600 microns
Current 0 microamps.
Voltage 1320 volts

Oscilloscope settings
2 volts/div.
200 microsec./div.

(a)

Pressure 900 microns
Current 100 microamps.
Voltage 1105 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

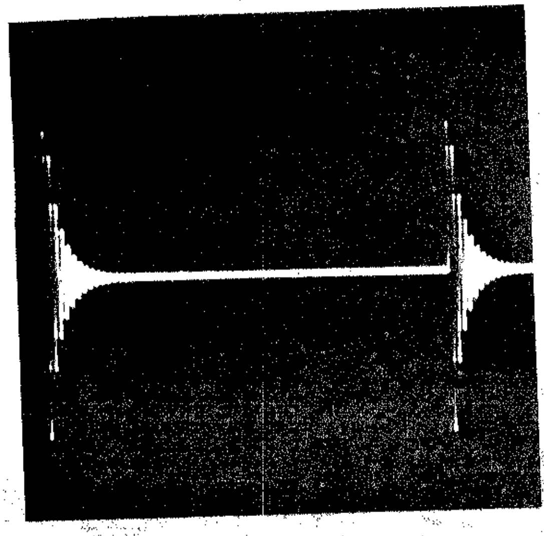
(b)

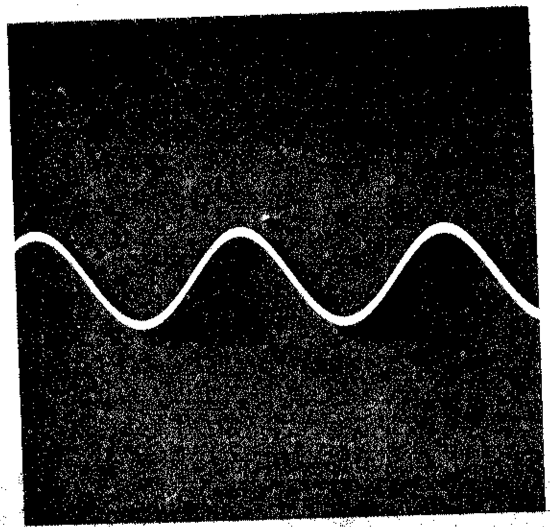
Pressure 1200 microns
Current 120 microamps.
Voltage 3550 volts

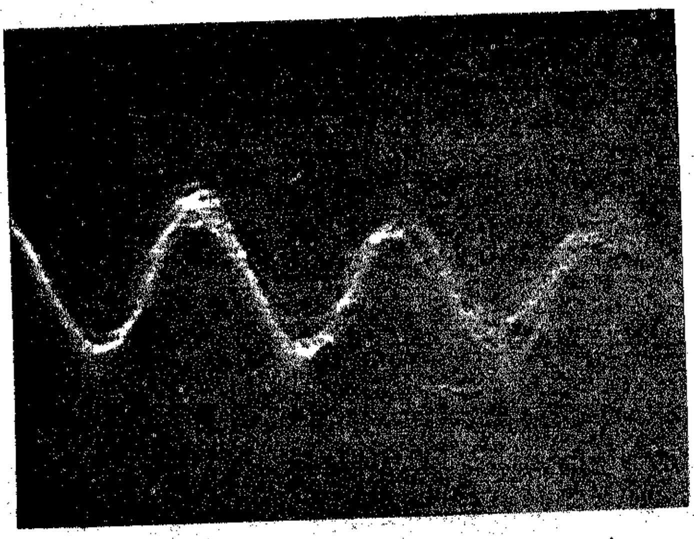
Oscilloscope settings
0.05 volts/div.
2 microsec./div.

(c)

Fig. 59--Plasma oscillations for deuterium in a tube 5.2 mm. in diameter and 20 cm. in length.







Pressure 600 microns
Current 120 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(a)

Pressure 600 microns
Current 110 microamps.
Voltage 3290 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 129 microamps.
Voltage 3050 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

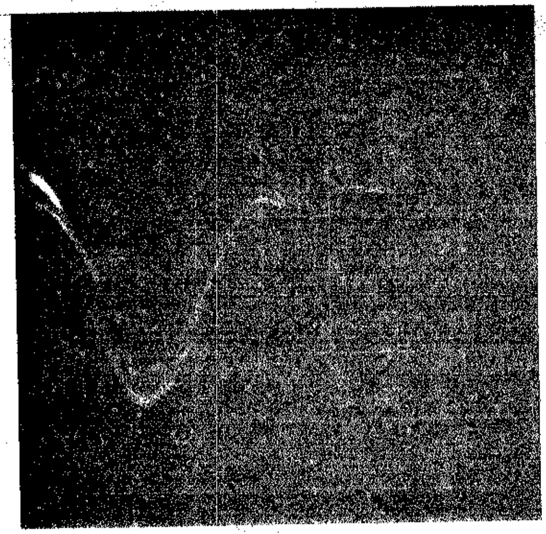
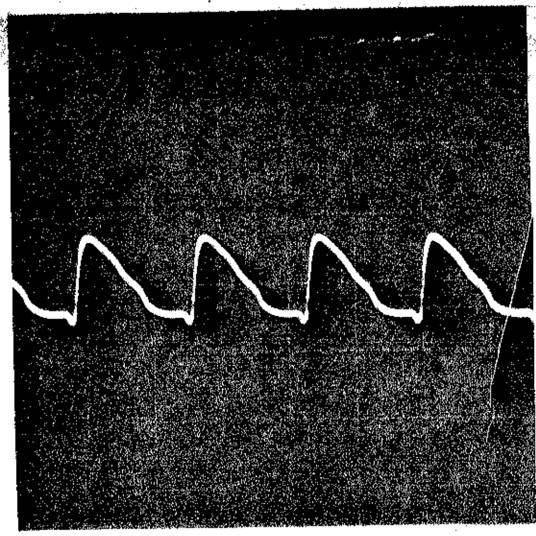
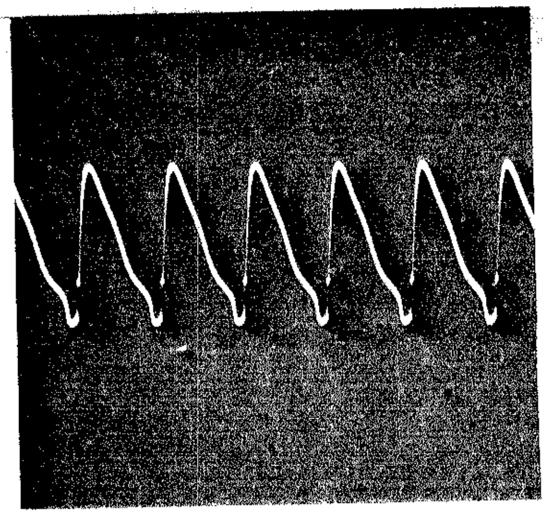
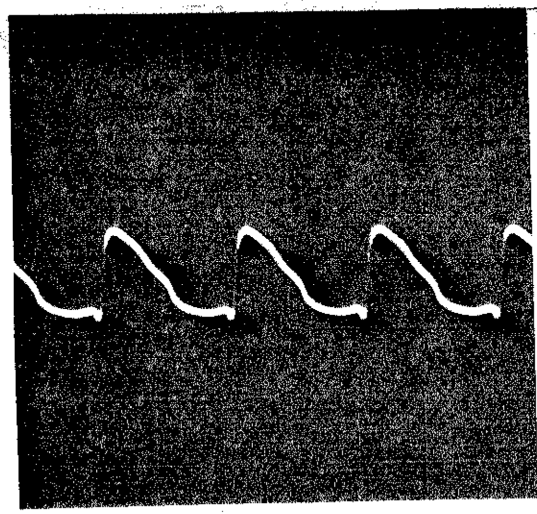
(c)

Pressure 900 microns
Current 99 microamps.
Voltage 2420 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(d)

Fig. 60--Plasma oscillations for deuterium gas in a tube 3.9 mm. in diameter and 20 cm. in length.

Pressure 900 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(a)

Pressure 1200 microns
Current 121 microamps.
Voltage 3050 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

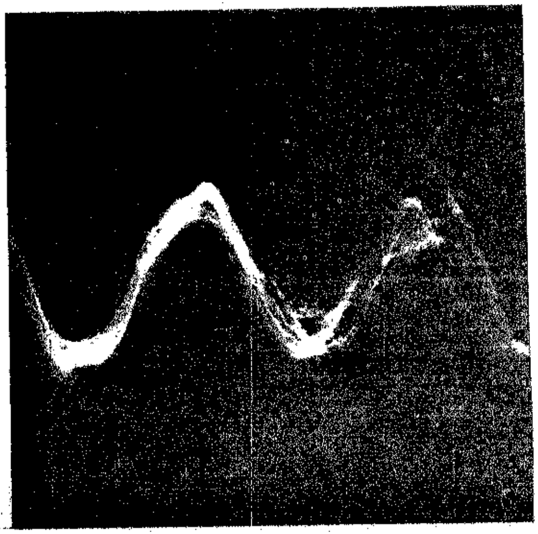
(b)

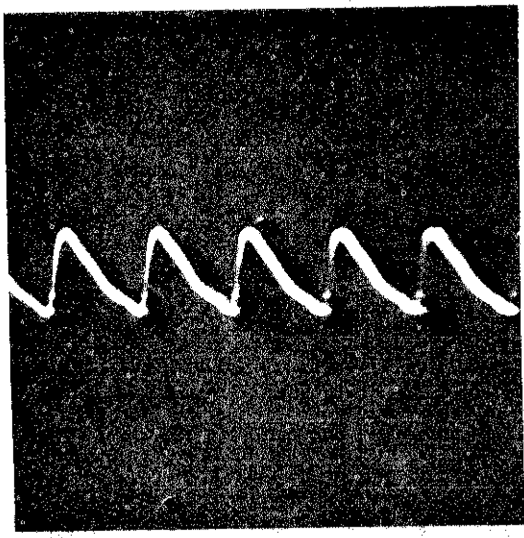
Pressure 1200 microns
Current 124 microamps.
Voltage 2300 volts

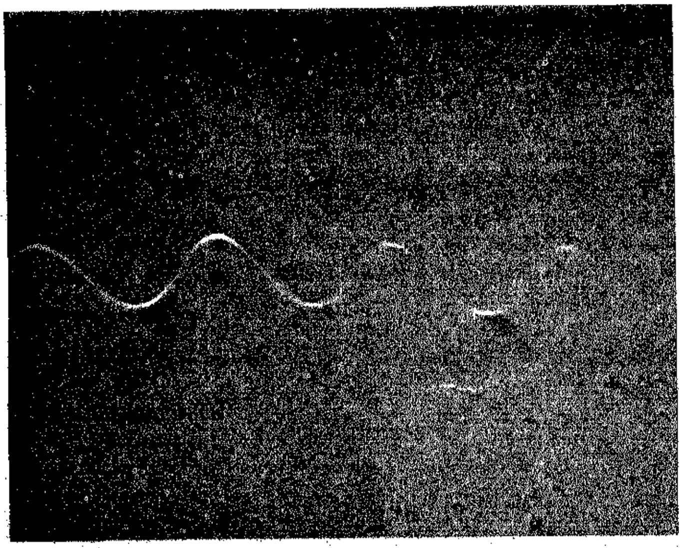
Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(c)

Fig. 61--Plasma oscillations for deuterium gas in a tube 3.9 mm. in diameter and 20 cm. in length.







Pressure 300 microns
Current 120 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(a)

Pressure 300 microns
Current 690 microamps.
Voltage 2390 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(b)

Pressure 300 microns
Current 140 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(c)

Pressure 300 microns
Current 170 microamps.
Voltage 3550 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(d)

Pressure 600 microns
Current 131 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

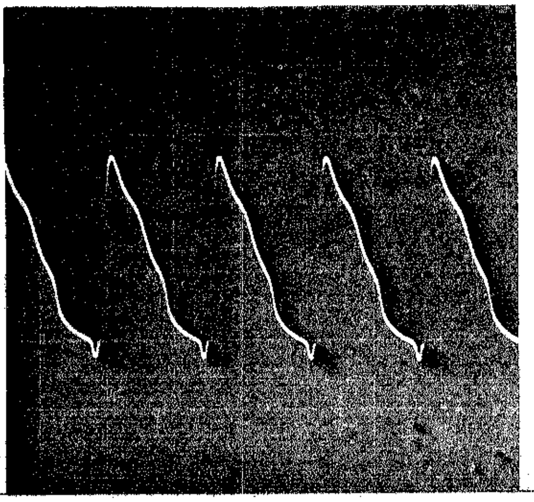
(e)

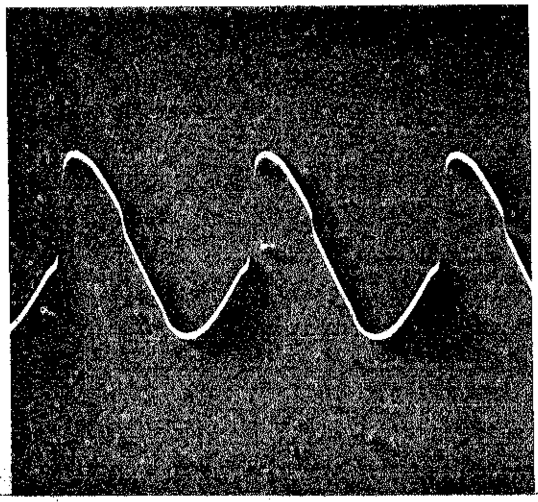
Pressure 600 microns
Current 180 microamps.
Voltage 3550 volts

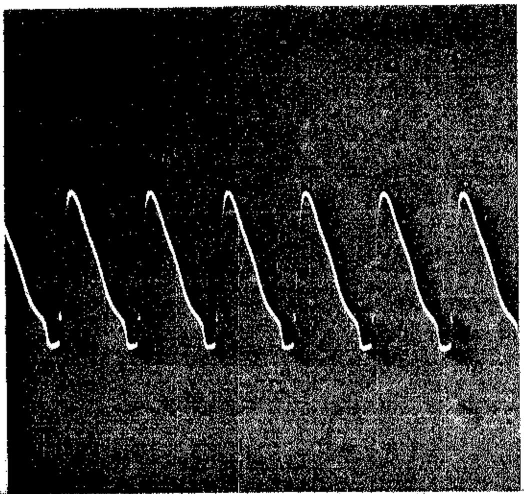
Oscilloscope settings
0.5 volts/div.
2 microsec./div.

