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The effect of plasma boundaries on the frequency of oscillations of a gas plasma in a static magnetic field was determined by means of a cylindrical diode discharge tube in which the length of the cylindrical plasma was controlled by movable metal discs which functioned as boundary electrodes. The variable plasma dimension was parallel with both the magnetic field lines and the axis of the cylinder.

It was found that the electrode spacing, and thus the plasma volume, could be varied by 70 per cent, or more, without altering the oscillation frequency. Larger changes in electrode spacing sometimes caused a shift in frequency due to the limitations of the experimental apparatus. The data obtained indicate that plasma oscillations can exist without the formation of standing waves in the direction of the magnetic field lines and that if standing waves are formed they have little if any effect on the oscillations.

THE EFFECT OF PLASMA VOLUME ON THE FREQUENCY OF PLASMA OSCILLATIONS

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THE EFFECT OF PLASMA VOLUME ON THE FREQUENCY OF PLASMA OSCILLATIONS

INTRODUCTION AND THEORY

The term plasma is used to denote a gas with an appropriately high concentration of free positive and negative charges in equal numbers. A plasma oscillation is defined as a vibratory motion of either the positive or the negative charges within the plasma. This thesis is concerned with a study of the effect of plasma boundaries on the frequency of these oscillations.

Plasmas occur in the ionized atmospheres of the stars and planets. Many of the radio waves reaching the earth from the sun and other parts of the galaxy are thought to be generated by oscillations in these plasmas. Analysis of these radio waves may yield information on the magnitudes of the charge densities and magnetic fields throughout the galaxy when the fundamental mechanisms governing these oscillations are more fully understood. Plasmas can also be created in gaseous discharge tubes for laboratory study and can be used as generating sources for ultra-high frequency radio waves. Plasma oscillations have also been investigated as a possible case of the reflection of radio waves from the ionosphere (13, pp. 1-43).

There is considerable disagreement concerning the factors that influence the oscillation frequency and the radiation of energy. Langmuir and Tonks (16, pp. 195-210) have studied plasma oscillations both experimentally and theoretically and conclude that the frequency is dependent only on the mass, charge and charge density of the oscillating particles when there is no magnetic field in the plasma. They also believe there is no natural frequency for electromagnetic oscillations in an infinite medium and that these oscillations, and the radiation accompanying them, can only exist when standing waves are established in the plasma by reflection processes at the plasma boundaries. Others (11, pp. 26-28) (15, pp. 752-754) agree with Langmuir and Tonks on the parameters controlling frequency but believe that oscillations resulting in electromagnetic radiation can be established in an unbounded medium without the formation of standing waves. Bohm and Gross (2, pp. 1851-1864) (3, pp. 1864-1876) and Bailey (1, pp. 421-443) studied plasma oscillations theoretically and concluded that oscillation frequency will be dependent on the magnetic field strength as well as on the mass, charge and charge density of the oscillation particles.

They also predict that oscillations can be established and maintained without the formation of standing waves in the plasma.

One of the fundamental questions concerning the mechanisms governing plasma oscillations is thus whether or not standing waves are necessary before the oscillations can be maintained. Also it is not known what effect the spacing and geometry of plasma boundaries have on the frequency of these oscillations. It was in the hope of obtaining experimental data to answer these questions that this thesis problem was chosen.

It is the high mobility of the electrons in the plasma that makes ultra high frequency oscillations possible. The charges tend to orient themselves in such a way as to shield out any electric fields and thus form a field free region. If, for example, there were an excess of electrons in a given region they would repel each other and some would move out of the region. By the time that neutrality had been established the electrons would have an outward velocity and would continue on, thus leaving a deficiency of electrons that attracts them back into the region. In time their direction of motion would be reversed and an oscillation of definite frequency would be established.

The existence of these oscillations was first suspected because of data obtained in studying the energy distribution of electrons in a low pressure mercury arc. Langmuir (9, pp. 585-613) and Dittmer (5, pp. 507-520) had observed that some of the primary electrons acquired more energy than they should have obtained from the voltage applied across the discharge tube. They postulated that electrical oscillations were present in the discharge and that some of the electrons gained energy from these oscillations while others lost energy to them. In order to verify this theory Tonks and Langmuir (16, pp. 195-210) made the first careful study of plasma oscillations.

They used a mercury vapor discharge tube that had a hot filament as an electron source. The tube had a collector, so placed so that it would intercept part of the primary electron beam, and an anode placed off to one side to maintain the discharge. They made some of their measurements on the collector and some by using a small circular metal plate fastened to the outside of the tube wall. Either the collector or the external plate was then connected to an external circuit that could be tuned to the oscillation frequency; the oscillation was then measured by using a zincite-tellurium detector and a galvanometer.

Tonks and Langmuir investigated the oscillations of both electrons and ions. The ions oscillate at a much lower frequency, since the frequency is inversely proportional to the mass of the individual charged particles. Their experimental data on each of the two types of oscillations agreed well with their theory.

They derived for the frequency of the oscillations, an equation $\omega = \left(\frac{4\pi ne^2}{m}\right)^{\frac{1}{2}}$ where n is the charge density m the mass of the individual charged particles and e the electronic charge, all in cgs units. This equation was derived by two different, although very similar, methods. In one method they assumed an initially uniform charge density and then displaced each charge in the x direction, the displacement being a function of the coordinates of the region. They then solved Poisson's equation,using the continuity of charge equation and Newton's second law, for the new charge distribution and obtained an equation describing simple harmonic motion at the above frequency. In the second method they derived the oscillation frequency by solving Maxwell's electromagnetic equations. In both derivations the equation $\ddot{E} + \frac{4\pi ne^2}{m} E = 0$ was obtained. This is the equation for simple harmonic motion, but the absence of space coordinates shows that the group velocity is zero so that there is no tendency for the oscillations to propogate through the plasma.

Langmuir and Tonks also state that there is no natural frequency for the electromagnetic oscillations in an infinite medium. They predicted that radiation will occur only when reflection from tube walls or other boundaries establishes standing waves in the plasma. In this case there would be a fundamental resonance frequency and a series of overtones so the radiation frequency would be dependent on the geometry of the plasma boundaries.

