IONIC OSCILLATIONS IN THE GLOW DISCHARGE

By L. A. Pardue and J. S. Webb

Abstract

In an effort to correlate Whiddington's work on moving striae and Appleton's work on ionic osciallations from a striated discharge, it was found that the ionic oscillation phenomenon was sufficiently involved to warrant a detailed study. The discharge tube was of the hot cathode type, 3 cm in diameter and 26 cm long. The oscillations were detected in three ways: first, by means of curved plates on the tube which were connected in parallel with the tuning condenser of the receiver; second, by direct inductive "pick-up" from the tube itself; third, by inductive "pick-up" from a coil in series with the tube. By these methods frequencies from 15×10^4 to a few hundred cycles were obtained, the higher frequencies being detected on an auto-dyne receiver, the lower frequencies on a straight low-frequency amplifier. Characteristic curves obtained show an increase of frequency with filament current, an increase of frequency with anode potential and a decrease with pressure except at the lower pressures where the frequency increases, passing through a maximum. With a varying pressure and without plates on the tube, oscillations do not occur when there are sharply defined striae but begin just as striae begin to diffuse, decreasing in frequency and becoming audible when a uniform glow fills the tube.

Introduction

The phenomena in the discharge tube have long been the study of many workers but still present many unsolved problems. The work of Whiddington[1] and of Appleton[2] has suggested possibilities that may lead to interesting and worthwhile conclusions. It occurred to the writers that a correlation between moving striae as observed by Whiddington and ionic oscillations from a striated discharge as observed by Appleton might be found. Before making this investigation it was found important to study the dependence of the oscillations upon pressure, voltage and filament-current variations. The object of this paper is to report the results of this work.

The Apparatus

The discharge tube was of the hot cathode type, 3 cm in diameter and 26 cm long. The oxide-coated filament was heated by a current which could be kept quite constant, the necessity for which will be evident when a characteristic curve showing the relation between frequency and filament current is studied. The effect of a changing pressure was observed by permitting the pressure of the air in the tube to increase very slowly by leakage into the vacuum system. The rate of leakage was less than 0.1 mm in three hours. The anode potential was varied by a potentiometer around a storage battery making available as much as 640 volts. The oscillations were detected in three ways: first, by means of curved plates on the tube which were connected in parallel with the tuning condenser of the receiver; second, by direct inductive "pick-up" from the tube by detector, having inductance of detector close to the tube; third, by inductive "pick-up" from an inductance in series with the tube, having this inductance and the detector far enough away from the tube to eliminate detection by the second method. In the first and second

[1] Whiddington, Engineering **120,** 20 (1925).

[2] Appleton, Phil. Mag. **45,** 879 (1923).

methods the inductance shown in series with the tube was not in the circuit. These arrangements will be evident when Fig. 1, giving a diagram of the apparatus, is inspected. The auto-dyne circuit used has the advantage of functioning as an oscillator and detector. Since the higher frequencies were far out of the range of audibility it was necessary to be able to detect a beat frequency. A separate oscillator and detector might have been used but the auto-dyne circuit is particularly advantageous in that it functions as both. The oscillating circuit was calibrated with a high-precision wave-meter. The vacuum system including pumps and McLeod gauge is not shown.

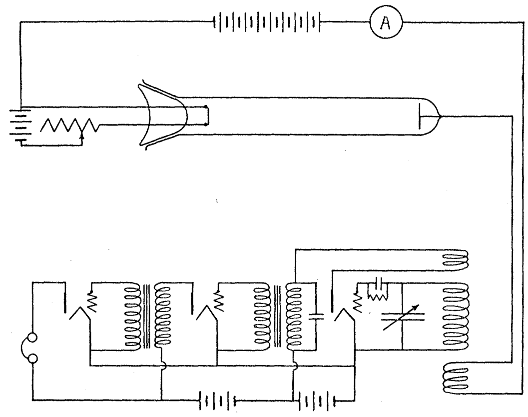

Fig. 1. Diagram of the apparatus.

Theoretical Considerations

It is a well established fact that a constant e.m.f. impressed upon a discharge tube causes a varying current to flow through the tube. This is doubtless due to a changing potential gradient within the tube caused by a shifting space-charge concentration. In the present work frequencies were observed from 15×10^4 down to a few hundred, the high frequencies being detected on the auto-dyne receiver and the lower frequencies on a straight low-frequency amplifier. These observations are not to be confused with periodic discharges from tubes which depend for their periodicity on resistance and capacity in parallel with the tube.[3] The constants of the circuit do not affect these ionic oscillations. The frequency depends on pressure, anode potential and filament current as the data will show.

The recent work of I. Langmuir, L. Tonks and H. Mott-Smith[4] in theory and in corroborating experiment indicates that if a "plasma" contains n electrons per unit volume (and an equal number of positive ions) and if the concentration of electrons be slightly altered, the concentration in trying to return to its original value may cause to occur waves (compressional waves) whose frequency is independent of the wave-length. The frequency is given by the equation

$$\nu = e(n/\pi m)^{1/2} \qquad (1)$$

This equation applies to electronic space-charge. Usually, however, in a gaseous discharge the electrons are at a very high temperature relative to the positive ions. It is assumed that the electrons tend to a uniform concentration while the positive-ion concentration will vary, setting up potentials given by the Boltzmann equation. The positive ions will oscillate with a frequency which will approach the value given by Equation (1) where m is the mass of the positive ion. This value will be reached when the temperature of the electrons becomes infinite.