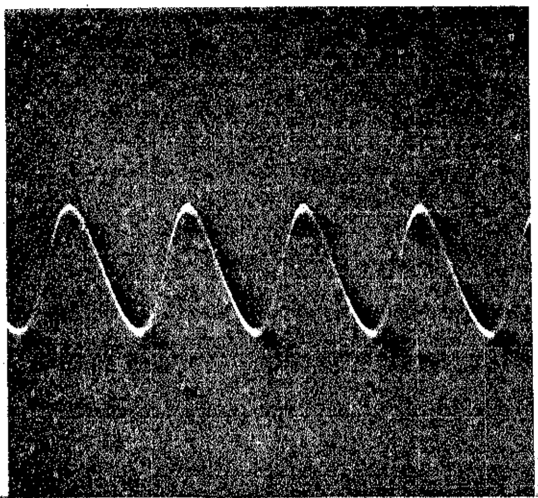
(f)

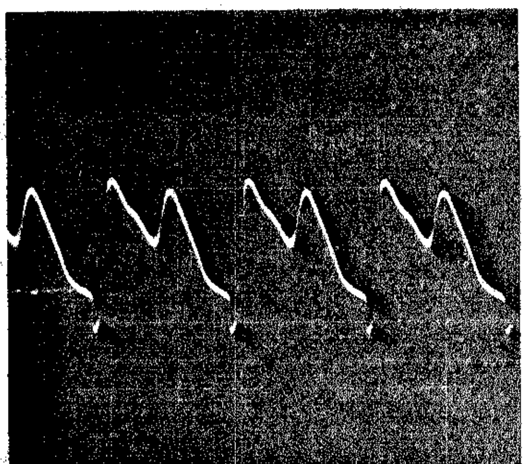
Fig. 62--Plasma oscillations for deuterium gas in a tube 3.5 mm. in diameter and 20 cm. in length.

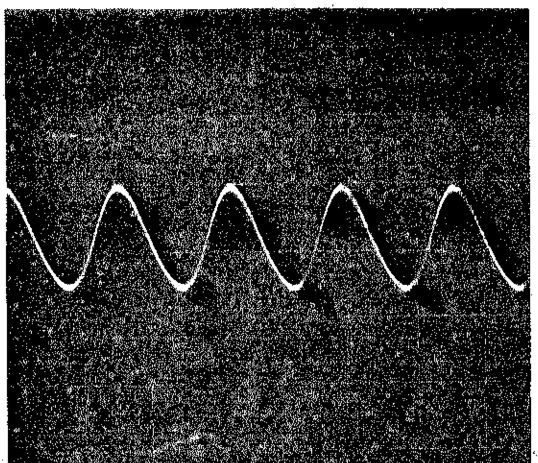












Pressure 900 microns
Current 157 microamps.
Voltage 3550 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(a)

Pressure 900 microns
Current 140 microamps.
Voltage 3050 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(b)

Pressure 900 microns
Current 129 microamps.
Voltage 2765 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

(c)

Pressure 1200 microns
Current 290 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
20 microsec./div.

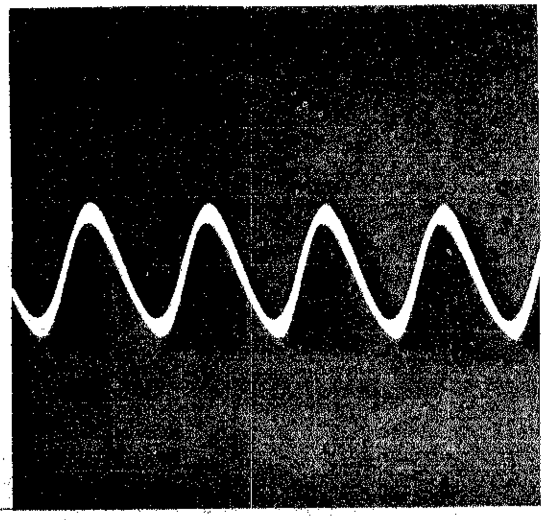
(d)

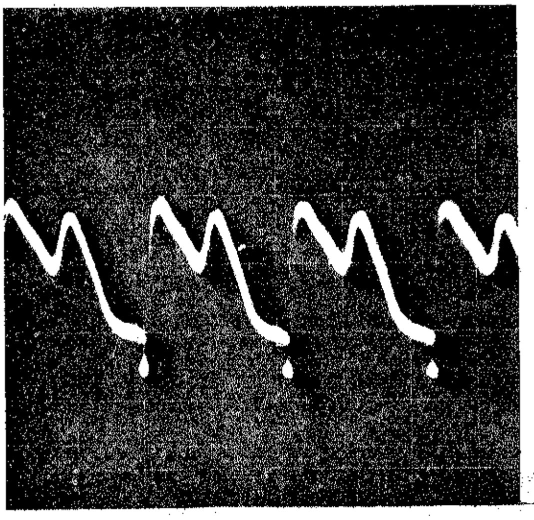
Pressure 1200 microns
Current 130 microamps.
Voltage 3550 volts

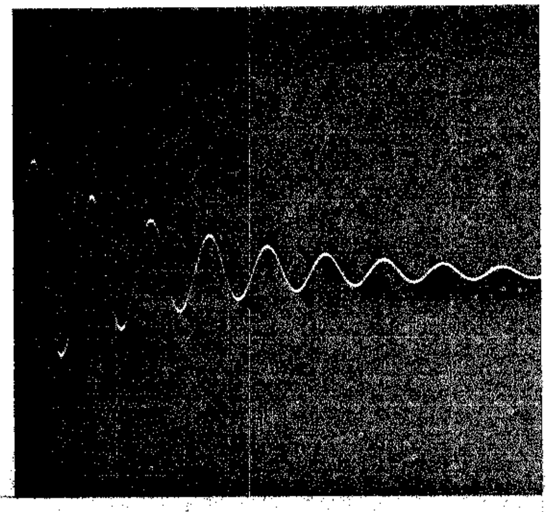
Oscilloscope settings
2 volts/div.
2 microsec./div.

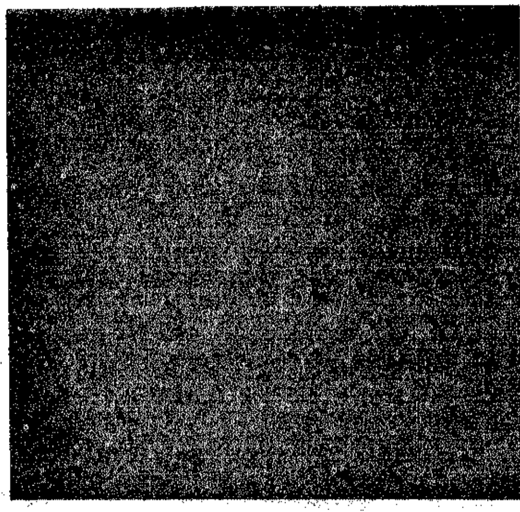
(e)

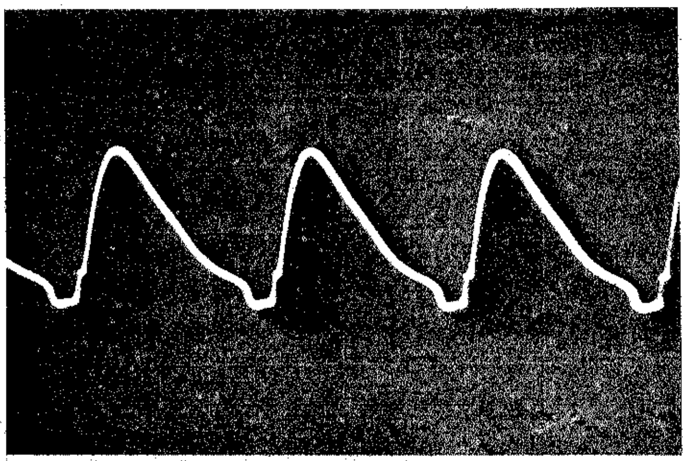
Fig. 63--Plasma oscillations for deuterium gas in a tube 3.5 mm. in diameter and 20 cm. in length.











Pressure 300 microns
Current 170 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
2 microsec./div.

(a)

Pressure 300 microns
Current 121 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(b)

Pressure 300 microns
Current 300 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(c)

Pressure 900 microns
Current 126 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
5 microsec./div.

(d)

Pressure 1200 microns
Current 127 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

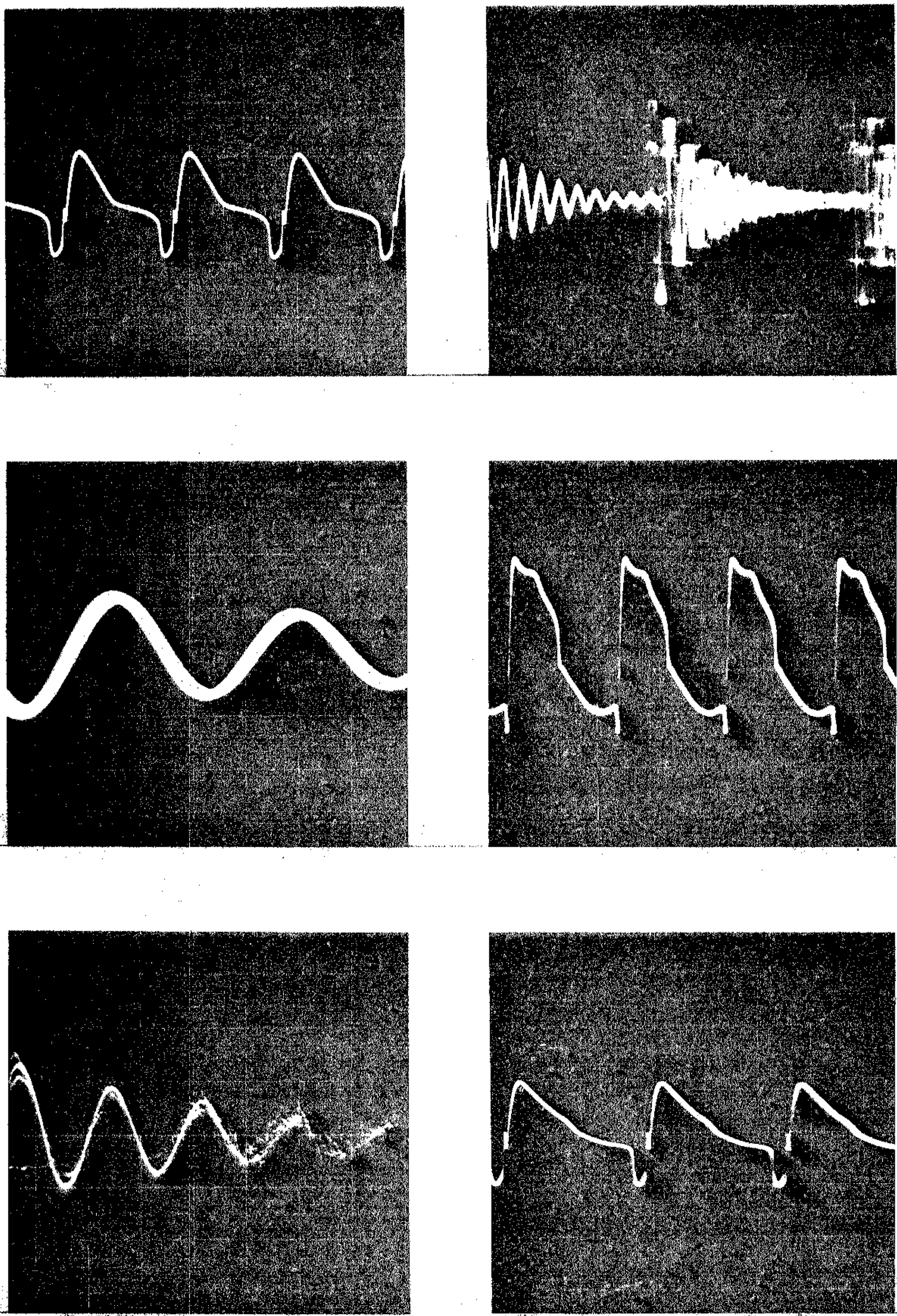
(e)

Pressure 1200 microns
Current 150 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
2 microsec./div.

(f)

Fig. 64--Plasma oscillations for deuterium gas in a tube 2.3 mm. in diameter and 20 cm. in length.



Pressure 600 microns
Current 124 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
2 microsec./div.