Schklovsky, (15, pp. 752-754) however, believes that plasmas without definite boundaries, such as those found at the sun's surface, will radiate energy at the frequency predicted by Langmuir and Tonks. He has studied radio waves reaching the earth from various parts of the galaxy and attributes these to plasma oscillations. Martyn (11, pp. 26-28) has also studied solar radiation and found that in the presence of a magnetic field a plasma possesses two natural periods of oscillation, both being defined by the condition that the dielectric constant of the medium is zero. He believes that there will be considerable radiation due to collisional friction but does not give any details of his experiments or derivations in his paper.

V. A. Bailey (1, pp. 421-443) also believes that plasma oscillations and resultant energy radiation can occur without the existence of standing waves in the plasma. He has developed a theory on the origin of solar radio noise by the mathematical analysis of a plasma in a static magnetic field. In his analysis he used Maxwell's electromagnetic equations, the equation of continuity, and Maxwell's transfer equations to define the conditions in the plasma. He used the general transfer equation which describes momentum transfers in a mixture of different kinds of particles where the particles are also subject to fields of force. These transfer equations are only a first approximation of the exact laws governing momentum exchanges but, as Bailey points out, the exact laws are very complicated, and in the cases that have been rigorously studied it has been shown that these transfer equations are very good approximations.

Using the equations mentioned above, and assuming that the collision frequency was much less than the plasma frequency, he derived the following dispersion equation by choosing his coordinate system so the xy plane contained the direction of the drift velocity and the wave propogation was in the x direction.

$$(\omega^2 + P_o^2)\left[\omega^2(Z+P_o^2)^2 - \Omega_x Z^2\right] - (\Omega_y^2 + \Omega_z^2)\,\omega^2 Z(Z+P_o^2) = 0$$

ω = angular wave frequency

P_o = angular plasma frequency derived by Tonks and Langmuir

$Z = C^2L^2 - \omega^2$,

C = velocity of light

L = angular wave number

$\Omega_o = \frac{e}{mc} H$, the angular electron gyro frequency

$\Omega_x, \Omega_y, \Omega_z$ = components of Ω_o

By solving this dispersion equation Bailey was able to predict some frequency bands where circularly polarized electromagnetic waves will grow in a plasma which is in a magnetic field and in which the plasma electrons have a finite drift velocity. The growth will be a maximum when the magnetic field, electron drift and the wave propagation directions coincide. The initial drift kinetic energy of the plasma electrons is ultimately converted into oscillatory kinetic energy and radiated transverse wave energy.

The frequencies, and relative amplitudes of radio waves from the sun can be measured quite accurately. From various other lines of investigation the approximate values of the charge density and magnetic field strength in the sun's atmosphere have been determined. Bailey found good agreement between his theory and what is known about solar radio noise and the sun's atmosphere.

Andrew Haeff (7, pp. 1546-1551) also published a theory on the origin of solar radio noise in which he considers the intermingling of two or more beams of charged particles with different energies. He shows that the space-charge-wave interaction in streams of charged particles could lead to an exponential amplication of any initial perturbation as the disturbance propagates along the stream.

Haeff derived the equation for the total energy that could be radiated from two interacting beams of different current and energy and found that $P = \frac{1}{2} (V_1 - V_2)(I_1 - I_2)$ where P is the total energy that can be radiated, V_1 and V_2 equal the voltage equivalent of the particle energy in beams one and two respectively. The currents in beam one and two are I_1 and I_2 respectively.

The energy that is radiated comes from the kinetic energy of the beam particles so that the total kinetic energy of the electrons would decrease with time. His calculation showed that the oscillations should occur over a broad band, with the maximum amplitude at the frequency $\omega_o = \frac{\sqrt{3}}{2} \omega \frac{V}{\delta}$ where δ is the electron plasma frequency, V the average velocity of the beam particles and δ half of the difference in velocity of the electrons in the two beams.

Bailey has pointed out that in correlating Haeff's theory with experimental knowledge of solar radio noise it is necessary to assume an electron density about one millionth of the value that is believed to be correct. He also points out that there is no Poynting Flux associated with the oscillations predicted by Haeff.

Bohm and Gross (2, pp. 1851-1864) (3, pp. 1864-1876) (4, pp. 992-1001) have published several papers dealing with the theory of plasma oscillations. In their first two papers they investigated the behavior of plasma oscillations in an unbounded medium with zero magnetic field. In these they considered only longitudinal oscillations that do not radiate energy. A brief summary of these results therefore should be sufficient for the present work.

Any given particle in a plasma is subject to rapidly fluctuating forces due to interactions with other particles. Bohm and Gross found that the problem was too complex to solve unless they considered only large aggregates of particles and used an average electric field. They derived a dispersion equation by substituting a wave equation type of solution for the potential in Poisson's equation. From this dispersion equation they calculated the frequency of the oscillations as being $\omega^2 = \omega_p^2 \quad \left(\frac{3KT}{M}\right) K^2$

where ω_p is the plasma frequency and $K = \frac{2\pi}{\lambda}$.

They also studied damping due to collisions in the plasma and found that at the pressures and electron densities typically encountered in discharge tubes the inter-collision time may be of the order of a thousand times the period of oscillation. The time necessary for the intensity to fall to $\frac{1}{e}$ of its initial intensity is equal to the collision time, provided that no further energy is gained by the oscillation.

In a discharge tube the plasma is bounded by the electrodes and walls of the tube. These boundaries, except for the anode, will have positive ion sheaths formed near their surfaces, the thickness of the sheath being dependent on the tube geometry, the applied potential and the mass, average velocity and density of the positive ions in the plasma. In their third paper Bohm and Gross investigated the effects of these boundaries, and the possibility of setting up standing waves in the plasma by electrons reflected from the positive ion sheaths.

A plasma electron has a velocity that can be conveniently thought of as the sum of two velocities, its average velocity and its periodic perturbed velocity. To make a node of the electric field and an antinode of the potential at the plasma edge the perturbed velocity of the electron after reflection should be the negative of its perturbed velocity before reflection. This is not always the case, however. The electrons will penetrate the sheath to a depth that is dependent upon their energy, and any perturbation in velocity they have when striking the sheath may lose its coherence with the wave before they get back out. It is possible that they will be reflected in such a way that they will be out of phase with the wave and tend to damp out the oscillations instead of building up standing waves. Bohm and Gross found that damping arising from imperfect reflections from the electrode sheaths could be comparable with collision damping.