[3] Penning, Phys. Zeits. **27**, 187 (1926).

[4] In a paper which will soon appear in the Proceedings of the National Academy of Sciences.

From Appleton's paper one is led to believe that oscillations occur in sharply defined striae but we do not find this to be the case. Our observations indicate that oscillations do not exist when the striae are sharply defined but begin at the instant diffusion between adjacent striae begins and continue until all forms of striations disappear and a uniform glow fills the tube. At this point the oscillations become unstable and finally subside as the pressure is increased. This unstable condition lasts over a fairly wide range of pressures starting at 0.07 to 0.1 mm. The beginning of instability depends upon the filament current and plate voltage. In the receiver this condition seems to consist of the original oscillations superimposed on a background of noises or "atmospherics."

Frequency Variations

The results obtained by the three methods previously mentioned were generally the same except for one difference to be pointed out which was found when plates are used on the tube. The production of the oscillations seemed to be confined within the tube and to be governed by the physial conditions there. A condenser shunted around the tube had no noticeable effect. The effect of pressure was found to be the most interesting. The relation between frequency and pressure is shown in Fig. 2. From Eq. (1) it is to be expected that

$$\nu \propto n^{1/2}$$

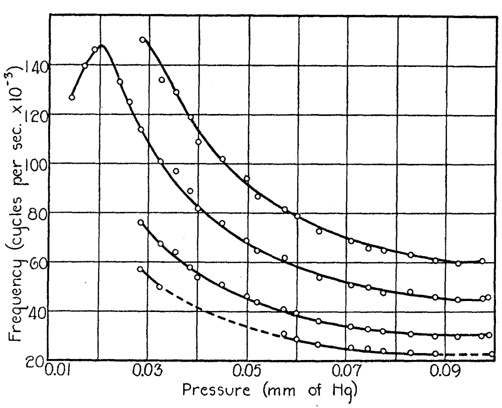

Fig. 2. Relation between frequency of oscillation and pressure.

Townsend[5] gives an equation for ionization by collision, $n \propto pe^{-evp/x}$:, in which c is the reciprocal of the electronic free-path at the pressure of 1 mm, p is the pressure in mm, x is the field strength and v the ionizing potential. It follows when p is varied, that the number of electrons, n, per cm^3, and correspondingly the frequency, rises to a maximum at $p=x/cv$, then falls. The curves in Fig. 2 are in accord with this. From the data chosen, which are typical of many trials, there are at least four frequencies at any given pressure. The values of the frequencies suggest the existence of two independent frequencies each having a harmonic. There was at times evidence of other frequencies and of harmonics higher than the first. In the observations, as shown in Fig. 2, one finds that the frequencies are almost exactly in the ratios of the integers 3, 4, 6, 8. These frequencies may well be the harmonics of an unobserved fundamental frequency. The point of maximum frequencies is displaced toward the lower pressures from the computed value. The computation is based on a uniform fall of potential throughout the tube. Since the fall is largely in the cathode region it follows that the average field strength in the region of the positive column is much lower.

[5] Townsend, Electricity in Gases—p. 294, Oxford, 1915.

On this basis the turning point is much more reasonable. The dotted portion in one of the curves shows a part in which the capacity range was not sufficient to accommodate all four frequencies. A large amount of other data of which Fig. 2 is typical shows that all the frequencies have a turning point at the same pressure. The anode potential was kept constant at 640 volts and the filament current at 6.3 amp.

In Fig. 3 the relation between frequency and anode potential is shown. The Townsend equation indicates that the frequency varies exponentially with the reciprocal of the anode potential. In Fig. 3 the pressure is 0.01 mm and the filament current 6.4 amp. Fig. 4 shows how variations in the filament

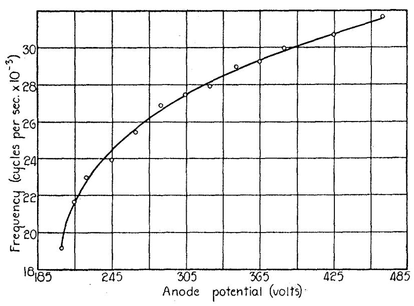

Fig. 3. Relation between frequency of oscillation and anode potential.

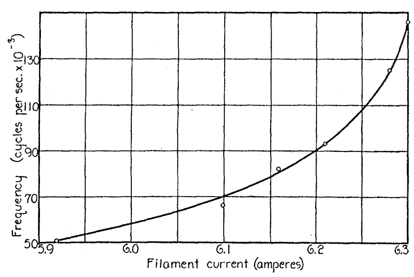

Fig. 4. Relation between frequency of oscillation and filament current.

current affect the frequency. The principle of electronic emission from hot bodies as expressed by Richardson's equation governs the number of ionizing electrons which in turn determines n in the equation, the other quantities remaining constant. It is then not surprising that the curve has the shape it does. The anode voltage in Fig. 4 is 640 volts and the gas pressure is 0.01 mm.

Conclusion

The foregoing results are being reported now as at the close of one stage of the work. The writers hope to be able to continue the work at some immediate future time, to investigate in particular one phase of the problem which may lead afield from the general course of this work. This has to do with attaching plates to the tube. When they are attached one finds a slightly different condition. At the lower filament temperatures, when the discharge fills the tube, the oscillations are audible and can be heard as mechanical vibrations of the tube under certain conditions. At the higher temperatures the oscillations become inaudible but can be detected as beats These occur even when striae are present. It is possible that the plates affect the potential gradient within the tube but this point has not been determined.

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