(a)

Pressure 600 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

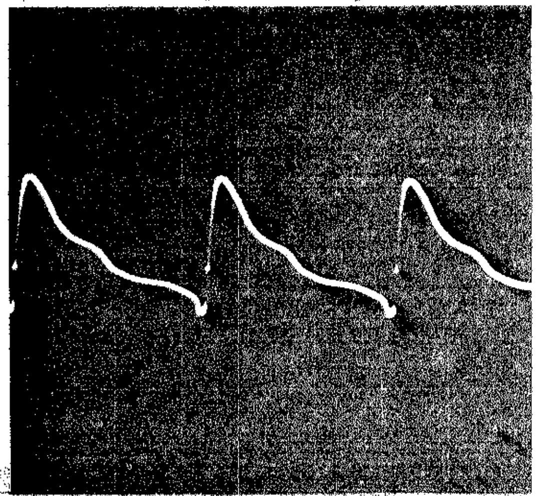
(b)

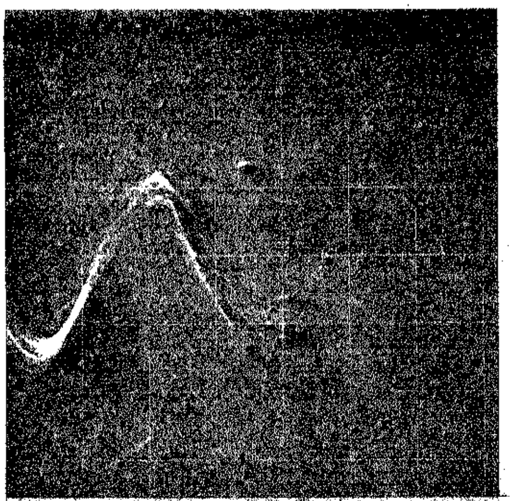
Pressure 1200 microns
Current 182 microamps.
Voltage 3550 volts

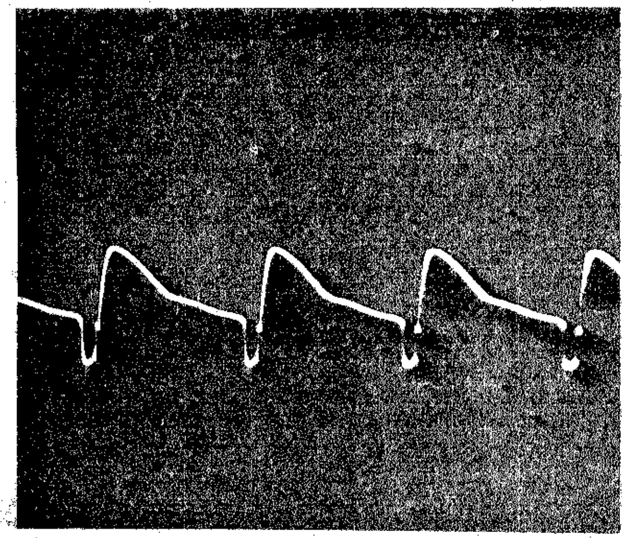
Oscilloscope settings
2 volts/div.
2 microsec./div.

(c)

Fig. 65--Plasma oscillations for deuterium gas in a tube 1.7 mm. in diameter and 20 cm. in length.







Pressure 250 microns
Current 360 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

(a)

Pressure 250 microns
Current 140 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
1 microsec./div.

(b)

Pressure 250 microns
Current 60 microamps.
Voltage 2570 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(c)

Pressure 500 microns
Current 122 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

(d)

Pressure 750 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

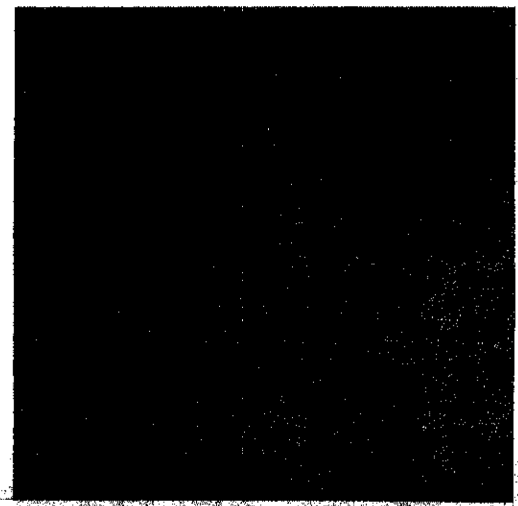
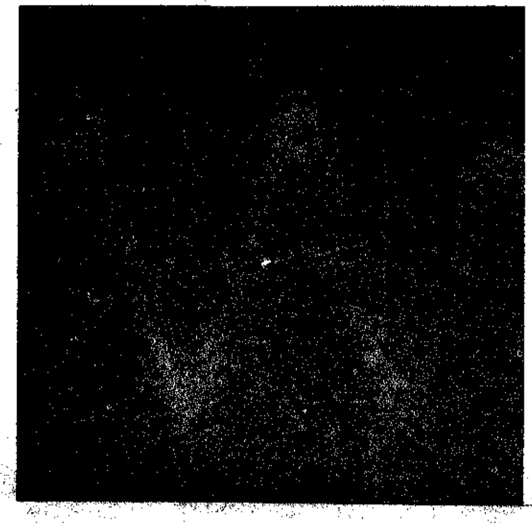
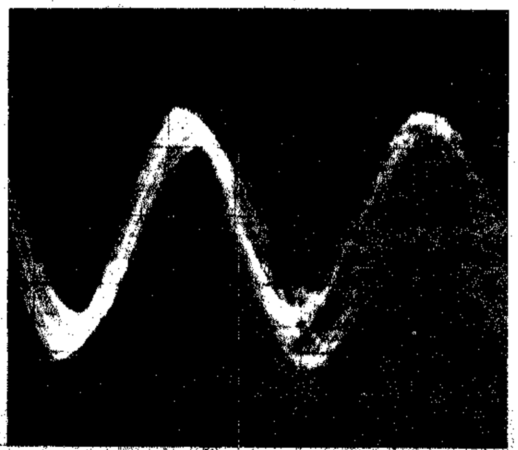
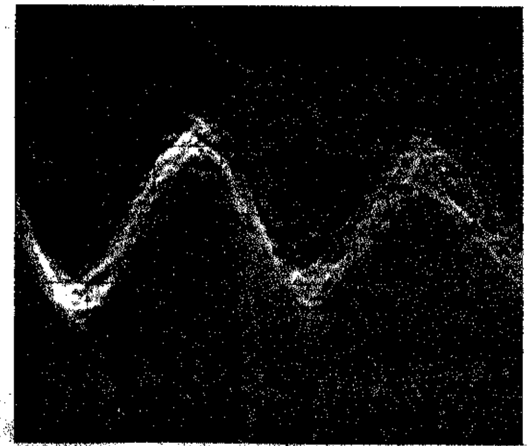
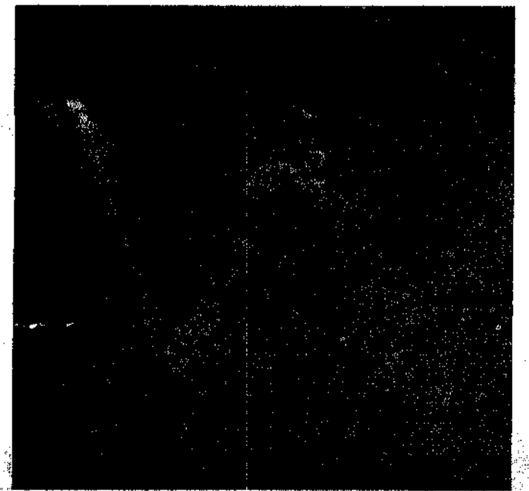
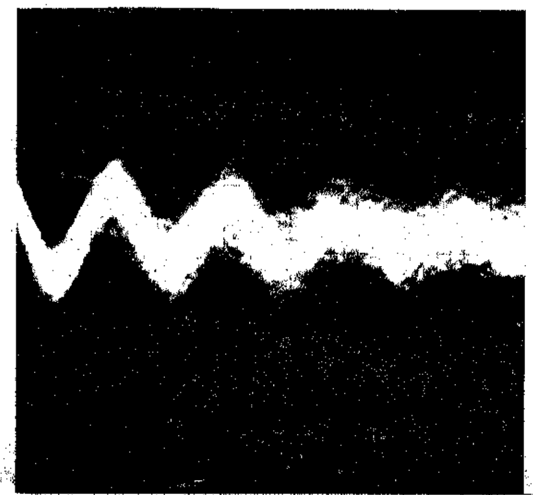
(e)

Pressure 1000 microns
Current 309 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
10 microsec./div.

(f)

Fig. 66--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 23 cm. in length.

Pressure 250 microns
Current 10 microamps.
Voltage 3550 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(a)

Pressure 500 microns
Current 141 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

(b)

Pressure 750 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

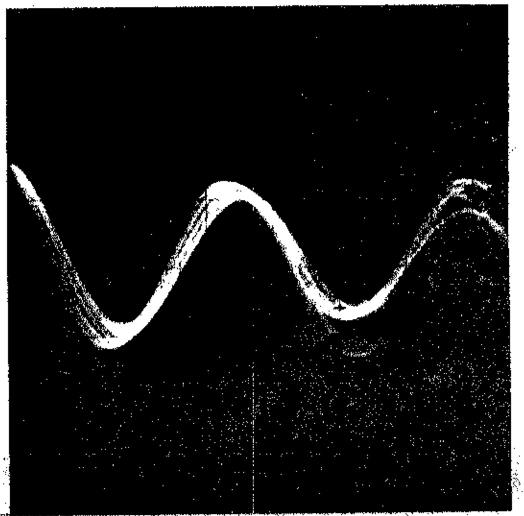
(c)

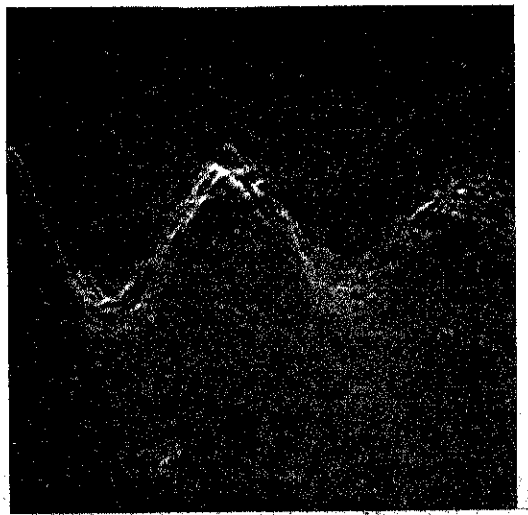
Pressure 1000 microns
Current 129 microamps.
Voltage 3550 volts

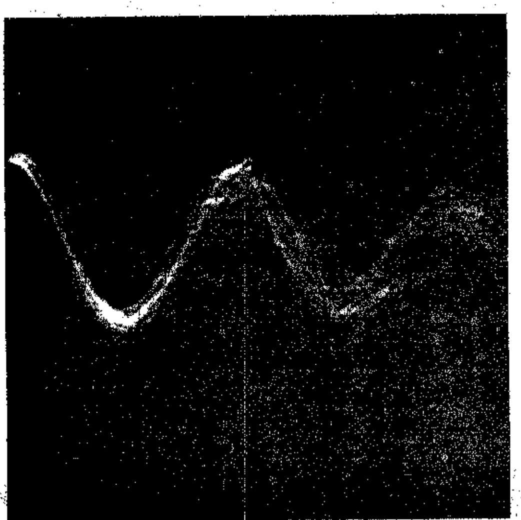
Oscilloscope settings
0.05 volts/div.
5 microsec./div.

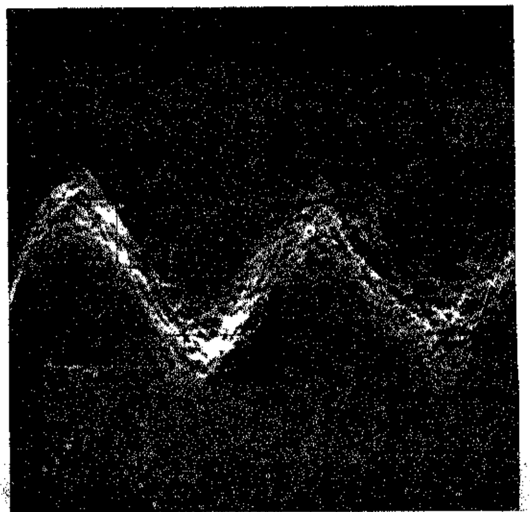
(d)

Fig. 67--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 20 cm. in length.









Pressure 250 microns
Current 250 microamps.
Voltage 3550 volts

Oscilloscope settings
0.01 volts/div.
5 microsec./div.

(a)

Pressure 250 microns
Current 200 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
1 microsec./div.

(b)

Pressure 250 microns
Current 0 microamps.
Voltage 2165 volts

Oscilloscope settings
5 volts/div.
50 microsec./div.

(c)

Pressure 500 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
5 microsec./div.

(d)

Pressure 750 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

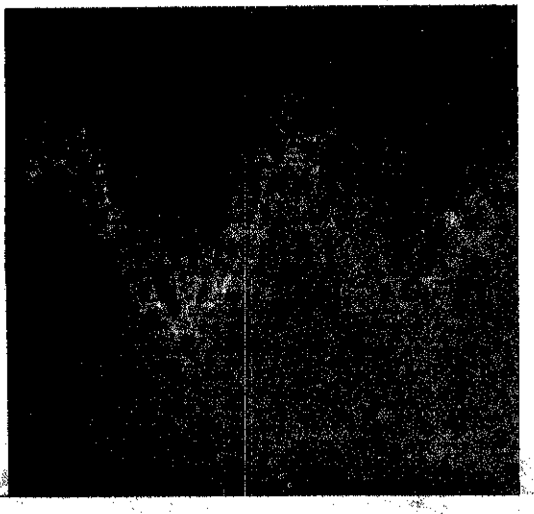
(e)

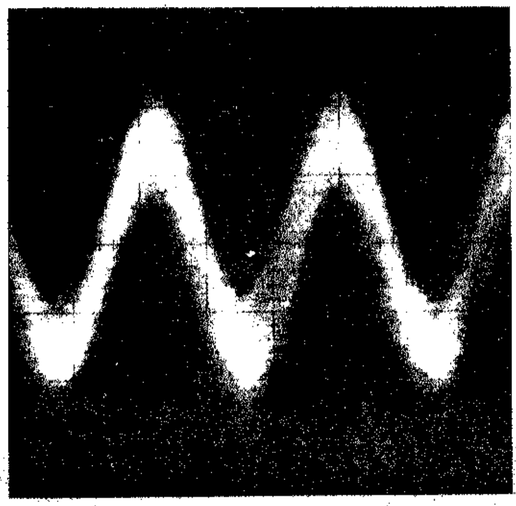
Pressure 1000 microns
Current 129 microamps.
Voltage 3550 volts

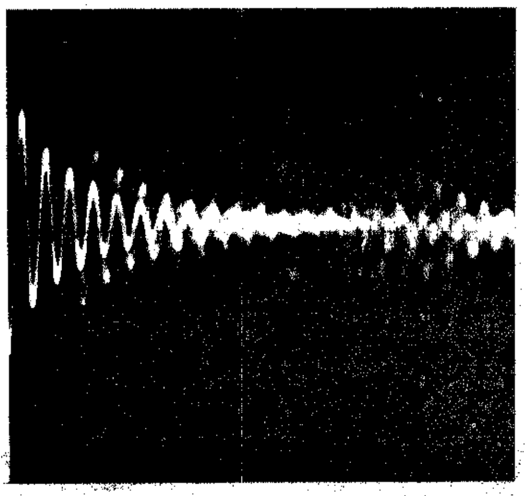
Oscilloscope settings
0.02 volts/div.
5 microsec./div.