For the special case where the boundary in question is a grounded metal electrode the conditions are different since the potential is always zero at the boundary. Bohm and Gross had previously shown that in the case where there are bounding electrodes on which the charge does not vanish any solution of Laplace's equation yields the complementary function part of the solution of the plasma equations. In investigating the case for grounded metal electrodes they used Laplace's equation and added suitable solutions so the potential and the electric field would vanish at the boundaries. They found that damping due to imperfect reflection from metal electrodes was negligible compared to collision damping.

Gross (6, pp. 1-30) investigated plasma oscillations in a static magnetic field and obtained a dispersion relation from the solutions of Boltzmann's equation of continuity in phase space and Maxwell's equations. The transport treatment, as used by Bailey, gives only approximate solutions to the problem while the Boltzmann equation gives exact solutions. Gross compared the results obtained by the two methods and showed that the transport method does not predict either heavy damping near the Debye wavelength or gaps in the frequency spectrum at multiples of the cyclotron frequency, while the solutions of Boltzmann's equations do.

The distribution function $f(x_1\ v_1\ t)$ gives the average number of particles in a small range of position and velocity at any given time. The distribution function varies with time, the variation being described by the Boltzmann equation,

$$\frac{\partial f}{\partial t} + V \cdot \nabla f + \frac{e}{m}\left(E + \frac{V \times H_0}{c}\right) \cdot \frac{\partial f}{\partial t} = \left.\frac{\delta f}{\delta t}\right|_{coll.}$$

where H_0 is the static magnetic field and E is the electric field arising from both the impressed electric fields and from charges in the plasma.

The forces that act on a particle in the plasma can be divided into two general classifications. The first type are the short range forces that involve large momentum changes as an electron is involved in a collision with a neutral atom. This force is taken into account by the term on the right in the Boltzmann equation. The second classification includes the long range coulomb forces coming from other charged particles in the system. An electron is thus engaged in a many body collision with a large number of distant particles, but only a very small momentum transfer is exchanged between two particles. The first type of force tends to damp the oscillations, but the second type depends upon the distribution function and gives rise to the characteristic properties of the plasma.

Gross then used the dispersion equation

$$(\omega^2-\omega_p^2)(\omega^2-\omega_p^2-c^2K^2)-\omega_c^2(\omega^2-c^2K^2)=0$$

and solved for the oscillation frequency. For the general case where ω_p and ω_c are small compared to CK he found two sets of waves, the longitudinal plasma waves and the transverse electromagnetic waves. The frequency of the plasma waves is $\omega^2 \simeq \omega_c^2 + \omega_p^2$; that of the electromagnetic waves $\omega^2 \simeq c^2 k^2 + \omega_p^2 + \frac{\omega_p^2 \omega_c^2}{c^2 k^2}$. Gross did not consider standing waves in his derivation so these oscillations can exist in an infinite medium.

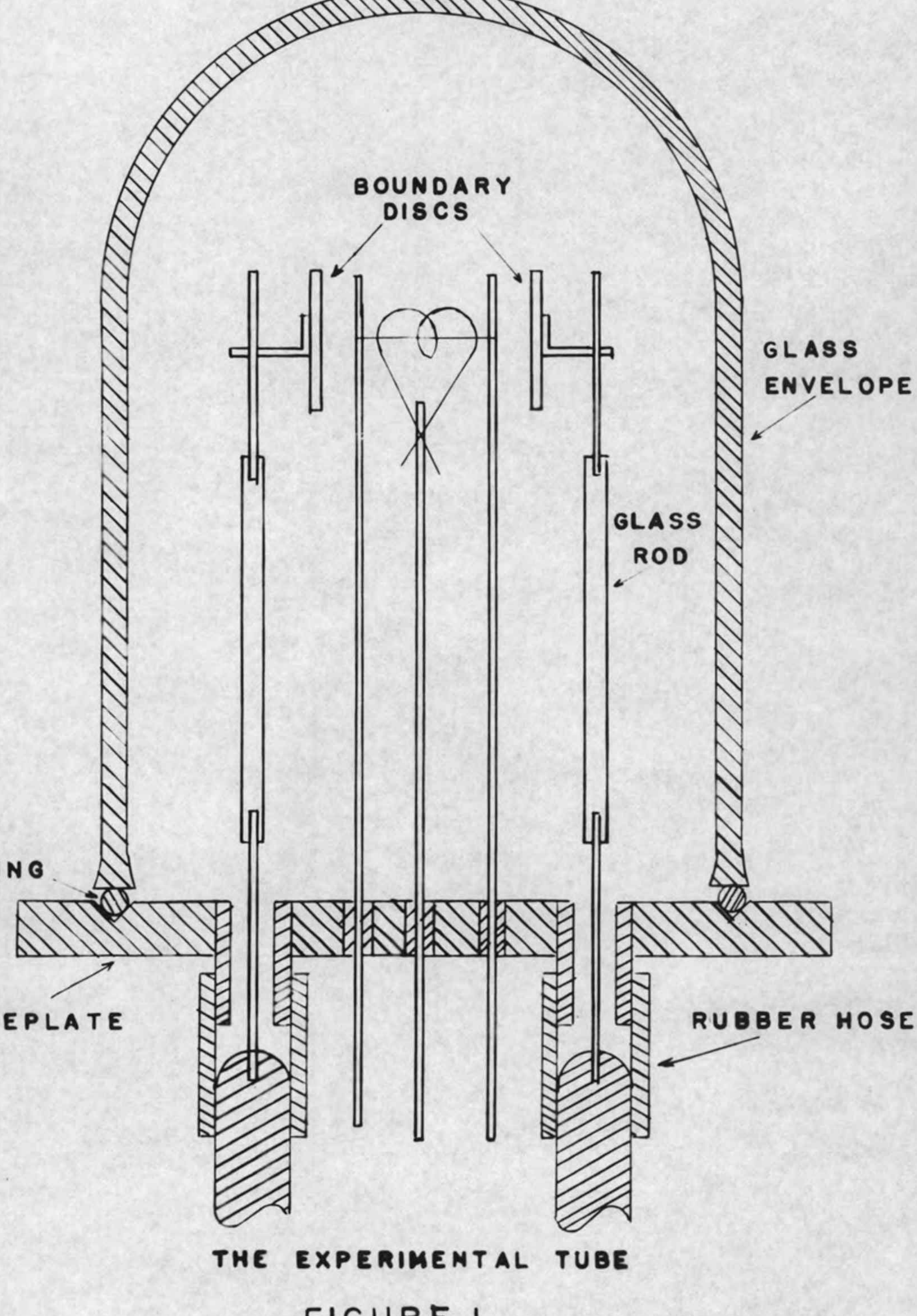
APPARATUS AND PROCEDURE

The tube used in these experiments was a cylindrical diode with two movable molybdenum discs that limited the length of the cylindrical plasma. A schematic representation of the tube is shown in Figure 1. The two turn helical anode, made of molybdenum wire, was 8 millimeters in length and 9 millimeters in diameter. The axial filament was a 10 mil tungsten wire spot welded to 40 mil tungsten supports.