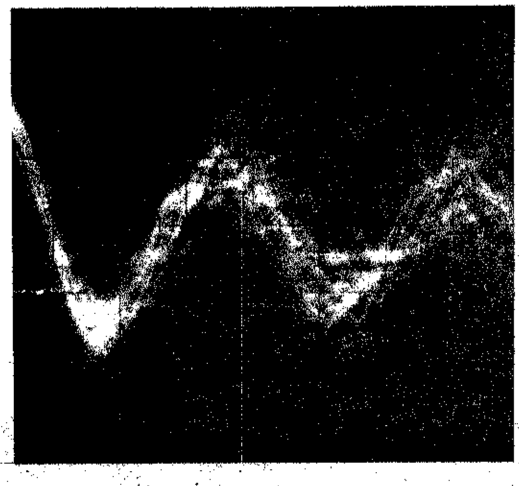
(f)

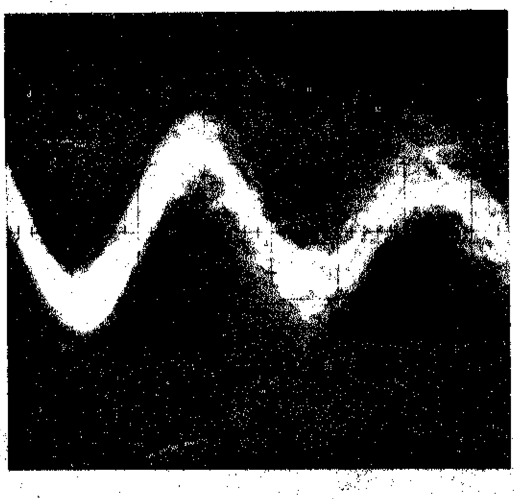
Fig. 68--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 17 cm. in length.











Pressure 250 microns
Current 20 microamps.
Voltage 2550 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(a)

Pressure 500 microns
Current 310 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

(b)

Pressure 750 microns
Current 209 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

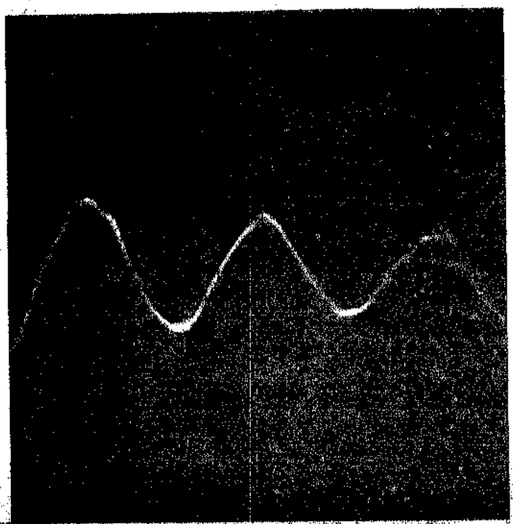
(c)

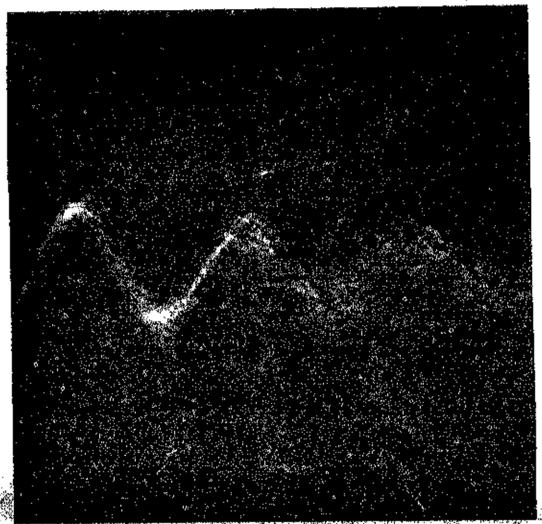
Pressure 1000 microns
Current 500 microamps.
Voltage 3550 volts

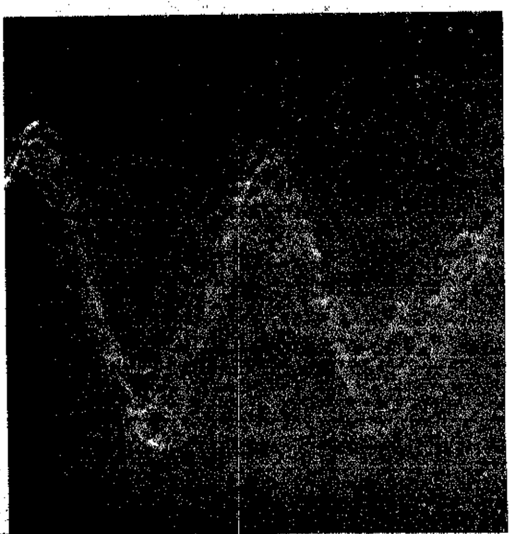
Oscilloscope settings
0.02 volts/div.
5 microsec./div.

(d)

Fig. 69--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 13 cm. in length.







Pressure 250 microns
Current 20 microamps.
Voltage 2550 volts

Oscilloscope settings
10 volts/div.
5 microsec./div.

(a)

Pressure 750 microns
Current 290 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
5 microsec./div.

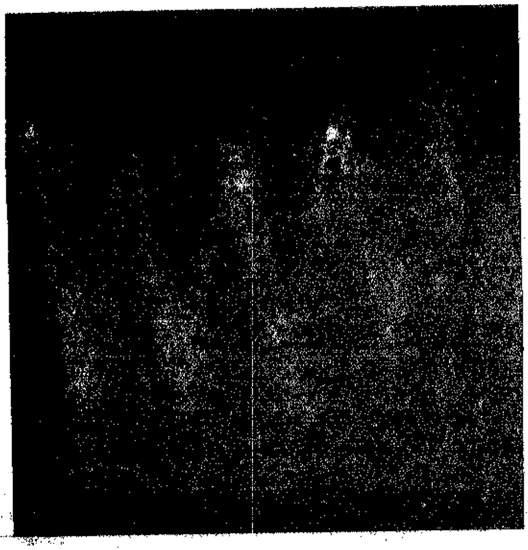
(b)

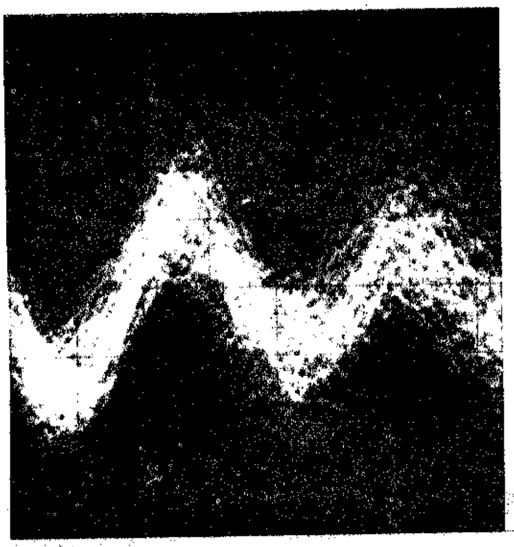
Pressure 1000 microns
Current 479 microamps.
Voltage 3550 volts

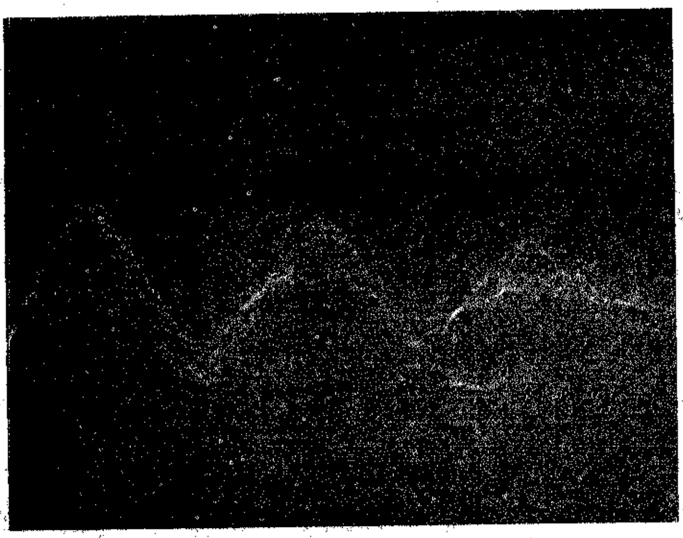
Oscilloscope settings
0.02 volts/div.
5 microsec./div.

(c)

Fig. 70--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 10 cm. in length.







Pressure 250 microns
Current 230 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
1 microsec./div.

(a)

Pressure 250 microns
Current 140 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

(b)

Pressure 500 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
5 microsec./div.

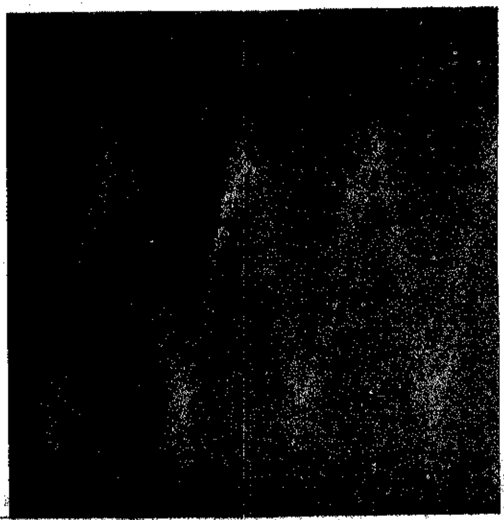
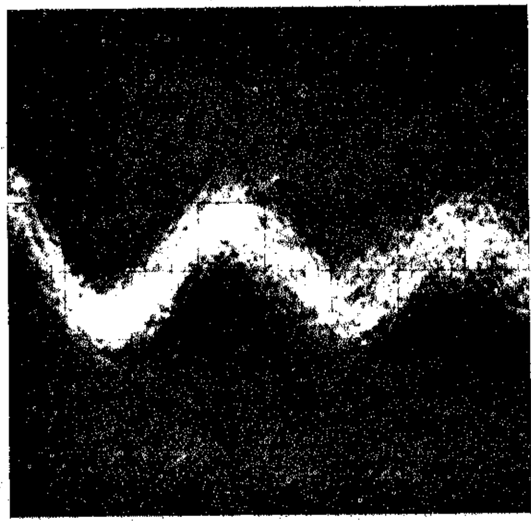
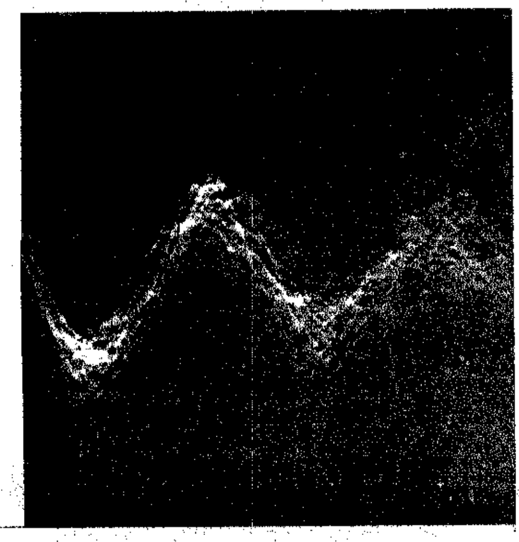
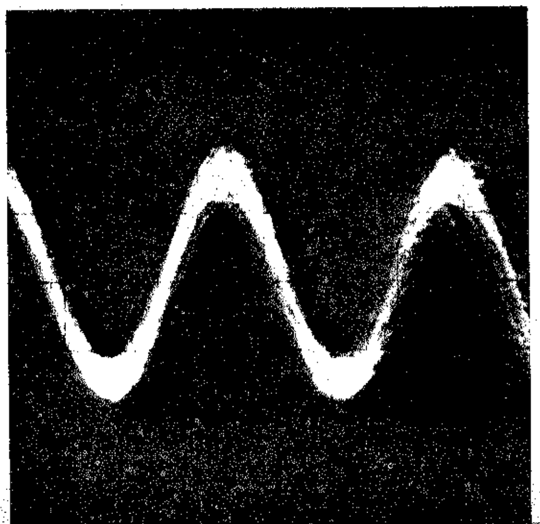
(c)

Pressure 1000 microns
Current 479 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

(d)

Fig. 71--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 8 cm. in length.

Pressure 250 microns
Current 80 microamps.
Voltage 1460 volts

Oscilloscope settings
0.01 volts/div.
1 microsec./div.

(a)

Pressure 250 microns
Current 40 microamps.
Voltage 1140 volts

Oscilloscope settings
0.1 volts/div.
2 microsec./div.

(b)

Pressure 250 microns
Current 10 microamps.
Voltage 905 volts

Oscilloscope settings
1 volt/div.
5 microsec./div.