The filament deteriorated rapidly when the tube was in operation so that it was necessary to construct a tube that could be dismounted readily for filament replacement. This was accomplished by using a rubber O ring, coated with vacuum grease, as the seal between the glass envelope and the brass baseplate. A clamp was installed to force the glass envelope down against the O ring. A circular groove, whose diameter was the same as the diameter of the glass envelope, was machined in the baseplate to secure the O ring and obtain a good seal. The baseplate was also fitted with appropriate glass-to-metal seals so that electrical connections could be made to the anode and the filament.

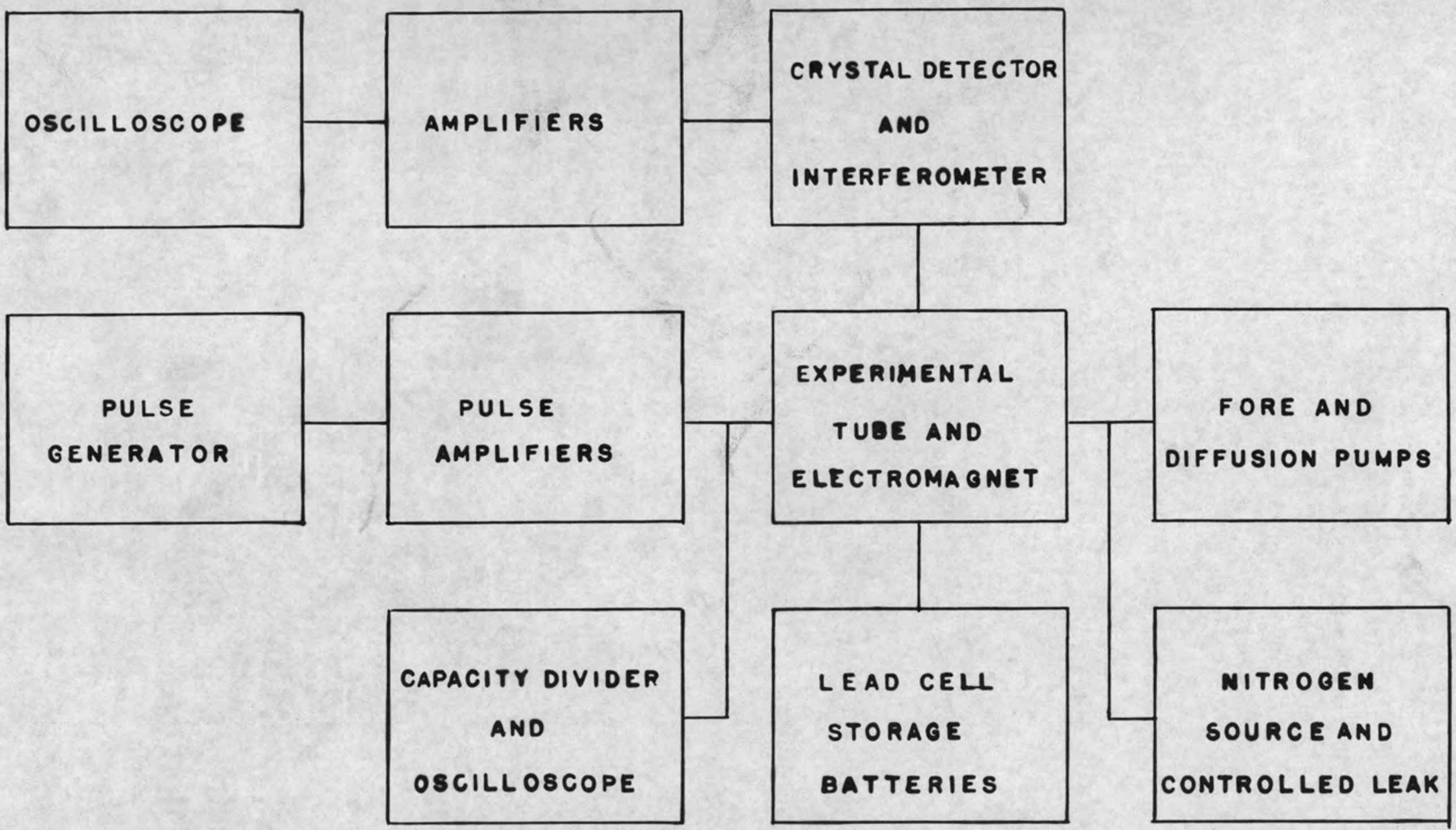
The molybdenum discs, which functioned as boundary electrodes, were supported in such a manner that the distance between them could be continuously varied from 20 to 50 millimeters. Two holes were drilled in the baseplate and a short piece of copper tubing inserted in each hole. The tubes were soldered to the baseplate so that their upper ends were flush with the top of the baseplate, their lower ends extending about three-fourths of an inch below. Each of the molybdenum discs had its own support rod; each rod was made in three mechanically connected sections. The center section of each rod was a glass tube and the upper and lower sections were each 40 mil tungsten wires sealed in the ends of the glass tube. The lower tungsten wire extended down through one of the copper tubes and was connected to a brass rod. A short piece of rubber hose was used to connect the brass rod to the copper tube. This connection was sufficiently flexible to make the boundary discs easily movable while the desired pressure was maintained in the tube. A block diagram of the experimental equipment is shown in Figure 2.

A dipole crystal detector was constructed from a 1N26 crystal cartridge and placed directly above the experimental tube. The dipole output voltage was amplified and applied to the vertical deflection plates of an oscilloscope. Three separate broadband amplifiers



THE EXPERIMENTAL TUBE

FIGURE I

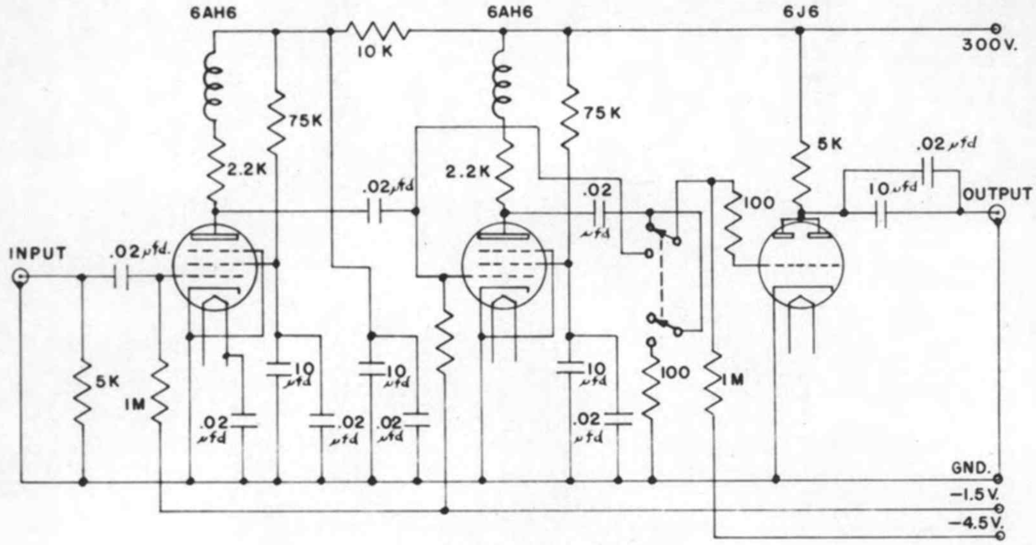


BLOCK DIAGRAM OF THE EXPERIMENTAL EQUIPMENT

FIGURE 2

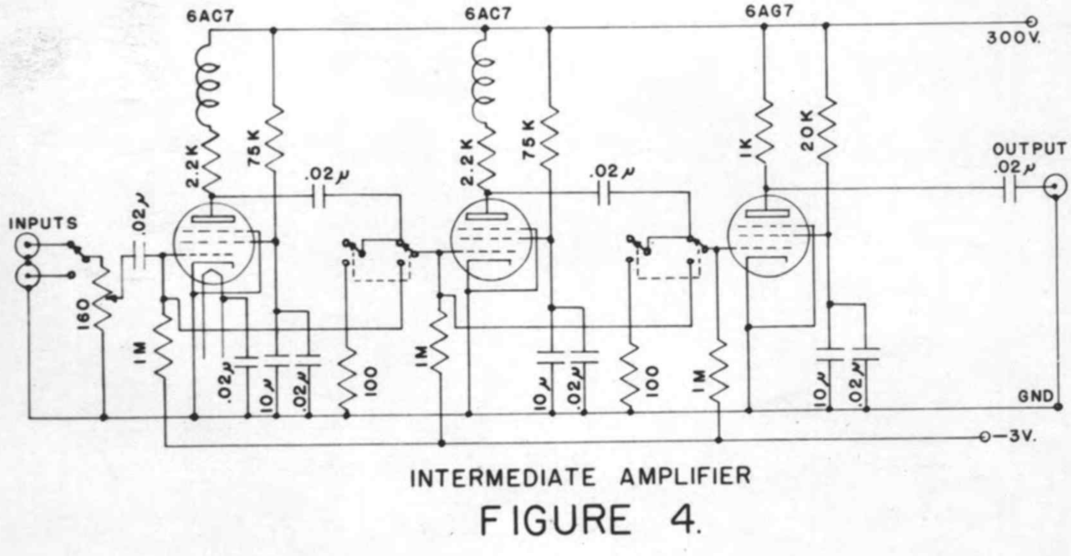
were used to obtain sufficient gain. The first amplifier, shown in Figure 3 and designated as the pre-amplifier, had a gain of either 20 or 400 depending on the switch position. The pre-amplifier and the intermediate amplifier, shown in Figure 4, had two megacycle bandwidths, the gain of the intermediate amplifier was continuously variable from 2 to 400. The vertical deflection amplifier of the oscilloscope was also used and had a voltage gain continuously variable from 1 to 100. The total gain of the system was thus variable from 40 to 1.6×10^6.

An interferometer, utilizing a horizontal aluminum plate, movable vertically, was used to measure the radiation wavelength. The metal plate was directly above both the detector and the experimental tube and could be moved up or down by means of a motor driven drum and cable. As the plate moved the output of the detector would go through maxima and minima because of interference between the radiation directly from the tube to the detector with that reflected back from the metal plate. A selsyn circuit synchronized the movement of the plate with dials on the console panel. The dials were calibrated to read the wavelength directly in millimeters when five successive minima were obtained by the vertical motion of the plate.



PRE AMPLIFIER

FIGURE 3.



INTERMEDIATE AMPLIFIER

FIGURE 4.

A Cenco No. 79,650 electromagnet was used to produce the magnetic field. The experimental tube was placed between the pole pieces of the electromagnet with the axes of the filament and anode parallel to the lines of magnetic force. The magnetic field was continuously variable from 0 to about 2000 gauss, the current for the electromagnet being supplied by 5 six volt storage batteries connected in series.

A rotating coil and a microammeter were used to measure the magnetic field strength. The coil was mounted at the end of the shaft of a synchronous motor and placed in the magnetic field. The voltage output from the coil was then rectified and applied to the microammeter which was calibrated to read the field strength directly in gauss. The coil is mounted inside the motor shaft cover of the assembly shown in Figure 6.