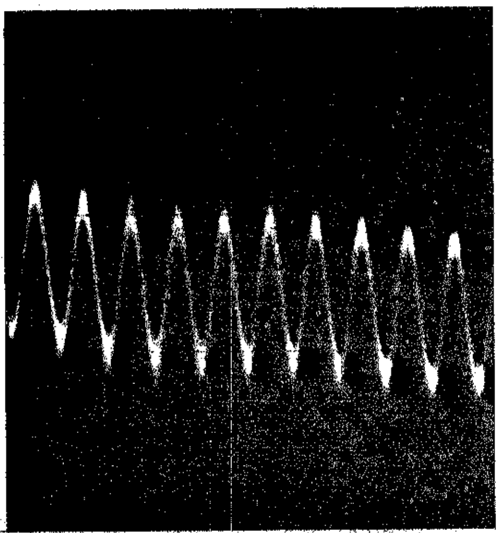
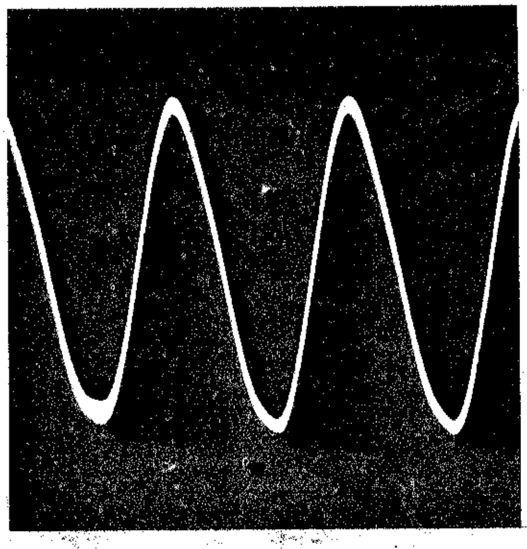
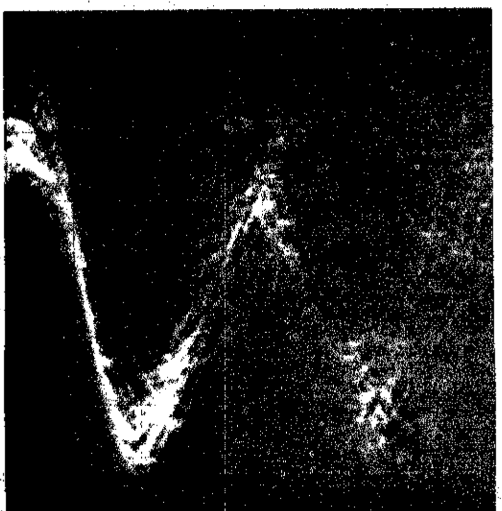
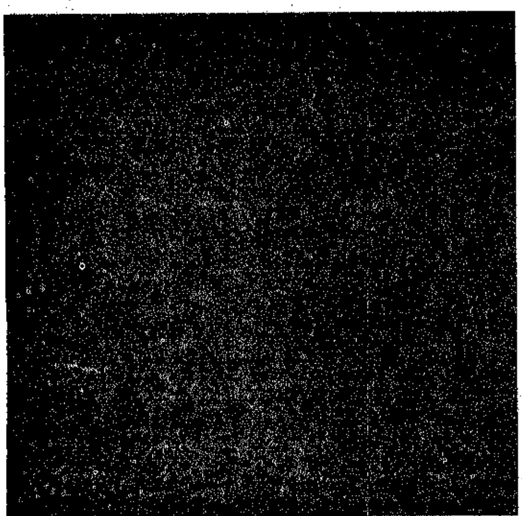
(c)

Pressure 500 microns
Current 90 microamps.
Voltage 1100 volts

Oscilloscope settings
0.01 volts/div.
1 microsec./div.

(d)

Fig. 72--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 6 cm. in length.

Pressure 500 microns
Current 124 microamps.
Voltage 3550 volts

Oscilloscope settings
0.01 volts/div.
1 microsec./div.

(a)

Pressure 500 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.01 volts/div.
5 microsec./div.

(b)

Pressure 750 microns
Current 320 microamps.
Voltage 3550 volts

Oscilloscope settings
0.01 volts/div.
5 microsec./div.

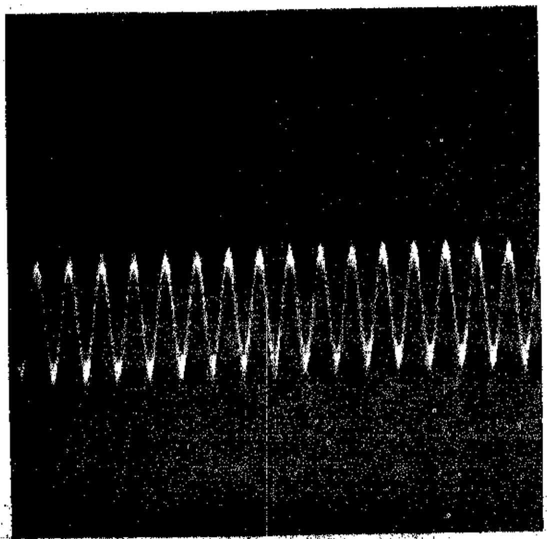
(c)

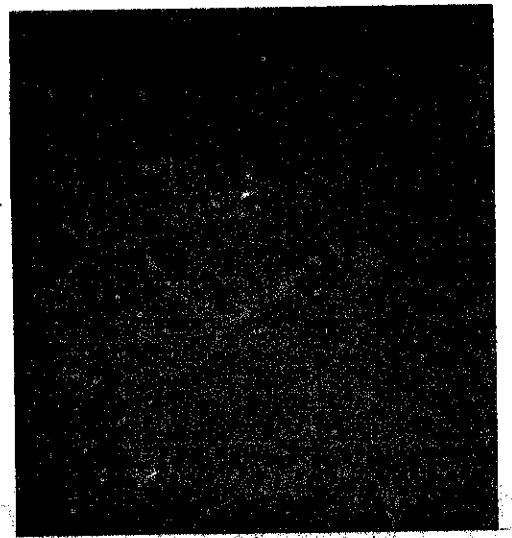
Pressure 1000 microns
Current 200 microamps.
Voltage 3550 volts

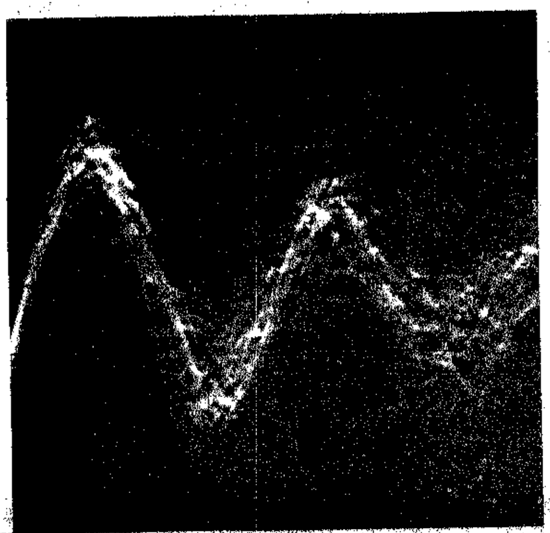
Oscilloscope settings
0.01 volts/div.
5 microsec./div.

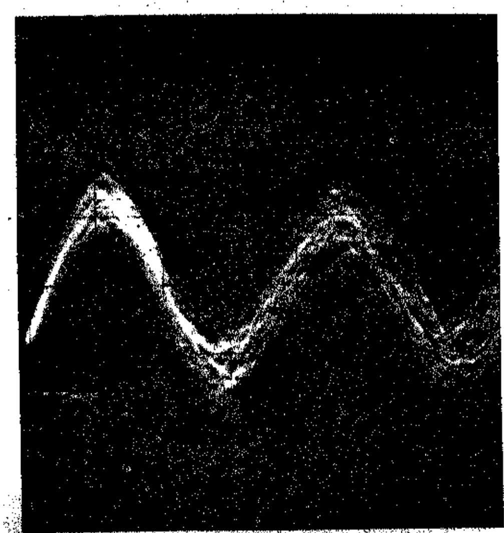
(d)

Fig. 73--Plasma oscillations for nitrogen tetroxide gas in a tube 6 mm. in diameter and 6 cm. in length.









Pressure 250 microns
Current 211 microamps.
Voltage 3550 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(a)

Pressure 250 microns
Current 120 microamps.
Voltage 2250 volts

Oscilloscope settings
5 volts/div.
2 microsec./div.

(b)

Pressure 250 microns
Current 122 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

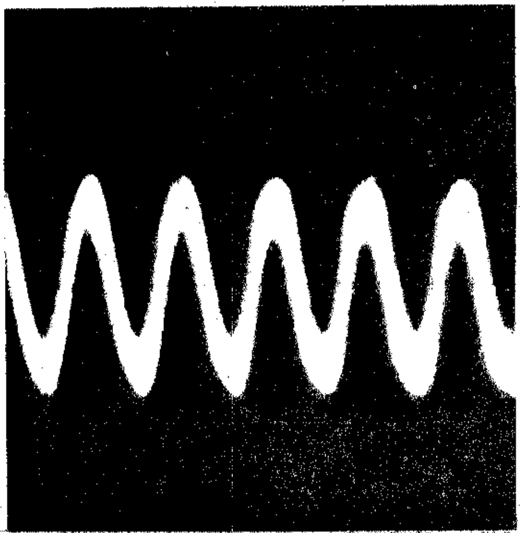
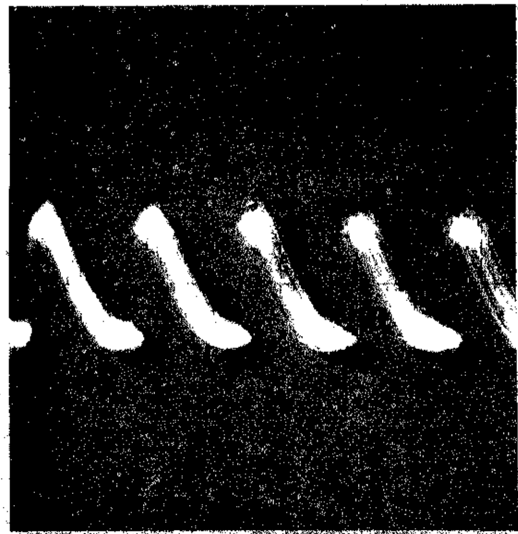
(c)

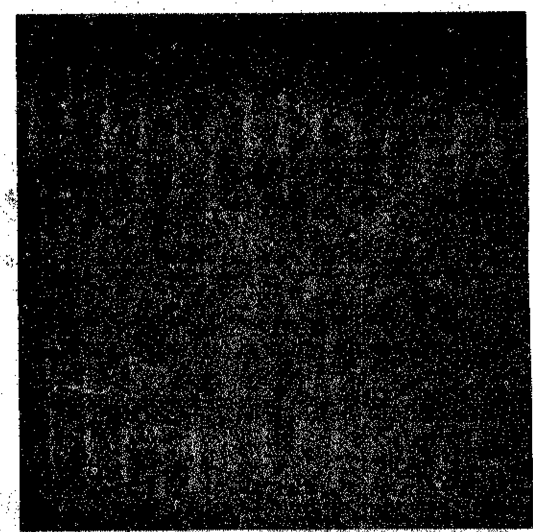
Pressure 500 microns
Current 189 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

(d)

Fig 74--Plasma oscillations for nitrogen tetroxide gas in a tube 5.2 mm. in diameter and 20 cm. in length.



Pressure 500 microns
Current 160 microamps.
Voltage 3550 volts

Oscilloscope settings
0.5 volts/div.
2 microsecl/div.

(a)

Pressure 500 microns
Current 40 microamps.
Voltage 2550 volts

Oscilloscope settings
5 volts/div.
10 microsec./div.

(b)

Pressure 750 microns
Current 121 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

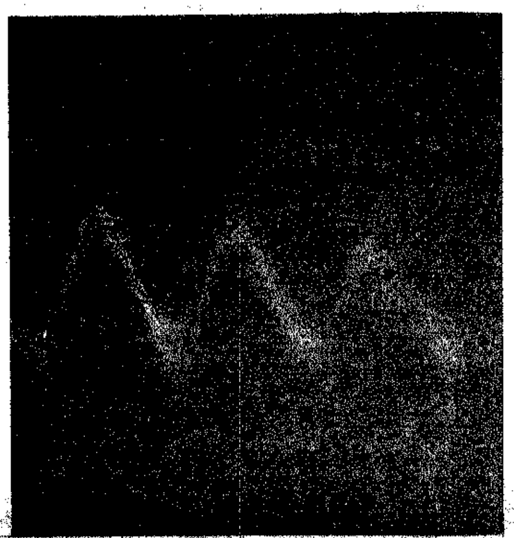
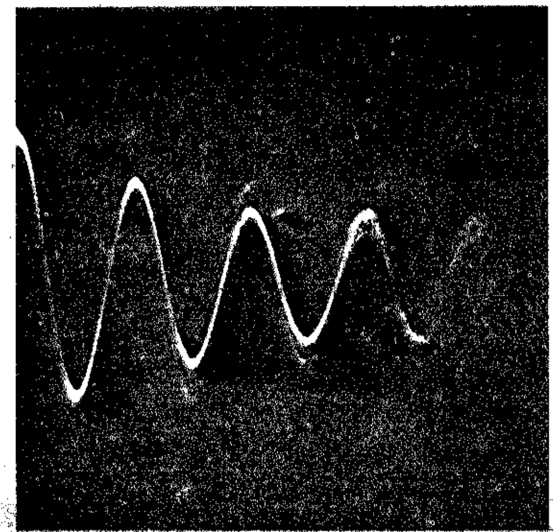
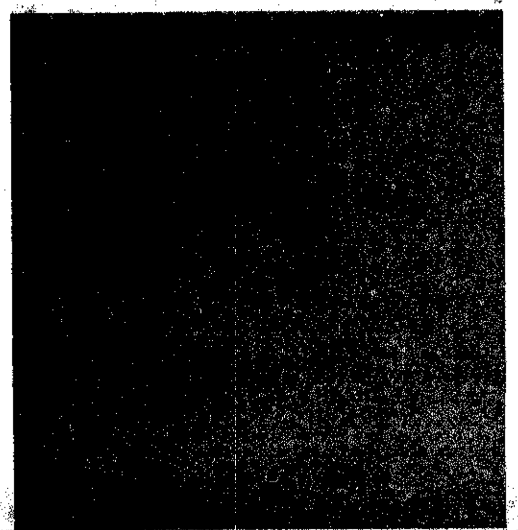
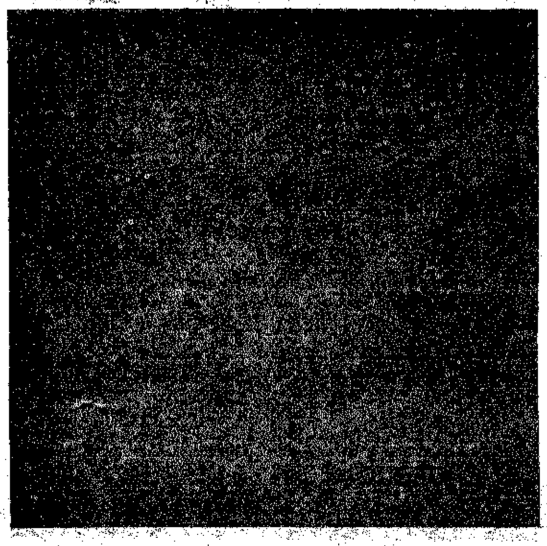
(c)

Pressure 1000 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.05 volts/div.
5 microsec./div.