A photograph of the experimental equipment is shown in Figure 5. The experimental tube is shown between the pole pieces of the electromagnet at A. The control and indication circuits for the vacuum system are mounted on the front panel of the table which supports the magnet. The fore pump and the oil diffusion pump are located under this table. The two oscilloscopes, the monitoring instruments and the controls are located on

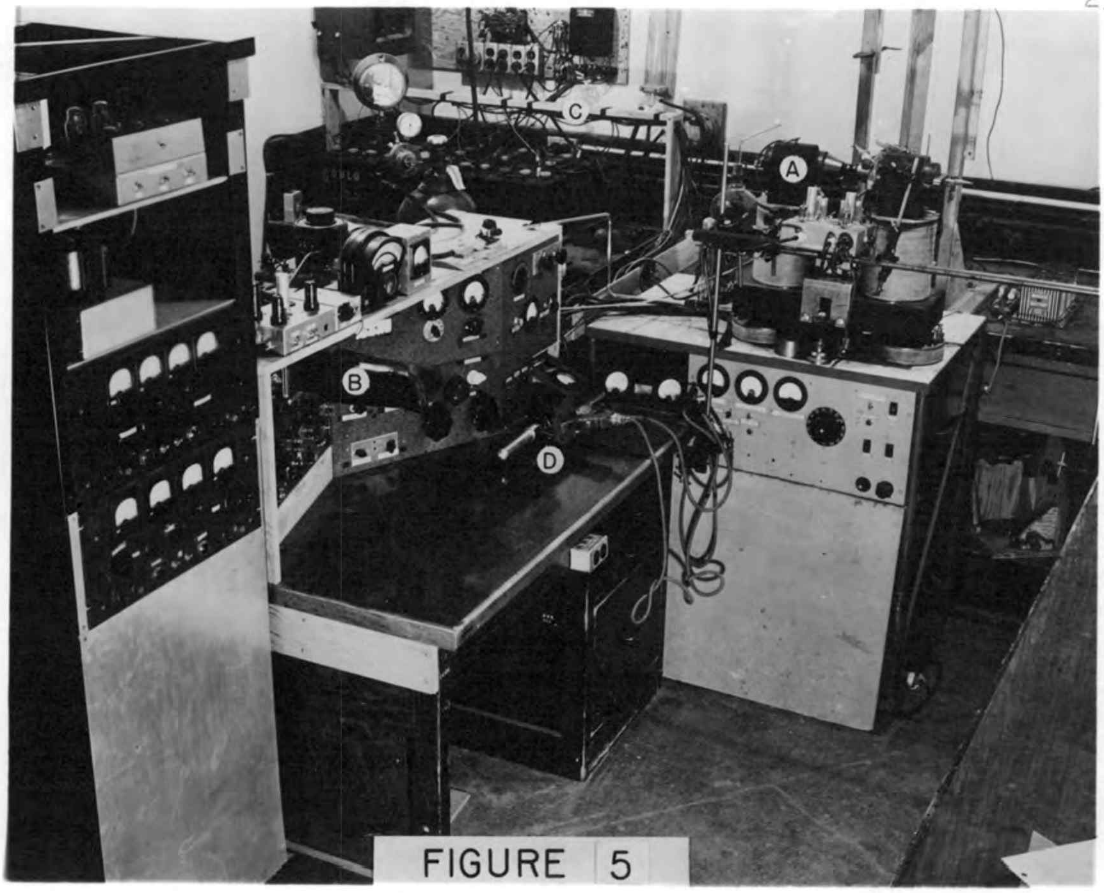


Fig.5 Photograph of the Experimental Equipment.

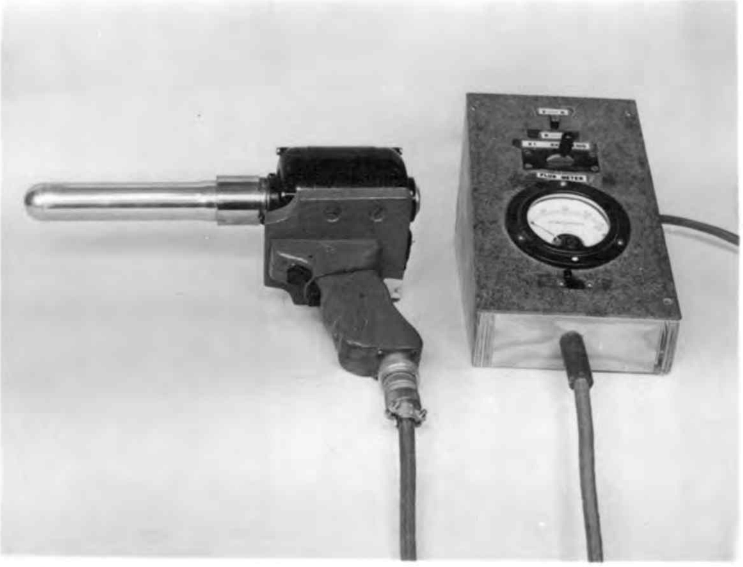
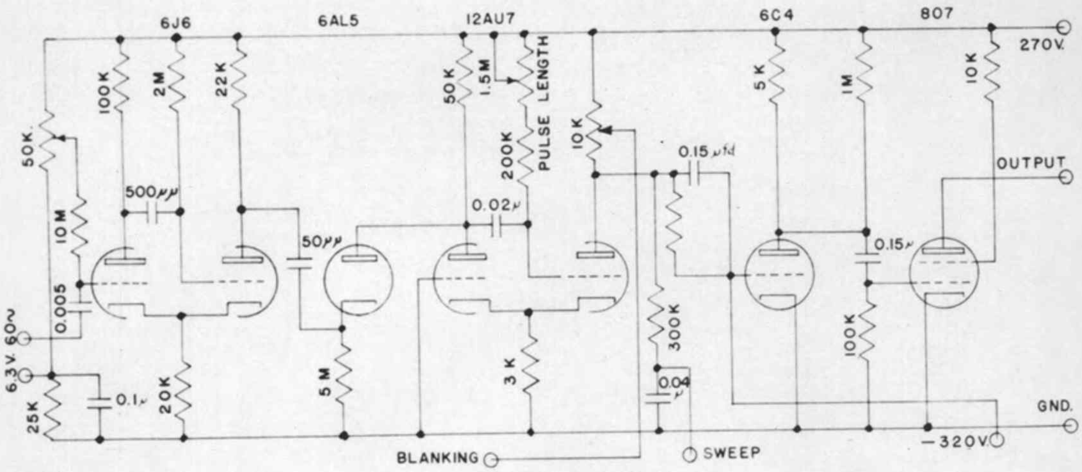


Fig. 6 Equipment for Measuring the Magnetic Field.

the main console panel at B. The pulse power amplifier and power supplies are located in the rack at the left. The lead cell batteries that supplied the current for the experimental tube filament and the electromagnet are shown at C and the motor and meter used to measure the magnetic field strength at D.

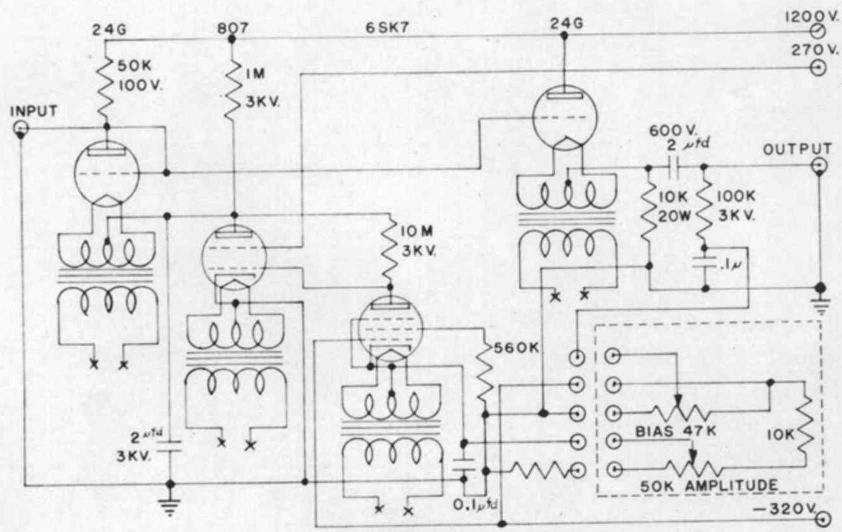
The tube filament was held at ground potential and positive voltage pulses applied to the anode at a repetition frequency of 15 cycles per second. The pulse amplitude could be varied continuously from 0 to 1200 volts, the pulse duration from 120 to 1000 microseconds. The pulse generator and driver units are shown schematically in Figures 7 and 8. The output of the pulse amplifier, shown in diagram in Figure 9, is applied to the anode of the experimental tube. The amplitude of the voltage pulse and the average plate current are measured by use of the monitoring equipment shown in Figure 10. The sweep circuits of both oscilloscopes were triggered from the pulse generator to synchronize the sweeps with the voltage pulse.

It was necessary to have the gas pressure in the tube variable from 2 or 3 microns to about 50 microns. This was accomplished by using a fore pump and diffusion pump in conjunction with a manually operated control valve that allowed nitrogen to leak into the system.



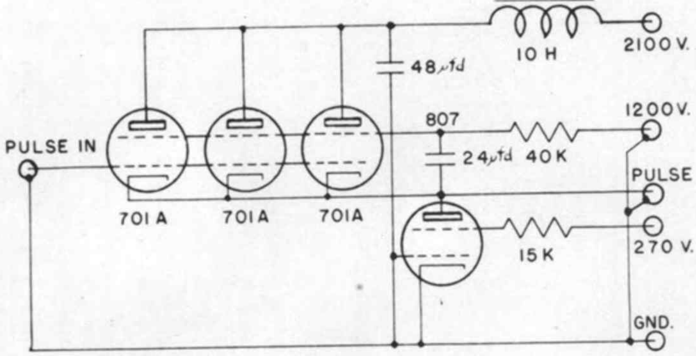
PULSE GENERATOR

FIGURE 7.



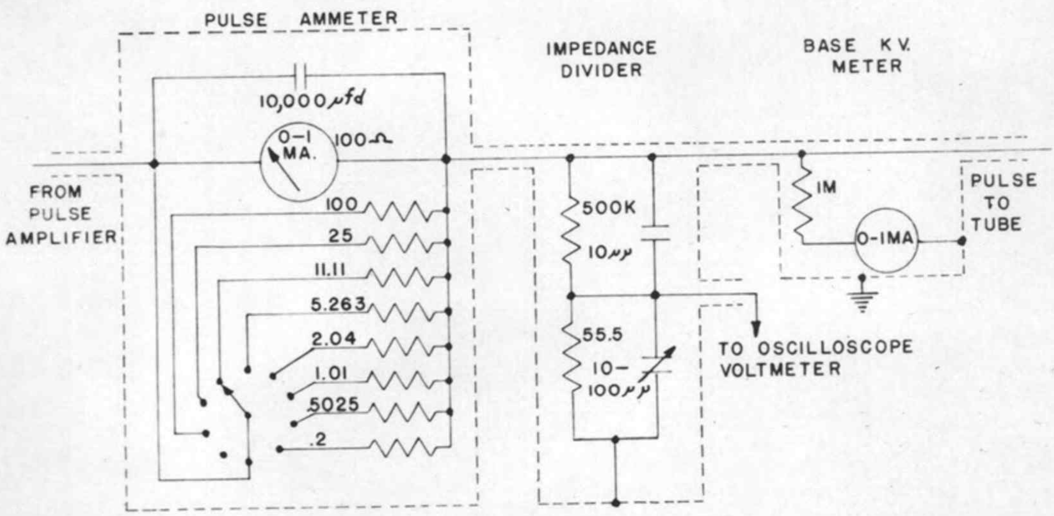
PULSE DRIVER

FIGURE 8.



PULSE POWER AMPLIFIER

FIGURE 9.



MONITORING EQUIPMENT

FIGURE 10.

A Cenco Megavac fore pump and a Distillation Products Type GF-25W three stage fractionating pump were used. The cylinder of compressed nitrogen was connected to the vacuum system with a rubber hose. A 15 mil bronze wire was placed in the hose and a pinch clamp used to control the gas leak thus maintaining the desired pressure. A Sylvania Type R-1111 Pirani gauge was usually used for measuring the pressure, but there was also a Distillation Products Type VG-1A ionization guage for measuring higher vacua.

The filament current, magnetic field, pressure, and voltage amplitude were all independently and continuously variable so all of the combinations of these variables that produced oscillations could be investigated. The spacing of the boundary electrodes was varied over the range from 20 to 50 millimeters for each oscillation encountered.