(d)

Fig. 75--Plasma oscillations for nitrogen tetroxide gas in a tube 5.2 mm. in diameter and 20 cm. in length.

Pressure 250 microns
Current 121 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
5 microsec./div.

(a)

Pressure 250 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
5 microsec./div.

(b)

Pressure 500 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
5 microsec./div.

(c)

Pressure 750 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.02 volts/div.
5 microsec./div.

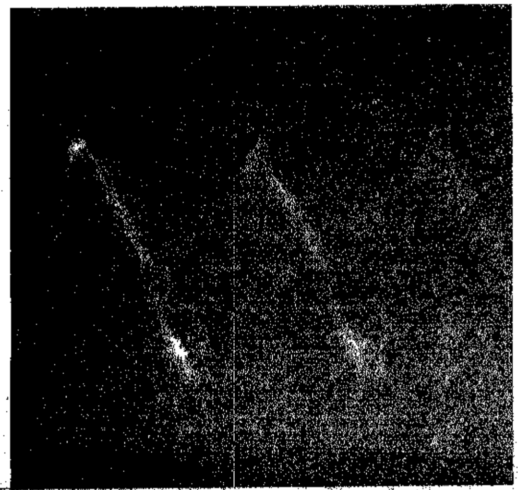
(d)

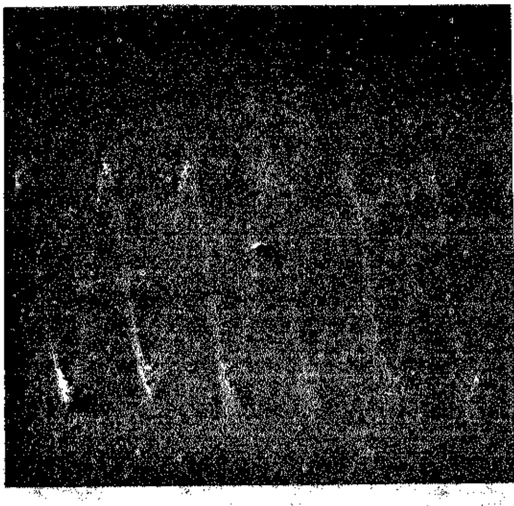
Pressure 1000 microns
Current 129 microamps.
Voltage 3550 volts

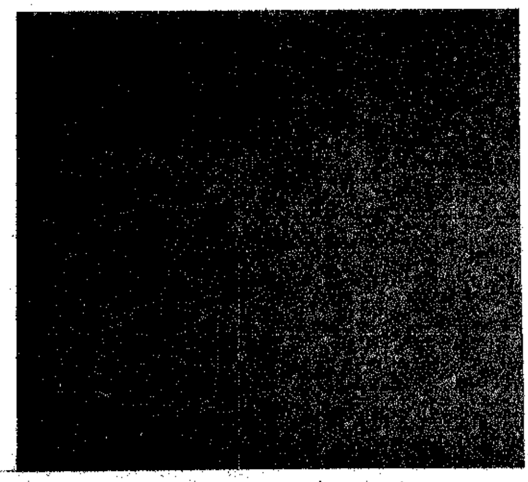
Oscilloscope settings
0.02 volts/div.
5 microsec./div.

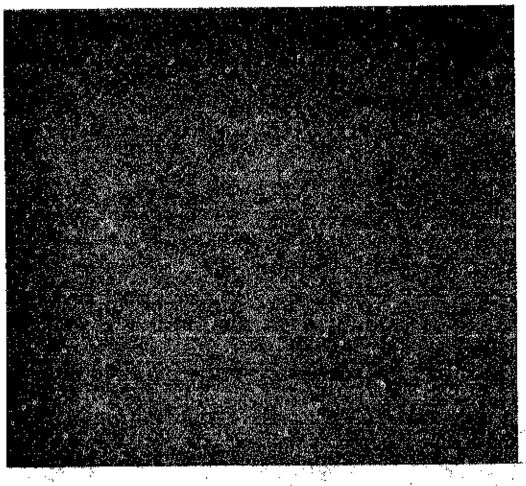
(e)

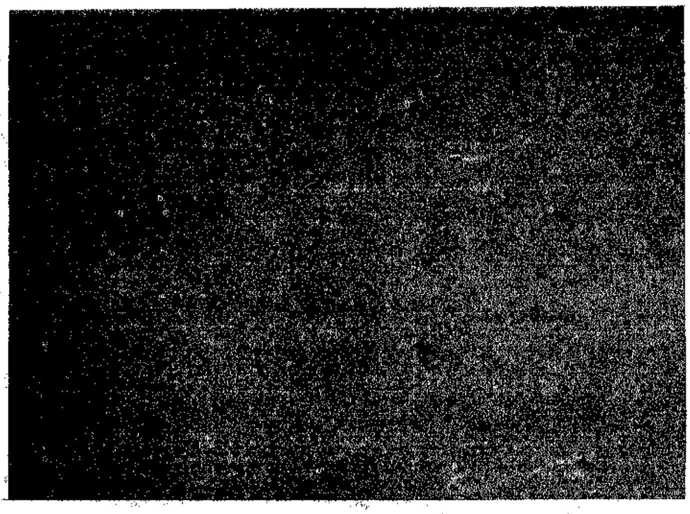
Fig. 76--Plasma oscillations for nitrogen tetroxide gas in a tube 3.9 mm. in diameter and 20 cm. in length.











Pressure 250 microns
Current 140 microamps.
Voltage 3550 volts

Oscilloscope settings
1 volt/div.
2 microsec./div.

(a)

Pressure 250 microns
Current 129 microamps.
Voltage 2550 volts

Oscilloscope settings
5 volts/div.
5 microsec./div.

(b)

Pressure 500 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(c)

Pressure 500 microns
Current 130 microamps.
Voltage 1930 volts

Oscilloscope settings
0.05 volts/div.
10 microsec./div.

(d)

Pressure 750 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

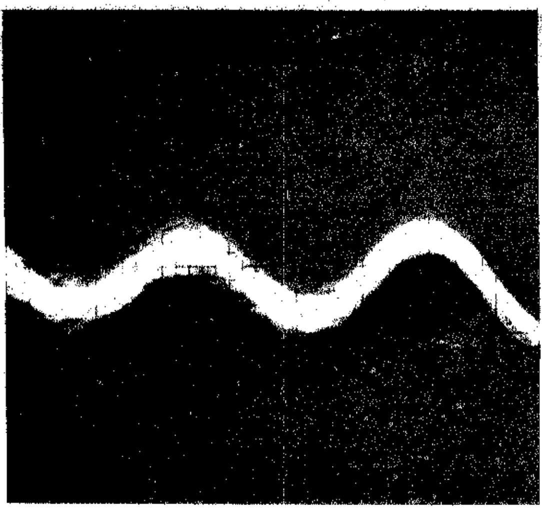
(e)

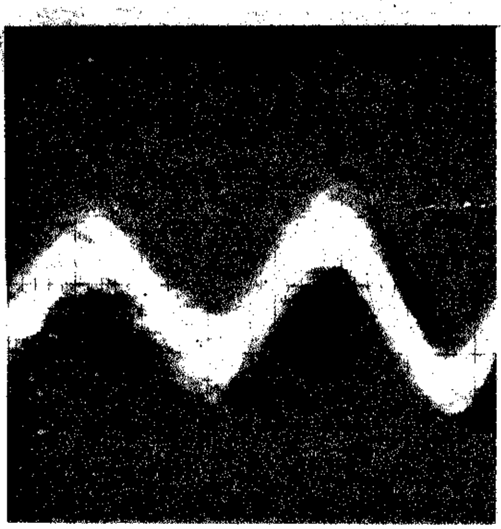
Pressure 1000 microns
Current 129 microamps.
Voltage 3550 volts

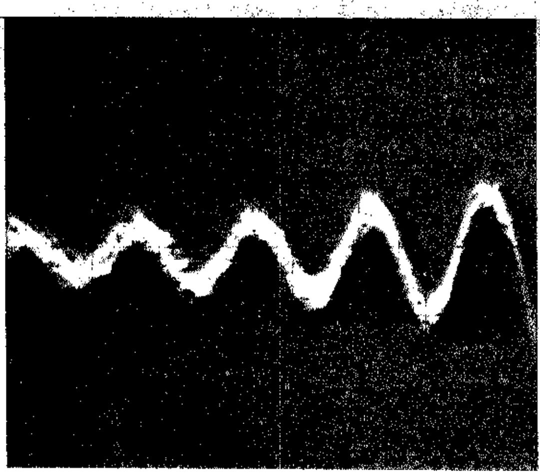
Oscilloscope settings
0.2 volts/div.
5 microsec./div.

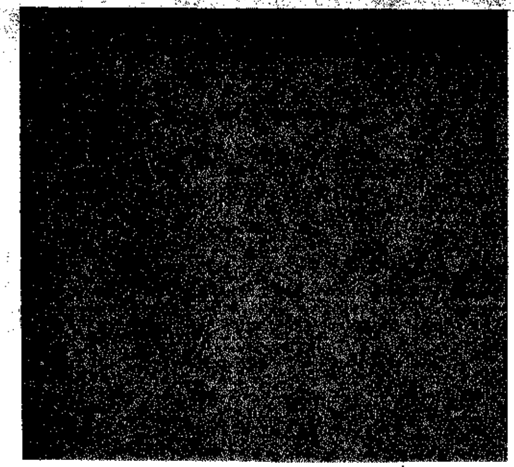
(f)

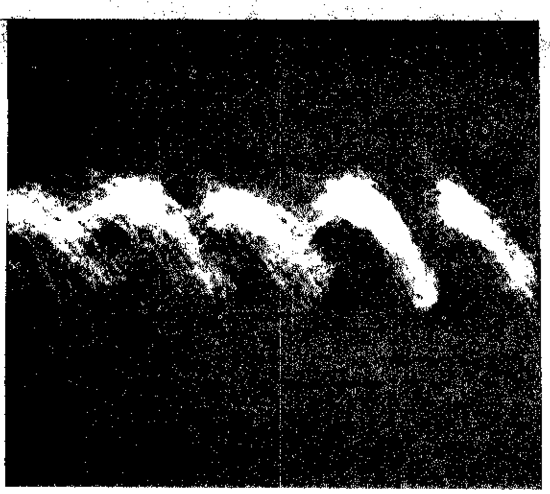
Fig. 77--Plasma oscillations for nitrogen tetroxide gas in a tube 3.5 mm. in diameter and 20 cm. in length.

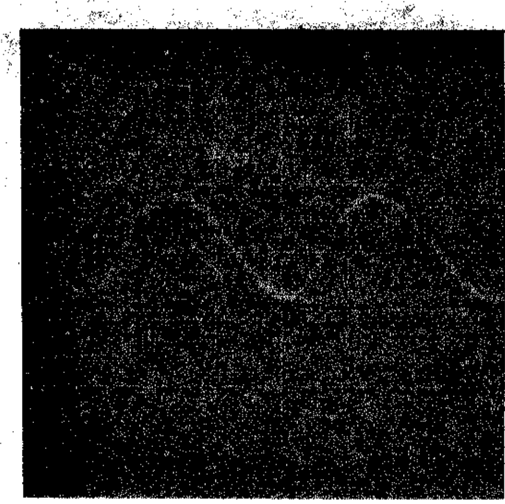












Pressure 250 microns
Current 210 microamps.
Voltage 3550 volts

Oscilloscope settings
0.5 volts/div.
2 microsec./div.

(a)

Pressure 250 microns
Current 121 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(b)

Pressure 500 microns
Current 235 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

(c)

Pressure 750 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
5 microsec./div.

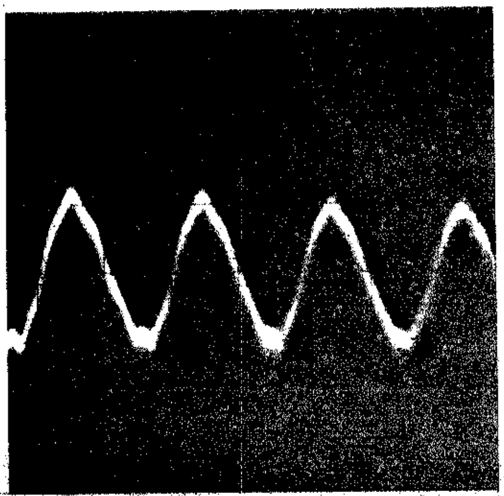
(d)

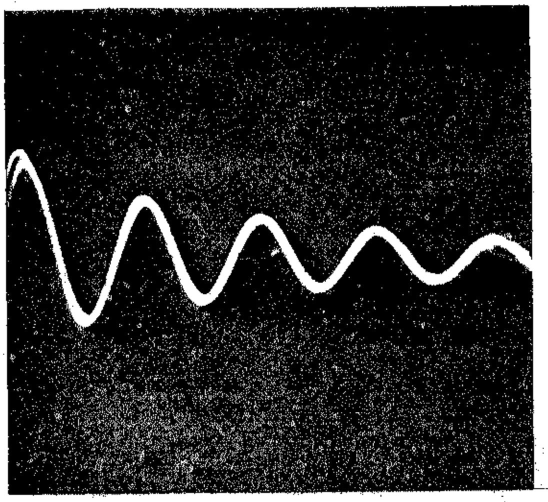
Pressure 1000 microns
Current 129 microamps.
Voltage 3550 volts

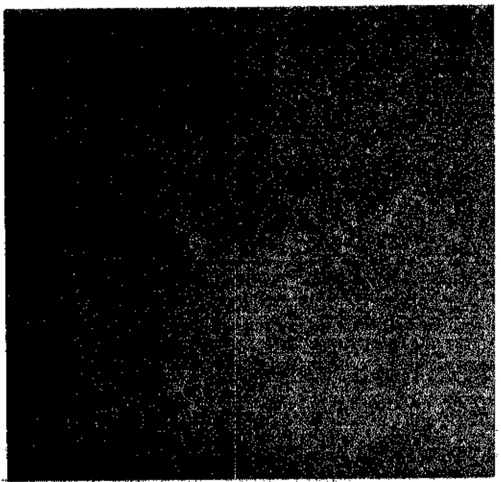
Oscilloscope settings
0.2 volts/div.
5 microsec./div.

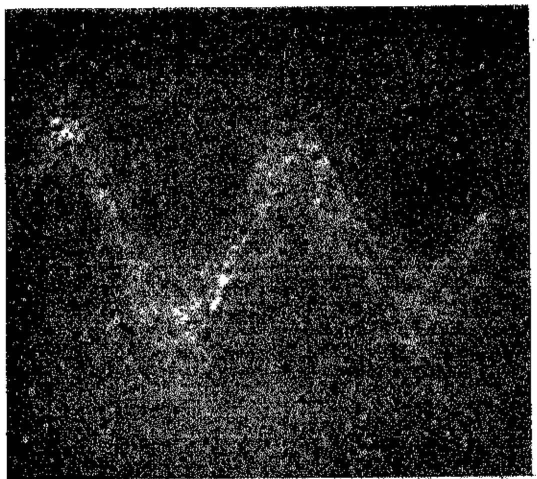
(e)

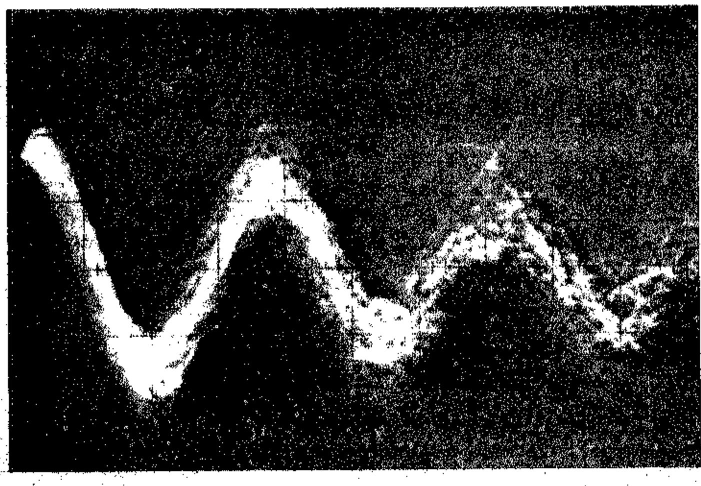
Fig. 78--Plasma oscillations for nitrogen tetroxide gas in a tube 2.3 mm. in diameter and 20 cm. in length.











Pressure 250 microns
Current 129 microamps.
Voltage 3550 volts

Oscilloscope settings
2 volts/div.
10 microsec./div.

(a)

Pressure 500 microns
Current 125 microamps.
Voltage 3550 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(b)

Pressure 500 microns
Current 243 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

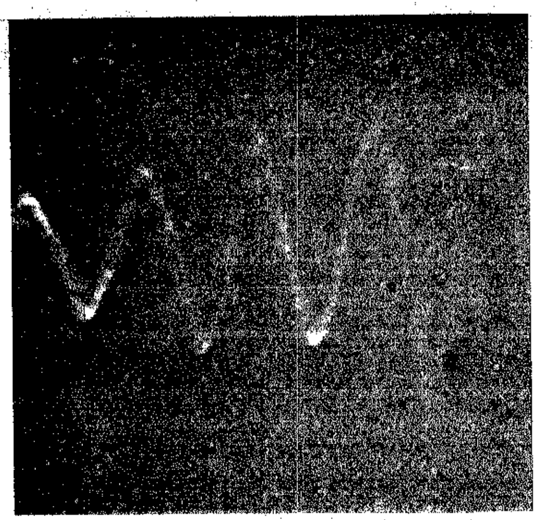
(c)

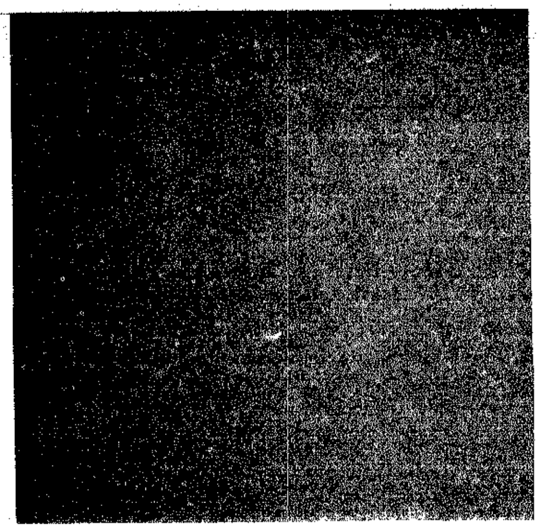
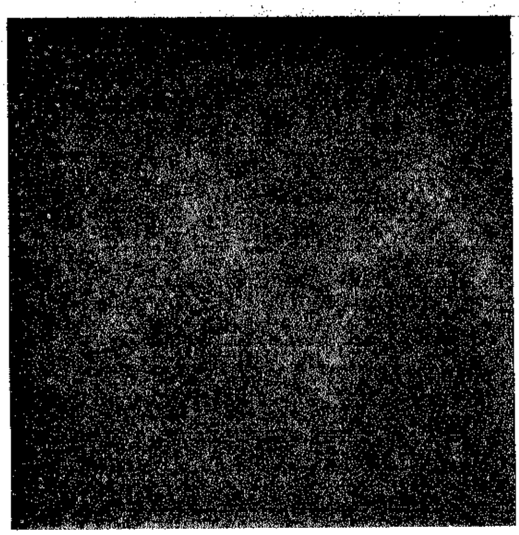
Pressure 750 microns
Current 124 microamps.
Voltage 3550 volts

Oscilloscope settings
1 volt/div.
10 microsec./div.

(d)

Fig. 79--Plasma oscillations for nitrogen tetroxide gas in a tube 1.7 mm. in diameter and 20 cm. in length.



Pressure 750 microns
Current 470 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

(a)

Pressure 750 microns
Current 168 microamps.
Voltage 3550 volts

Oscilloscope settings
0.2 volts/div.
2 microsec./div.

(b)

Pressure 1000 microns
Current 239 microamps.
Voltage 3550 volts

Oscilloscope settings
0.1 volts/div.
5 microsec./div.

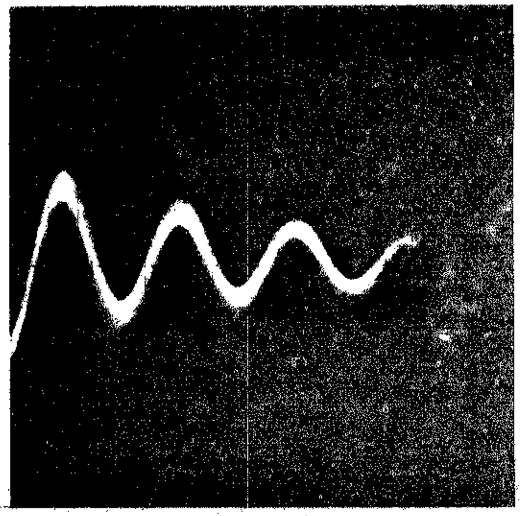
(c)

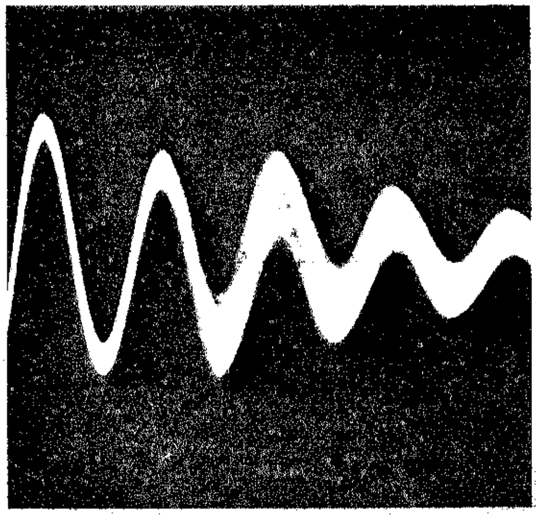
Pressure 1000 microns
Current 122 microamps.
Voltage 3550 volts

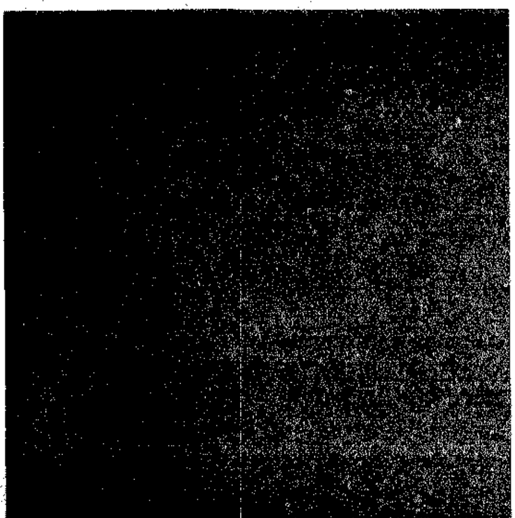
Oscilloscope settings
1 volt/div.
10 microsec./div.

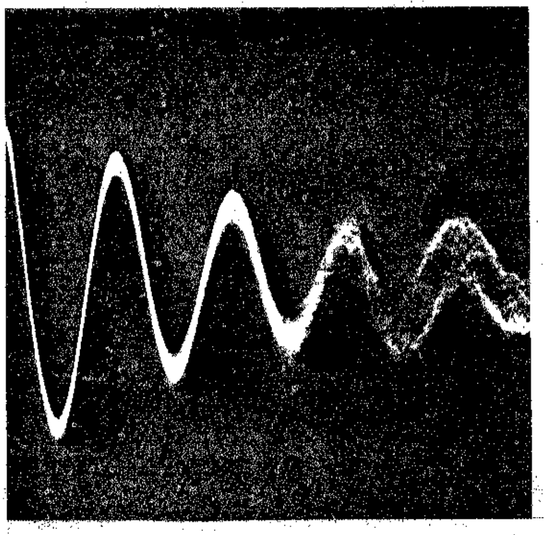
(d)

Fig. 80--Plasma oscillations for nitrogen tetroxide gas in a tube 1.7 mm. in diameter and 20 cm. in length.









APPENDIX II

Tables of the frequency and amplitude of the signals observed for the various plasmas.

TABLE I

PLASMA OSCILLATIONS FOR HELIUM GAS IN TUBES OF 6 mm. DIAMETER AND VARIOUS LENGTHS DISCHARGE TUBES

Length	P	I	V	f	Amp.*
23	250	100	3480	94	11
		70	3000	65	45
	500	90	3220	142	1
		16	2365	57	10
		129	3550	58	7
	750	40	2735	55	10
		90	3050	56	15
	1000	10	2340	50	2
		129	3550	58	8
20	300	74	2455	84	4.6
		19	2250	50	14.2
	600	96	2415	154	0.6
		8	2140	50	10
	900	44	2300	67	0.4
	1000	29	1875	44	26
17	250	49	3105	65	34
	500	2	1900	55	11
		9	3105	170	0.4
		7	2760	67	15
	750	19	2030	60	0.7
		59	2565	100	2
	1000	42	2170	60	6
		9	1840	60	4.8

TABLE I--Continued

Length	P	I	V	f	Amp.*
13	250	6	1700	74	13.5
		31	2140	109	12.0
		100	3040	250	0.3
	500	3	1700	63	8
		6	2150	180	0.7
	750	135	3550	57	8
		17	2000	57	8
	1000	131	3550	55	8
10	300	53	1550	240	1
		139	3550	56	0.02
		21	1300	77	6
		100	2000	34	0.03
		4	1200	57	5
	600	7	1500	50	2
		43	1340	140	1
	900	10	1430	50	6.7
	1200	19	1395	67	2.3
		20	1320	47	2.6
8	300	45	1660	250	0.32
		29	1325	50	7.2
		19	1120	71	2
	600	29	1470	91	0.7
		5	900	100	5
	900	6	1155	100	3.5
		22	1375	61	0.84
		21	1465	100	0.62
	1200	15	1360	53	2.1
		7	1240	100	2.25
6	300	25	1150	200	0.13

TABLE I--Continued

Length	P	I	V	f	Amp.*
6	300	189	3550	57	0.01
		299	3550	910	0.01
	600	6	830	...	6
		18	810	182	0.26
		15	785	95	0.43
	900	12	980	52	1.65
		15	910	50	0.6
		6	870	50	1
	1200	15	1000	364	0.2
		13	940	53	0.4

*Length--Tube length in centimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

TABLE II

PLASMA OSCILLATIONS FOR HELIUM GAS IN TUBES OF 20 cm. LENGTH AND VARIOUS DIAMETER DISCHARGE TUBES

Diameter	P	I	V	f	Amp.*
5.2	300	3	1550	50	10
		103	1500	180	0.56
		8	1635	53	14
		179	2750	67	0.1
	600	0	1860	50	5
		89	1460	147	0.52
		134	2500	192	0.32
		3	1880	56	8.8
	900	2	1750	100	10
	1200	62	1250	111	0.32
3.9	600	20	2550	57	0.12
		135	3550	43	6
	900	135	3250	38	14
		219	3050	263	0.4
	1200	138	2800	57	8
		136	2250	167	0.6
		239	2500	56	0.5
3.5	300	171	2550	278	0.6
		165	2550	80	8
		135	2800	125	3.4
	600	139	2550	54	10
		151	3250	250	0.68
		26	2250	54	11.2
	900	133	2550	200	0.15
2.3	200	133	3550	82	12

TABLE II--Continued

Diameter	P	I	V	f	Amp.*
1.7	300	139	3550	59	10

*Diameter--Tube diameter in millimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