EXPERIMENTAL RESULTS AND SUMMARY

The purpose of this thesis was to investigate experimentally the effect of boundary electrode spacing and standing waves on the frequency of plasma oscillations. The plasma dimension parallel with both the anode axis and the magnetic field lines was chosen as the variable since previous experimental work conducted under a United States Air Force contract indicated the oscillation frequencies were not dependent on the diameter of the cylindrical anode.

There were four variables other than the electrode spacing; the filament current, anode potential, pressure, and magnetic field were all independently and continuously variable. The oscillation frequency could be changed by varying any of these four parameters, but the frequency of the observed radiation was not continuously variable. Only certain discrete frequencies were observed and these could be obtained for only certain combinations of the four experimental parameters.

Two experimental methods were used to investigate the effect of the boundary electrode spacing on the oscillation frequency. In the first method the electrodes were initially placed so the spacing was a minimum. A stable oscillation was then obtained by varying the four parameters mentioned above. The frequency of the oscillation was measured and then the electrode spacing was slightly increased and the frequency was again measured. This process was continued until the electrodes were as far apart as experimental conditions would permit. The electrodes were then moved back to their original position and the frequency was again measured to make sure that the plasma conditions had not altered with time. This was necessary because the filament diameter was decreased by evaporation and ion bombardment causing the filament temperature to increase with time. Only reproducible data were retained and all variables other than electrode spacing were held constant as any given frequency was investigated.

In all cases the spacing could be increased by 70 per cent without changing the oscillation frequency. As the spacing was further increased, however, the oscillation became increasingly unstable and at still greater spacing there was no detectable radiation. In a few cases there would be a range of spacing in which no radiation could be detected and then, as the spacing was further increased, another oscillation of lower frequency would be observed.

The fact that the oscillations were not dependent on standing waves is shown in two ways. First the spacing could be continuously increased over a relatively wide range without changing the oscillation frequency, and secondly the original frequency could always be obtained by increasing the filament current regardless of the spacing. Presumably both the loss of the oscillation and the change in frequency were due to a decrease in charge density as the plasma volume was increased while the emitting area and temperature of the filament remained constant.

Data taken by this method are shown in Table 1. The values of the filament current, pressure, anode potential and magnetic field are shown as well as the range of electrode spacings in which the frequency was unchanged. There are three cases shown in the table where a lower oscillation frequency was obtained at large electrode spacing. These can be identified since all of the variables have the same value except the frequency and electrode spacing.

In the second experimental method the electrode spacing, pressure, anode potential and magnetic field were held constant while the filament current was varied and the frequency of each observed oscillation measured. The electrode spacing was then increased,

TABLE 1

Wave-length	Filament current	Anode Potential	Magnetic field	Pressure	Electrode spacing
15 *	7.60 Amps.	500 volts	935 Gauss	15 microns	20-38 *
17	7.60	500	935	15	45-50
26	7.45	500	935	15	20-40
35	7.40	500	935	16	20-45
30	7.10	700	1150	20	20-35
35	7.10	700	1150	20	42-50
44	7.05	750	1150	40	20-35
35	7.05	750	935	15	20-40
21	6.80	1000	935	18	20-35
26	6.80	1000	935	18	45-50
32	6.70	500	580	11	20-40
37	6.50	500	750	11	20-45
35	6.40	500	665	7	20-40
37	6.00	700	665	19	20-45
39	6.05	500	580	11	20-40

* The wavelengths and electrode spacings are given in millimeters.

but the magnetic field, pressure and anode potential were held at their original values. The electrodes remained fixed in their new positions while the filament current was again varied and the frequency of each observed oscillation was measured. This process was repeated for several different electrode spacings.

It was found that the same set of frequencies were observed for all values of the electrode spacing. It was further observed that the same value of filament current was necessary to obtain a given oscillation frequency for all electrode spacings less than approximately 40 millimeters. For spacings 40 millimeters or greater the same set of frequencies were observed but a slightly higher filament current was necessary to obtain any given frequency. Only longer wavelength oscillations, which are obtained at low filament temperatures, could be investigated in this manner since at higher temperatures the filament diameter decreased rapidly and it was not possible to make direct comparisons of the different values of filament current.

The data acquired by the latter experimental method agrees with the data obtained by the first experimental method. It is assumed that the charge density in the plasma decreased as the electrode spacing and plasma volume are increased and that the higher filament currents are necessary at the larger spacings to raise the filament temperature enough to compensate for this decrease.

The data shown in Table 2 were obtained in this manner. The data are shown in the time sequence in which they were obtained. The reproducibility of the data, as shown at the bottom of the table, indicates that the change in filament current was due only to the increased electrode spacing.

If the oscillations and radiation could occur only when standing waves were established in the plasma the oscillation frequency would be critically dependent on the plasma geometry. Since the frequency was found not to be dependent on the boundary electrode spacing it is apparent that the oscillations can exist without the formation of standing waves in the direction parallel to the magnetic field. The amplitude of the oscillations was relatively unstable, varying by as much as a factor of 3 with time. Because of this instability it was not possible to check for the formation of standing waves by amplitude variations as the electrode spacing was varied. It can be concluded, however, that if standing waves were formed their effect on the amplitude was not large compared to the normal fluctuation with time.

TABLE 2

Wave-length	Filament current	Anode Potential	Magnetic field	Pressure	Electrode spacing
120 *	6.65 Amps.	500 volts	420 Gauss	15 microns	20 *
82	6.75	500	420	15	20
61	6.80	500	420	15	20
44	6.90	500	420	15	20
120	6.65	500	420	15	26
82	6.75	500	420	15	26
61	6.80	500	420	15	26
44	6.90	500	420	15	26
120	6.65	500	420	15	35
82	6.75	500	420	15	35
61	6.80	500	420	15	35
44	6.90	500	420	15	35
120	6.70	500	420	15	40
82	6.80	500	420	15	40
61	6.85	500	420	15	40
44	7.00	500	420	15	40
120	6.65	500	420	15	20
82	6.75	500	420	15	20
61	6.80	500	420	15	20
44	6.90	500	420	15	20

* The wave lengths and ele ctrode spacings are given in millimeters.

The conclusions that may be drawn from data taken are that under the given experimental conditions the oscillations can exist without the formation of standing waves in the direction of the magnetic field and that if these standing waves are formed they have little if any effect on the oscillations or the resultant radiation.

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