TABLE III

PLASMA OSCILLATIONS FOR HYDROGEN GAS IN TUBES OF 6 mm. DIAMETER AND VARIOUS LENGTH DISCHARGE TUBES

Length	P	I	V	f	Amp.*
23	250	39	2468	54	22
		6	1920	50	10
		79	2875	80	6.4
		26	2385	56	12
	500	9	1960	50	12
		59	2250	54	25
	750	70	2050	74	6.8
		59	2160	54	25
	1000	59	2250	56	25
20	300	21	1770	54	13.6
	600	99	1710	45	0.18
	900	132	1865	50	16
		459	2800	53	0.02
	1200	490	2800	50	0.02
17	300	66	2555	89	4.8
		15	1675	56	11.2
		23	2355	54	10
	600	6	1300	73	8
		89	2050	222	0.18
		57	1830	56	27.5
		41	2050	54	18
	900	80	2110	54	15
	1200	136	2500	64	8
13	300	9	1840	53	4.3
		24	1880	54	12.8

TABLE III--Continued

Length	P	I	V	f	Amp.*
13	300	68	2360	140	2
	600	9	1390	54	8.8
		25	1800	56	11.4
		46	1915	108	2.6
	900	24	1350	60	8.4
		32	1375	81	3.6
		49	1415	152	0.6
		19	1455	53	12.8
		108	1815	265	0.05
		8	1370	43	8.8
		41	1410	51	22
	1200	119	1905	500	0.06
		59	1550	167	0.36
		38	1409	51	16
		19	1402	48	9.6
10	300	5	1540	62	4
		6	1750	50	3
		39	1145	89	3.6
	600	113	1060	290	0.04
	900	No Stable Signals Observed			
	1200	49	800	220	0.18
8	300	11	1495	52	8.4
		11	1610	54	5.8
		19	1750	65	2.8
	600	120	3050	50	4.8
	900	2	1155	50	5.4
		22	1350	52	11.2
	1200	4	1010	...	4
		4	1070	50	6
		31	1480	66	4

TABLE III--Continued

Length	P	I	V	f	Amp.*
6	300	No Stable Signals Observed			
	600	No Stable Signals Observed			
	900	39	780	55	1.2
		132	900	55	0.1
	1200	205	1890	55	0.1

*Length--Tube length in centimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

TABLE IV

PLASMA OSCILLATIONS FOR HYDROGEN GAS IN TUBES OF 20 cm. LENGTH AND VARIOUS DIAMETER DISCHARGE TUBES

Diameter	P	I	V	f	Amp.*
5.2	300	99	2550	99	4.8
	600	223	2500	56	0.27
	900	129	2500	526	0.18
	1200	No Stable Signals Observed			
3.9	300	No Stable Signals Observed			
	600	179	3550	58	10
		166	3250	180	5.4
		110	3325	125	2.2
	900	190	3500	58	16
	1200	179	3550	58	9.2
3.5	300	No Stable Signals Observed			
	600	129	2800	190	0.9
	900	129	2800	183	2.1
		129	2800	210	2
		199	3050	250	0.15
	1200	129	3300	204	0.26
2.3	300	No Stable Signals Observed			
	600	0	3550	52	1.5
	900	129	3050	55	15
	1050	99	3550	79	16
	1200	134	3550	51	16

TABLE IV--Continued

Diameter	P	I	V	f	Amp.*
2.3	1400	69	3350	77	9.8
	1500	129	3350	51	16
1.7	No Stable Signals Observed at Any Pressure				

*Diameter--Tube diameter in millimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

TABLE V

PLASMA OSCILLATIONS FOR DEUTERIUM GAS IN TUBES OF 6 mm. DIAMETER AND VARIOUS LENGTH DISCHARGE TUBES

Length	P	I	V	f	Amp.*
23	300	70	3550	56	47
		20	2455	55	16
	600	60	3050	87	8.5
		9	2010	56	13
	900	50	2600	74	11
		129	2800	125	0.08
		0	1905	590	17
	1200	79	2800	80	12
		89	1500	55	0.4
20	300	10	2190	60	15
	600	100	1880	170	0.6
		75	1990	91	8
	900	90	2750	160	0.5
		80	2500	91	9
		40	2030	50	18
		0	1585	57	10
	1200	90	2180	145	19
		79	2150	83	12
		41	2020	53	20
		40	1990	48	8
17	300	40	3550	50	10
		77	2880	62	22
		20	2130	60	12
		139	1800	270	0.08
		90	3510	110	7
	600	60	2590	59	30
		30	2200	95	6

TABLE V--Continued

Length	P	I	V	f	Amp.*
17	900	31	2500	71	10
		49	2330	87	20
	1200	40	1695	56	30
13	300	79	2500	270	0.4
		76	2300	140	4.8
		29	1550	42	6
		30	1530	62	20
		3	1275	60	8
		180	3550	50	1
	600	70	2765	230	0.8
		40	2230	87	6
		0	1535	57	4
		6	1840	37	7.6
	900	70	2260	185	0.68
		50	1945	98	6
		20	1595	240	8
		0	1450	57	8
		350	3550	59	0.02
	1200	70	1810	175	0.8
		40	1670	91	10
		10	1490	60	12
10	300	59	2190	240	0.34
		34	1780	77	4
		42	1780	95	3
		0	1050	57	5
	600	39	1665	190	0.48
		34	1470	80	5
		10	1120	60	5
	900	39	1680	140	0.8
		30	1640	69	8
		26	1510	57	10
		10	1250	60	7
	1200	35	1660	137	11

TABLE V--Continued

Length	P	I	V	f	Amp.*
10	1200	26	1580	79	9
		24	1500	59	17
		20	1415	45	5
		10	1290	60	10
8	300	20	2095	320	1
		18	1750	71	3
		10	1250	69	2
		0	1125	67	2
		0	860	63	6
		124	3550	200	0.05
	600	29	1880	230	0.6
		10	1540	53	3
		0	1370	87	3
		6	1280	60	6
		212	3550	59	0.02
	900	29	1870	200	0.46
		16	1600	77	2.5
		10	1400	67	2
		10	1340	68	3
		10	1270	60	5
	1200	20	1345	160	0.92
		10	1240	95	3
6	300	20	1860	180	0.19
		14	1325	57	8
		6	1140	57	3
		10	1210	77	1.4
	600	30	1570	190	0.2
		10	1305	60	2.5
		2	1140	40	2
	900	19	1365	175	0.4
		10	1240	130	1
		0	1100	56	6
		4	970	57	3
		10	1175	72	2.5

TABLE V--*Continued*

Length	P	I	V	f	Amp.*
6	1200	10	1290	270	0.6
		10	1130	57	7
		3	1000	60	2
		1	955	67	12

*Length--Tube length in centimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

TABLE VI

PLASMA OSCILLATIONS FOR DEUTERIUM GAS IN TUBES OF 20 cm. LENGTH AND VARIOUS DIAMETER DISCHARGE TUBES

Diameter	P	I	V	f	Amp.*
5.2	300	140	3550	250	0.6
		0	1270	58	6
	600	119	1375	230	7
		0	1300	52	6
		0	1320	60	9.2
	900	0	1105	160	0.06
	1200	120	3550	160	0.1
3.9	300	No Stable Signals Observed			
	600	120	3550	61	15
		110	3290	122	5
	900	129	3550	59	10
		129	3050	160	4
		99	2420	100	5
	1200	121	3050	140	5
		124	2300	190	0.5
3.5	300	120	3550	125	6
		170	3550	280	1
		140	3550	170	4
		690	2390	69	12.5
	600	180	3550	300	0.75
		131	3550	100	4
	900	157	3550	290	1
		140	3050	91	4
		129	2765	59	10
	1200	290	3550	59	8
		130	3550	170	4

TABLE VI--<u>Continued</u>

Diameter	P	I	V	f	Amp.*
2.3	300	170	3550	240	4
		300	3550	29	10
		121	3550	60	18
	600	No Stable Signals Observed			
	900	126	3550	95	6
	1200	127	3550	59	12
		150	3550	185	4
1.7	300	No Stable Signals Observed			
	600	124	3550	175	4
		129	3550	64	12
	900	No Stable Signals Observed			
	1200	182	3550	210	3

*Diameter--Tube diameter in millimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

TABLE VII

PLASMA OSCILLATIONS FOR NITROGEN TETROXIDE GAS IN TUBES OF 6 mm. DIAMETER AND VARIOUS LENGTH DISCHARGE TUBES

Length	P	I	V	f	Amp.*
23	250	360	3550	55	0.12
		140	3550	62	0.4
		60	2570	55	30
	500	122	3550	54	0.15
	750	129	3550	54	0.2
	1000	309	3550	55	0.02
20	250	10	3550	77	20
	500	141	3550	77	0.1
	750	129	3550	57	0.2
	1000	129	3550	80	0.15
17	250	250	3550	55	0.03
		200	3550	315	0.8
		0	2165	54	15
	500	129	3550	53	0.06
	750	129	3550	54	0.15
	1000	129	3550	54	0.06
13	250	20	2550	57	25
	500	310	3550	53	0.15
	750	209	3550	57	0.1
	1000	500	3550	53	0.06
10	250	129	3550	320	0.4

TABLE VII--Continued

Length	P	I	V	f	Amp.*
10	500	No Stable Signals Observed			
	750	290	3550	56	0.07
	1000	479	3550	56	0.04
8	250	230	3550	530	0.08
		140	3550	57	0.1
	500	129	3550	56	0.06
	750	No Stable Signals Observed			
	1000	479	3550	57	0.15
6	250	80	1460	1400	0.02
		40	1140	190	0.4
		10	905	52	4
	500	90	1100	2000	0.03
		124	3550	2000	0.02
		129	3550	57	0.01
	750	320	3550	54	0.04
	1000	200	3550	56	0.03

*Length--Tube length in centimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

TABLE VIII

PLASMA OSCILLATIONS FOR NITROGEN TETROXIDE GAS IN TUBES OF 20 cm. LENGTHS AND VARIOUS DIAMETER DISCHARGE TUBES

Diameter	P	I	V	f	Amp.*
5.2	250	122	3550	77	0.8
		211	3550	350	1.2
		120	2205	400	10
	500	189	3550	370	0.6
		160	3550	240	1
		40	2550	59	17
	750	121	3550	57	0.1
	1000	129	3550	54	0.1
3.9	250	121	3550	185	1.5
		129	3550	195	0.6
	500	129	3550	54	0.06
	750	129	3550	57	0.06
	1000	129	3550	55	0.1
3.5	250	140	3550	165	1.5
		129	2550	117	10
	500	129	3550	54	0.6
		130	1930	55	0.12
	750	129	3550	54	0.4
	1000	129	3550	54	0.3
2.3	250	121	3550	57	10
		210	3550	250	1
	500	235	3550	54	0.6
	750	129	3550	54	0.8

TABLE VIII--Continued

Diameter	P	I	V	f	Amp.*
2.3	1000	129	3550	54	0.6
1.7	250	129	3550	54	5
	500	125	3550	54	3.5
		243	3550	54	0.4
	750	124	3550	54	4.5
		470	3550	54	0.4
		168	3550	260	0.6
	1000	122	3550	54	4
		239	3550	54	0.4

*Diameter--Tube diameter in millimeters

P--Gas pressure in microns

I--Discharge current in microamps

V--Discharge voltage in volts

f--Frequency of signal in kilohertz

Amp.--Peak to peak signal amplitude in volts

REFERENCES

1. Tonks, L., and Langmuir, I., Phys. Rev., 33, 990 (1929).

2. Landau, L., "On the Vibrations of the Electronic Plasma", J. Phys. (U.S.S.R.), 10, 25 (1946).

3. Gabor, D., "Wave Theory of Plasma", Proc. Roy. Soc. (London), A213, 73 (1952).

4. Bohm, D., and Gross, E. P., "Theory of Plasma Oscillations", Phys. Rev., 75, 1851 (1949).

5. Looney, D. H., and Brown, S. C., "The Excitation of Plasma Oscillations", Phys. Rev., 93, 965 (1954).

6. Drummond, J. E., and Chang, D. B., "Unexcited Plasma", Bull. Am. Phys. Soc., 3, 411 (1958).

7. Revens, R. W., "The Transmission of Waves through an Ionized Gas", Phys. Rev., 44, 798 (1933).

8. Alexeff, I. and Neidigh, R. V., Bull. Am. Phys. Soc., 6, 309 (1961).

9. Consoli, T., Legardeaur, R., and Slama, L., "Detection of Stationary Ion Oscillations in a Reflex Discharge with Hot Cathodes", Comp. Rend. 253, 1923 (1961).

10. Crawford, F. W., "Electrostatic Sound Wave Modes in a Plasma", Phys. Rev. Letters, 6, 663 (1961).

11. Alexeff, I., and Neidigh, R. V., "Observations of Ionic Sound Waves in Plasmas; Their Properties and Applications", Phys. Rev. 129, 516 (1963).

12. Woods, L. C., "Density Waves in Low-Pressure Plasma Columns", J. Fluid Mec., 23, 315 (1965).

13. Bertotti, B., Cavaliere, A., and Giupponi, P., "Ion Waves in Bounded Plasma", Phys. of Fluids, 9, 265 (1968).

14. Cavaliere, A., Englemann, F., and Sestero, A., "Propagation of Ion Waves in a Plasma Flow towards a Transonic Point", Phys. of Fluids, 11, 158 (1968).

15. Rosa, R., and Allen, J., "One-Dimensional Ion-Acoustic Modes of Bonded Plasmas", J. Plasma Physics, 4, 195 (1970).

16. Crawford, F., Ewald, H., and Self, S. A., "Low-Frequency Waves and Instabilities on the Positive Column in a Magnetic Field", Phys. of Fluids, 12, 303 (1969).

17. Demokan, O., Hsuan, H. C., Lonngren, K. E., and Stern, R., "Parametric Excitation of Low Frequencies in a Bounded Plasma", J. Appl. Phys., 41, 21222 (1970).

18. Tang, Bun-Shing, "An Experimental Investigation of Plasma Ion Oscillations," unpublished master's thesis, Department of Physics, North Texas State University, Denton Texas, 1973.