OSCILLATIONS IN THE GLOW DISCHARGE IN NEON

By Gerald W. Fox
Department of Physics, University of Michigan

(Received February 26, 1930)

Abstract

Radio-frequency oscillations consisting of one or two fundamentals together with a series of harmonics for each fundamental have been observed in large current glow discharges in neon. The observed frequencies lie in the range from approximately 1.5×10^4 to 2×10^5 cycles per second. The oscillations are very sensitive to pressure changes, their frequency increasing rapidly with decreasing gas pressure. The oscillation frequency also increases markedly with increasing current. The frequency is quite independent of resistance in series with the discharge.

The suggestion is made that the oscillations are due to the presence of a reversed electric field in the negative glow of the discharge.

Introduction

Oscillations in gaseous discharges have been observed for many years. As far back as 1876, Spottswoode[1] reported observing intermittant electric discharges in gas filled tubes. More recently the work of Whiddington,[2] Appleton,[3] Penning,[4] Webb and Pardue,[5] Tonks and Langmuir,[6] and others have brought this phenomenon to the fore, with the result that many new and interesting data have come to light. The present paper deals only with glow discharges in neon.

Apparatus and Method

The discharge tube is shown in Fig. 1. The over all length was approximately 50 cm, of which the central section was a quartz tube 22 cm long and 2 cm in diameter. The two Pyrex bulbs contained respectively the heavy copper anode, *P* and the barium-oxide coated cylindrical nickel cathode, *C*. The cathode was indirectly heated by radiation from a 20 mil tungsten spiral inside. A close fitting glass sleeve diminished gas diffusion to the back of the anode so that only the front was effective. Ground joints, deKhotinsky sealed, connected the central quartz section to the two end bulbs. These joints were water cooled. The tube voltage was supplied through series resistance by a 600 volt storage battery.

The usual arrangement of pressure gauges and pumping equipment made up the vacuum system. The discharge tube itself was at all times isolated

[1] Spottswoode, Proc. Roy. Soc. May 18 (1876).
[2] Whiddington, Engineering, **120**, 20 (1925)
[3] Appleton, Phil. Mag. **45**, 879 (1923).
[4] Penning, Phys. Zeits. **27**, 187 (1926).
[5] Webb and Pardue, Phys. Rev. **32**, 946 (1928).
[6] Tonks and Langmuir, Phys. Rev. **33**, 195 (1929).

from the pumping system by a liquid air immersed charcoal trap close to the anode bulb, and a second liquid air trap nearer the pumps. At no time throughout the period of the experiments did the discharge show the presence of mercury vapor.

The detection scheme was essentially the same as that used by Webb and Pardue.[5] A regenerative detector circuit and a one stage audio amplifier worked admirably. The current through the discharge tube flowed through a

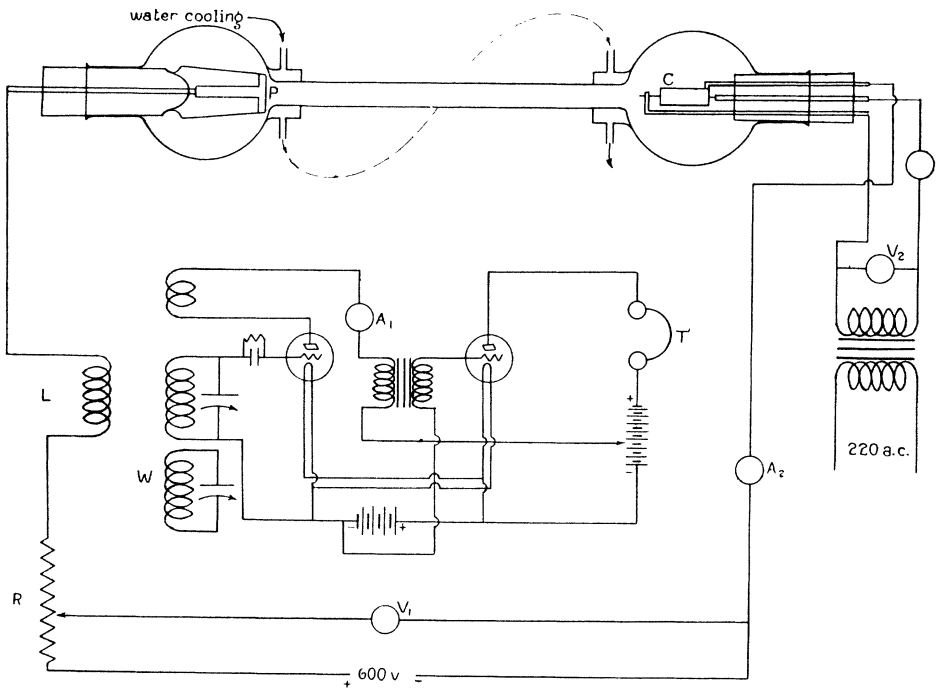

Fig. 1. Diagram of apparatus.

five turn coil of heavy wire which was very loosely coupled to the input of the detector tube. The frequency of the discharge was determined through the method of beats. On zero beat the frequency was measured by a loosely coupled wavemeter.

RESULTS

1. *Frequencies present at a given pressure.*

Data taken in a large number of runs show that several frequencies were present in the discharge at the same time. These frequencies appear to be multiples of a fundamental frequency. The pick up circuit allowed complete covering of a wave-length range of 24000 meters to 100 meters. Throughout this range a large number of frequencies were found. Table I shows one typical run and Table II another. It will be noticed that these are for different tube currents and gas pressures.

TABLE I. *Observed frequencies in glow discharge in neon.* (Tube current 1 ampere, tube voltage 170 volts, Gas pressure 0.52 mm Hg).

Wave-length (meters)	Frequency (cycles/sec)	Order
19800	15151	1
9540	31446	2
6580	45592	3
3960	75757	5
2830	106007	7
2480	120968	8
1990	151753	10
1800	166666	11

TABLE II. *Observed frequencies in glow discharge in neon.* (Tube current 3 amperes, tube voltage 165 volts, gas pressure 1.8 mm Hg).

Wave-length (meters)	Frequency (cycles/sec)	Order
15460	19404	1
7700	38961	2
5150	58252	3
3900	76923	4
3080	97402	5
2580	116279	6
2200	136363	7
1930	155440	8

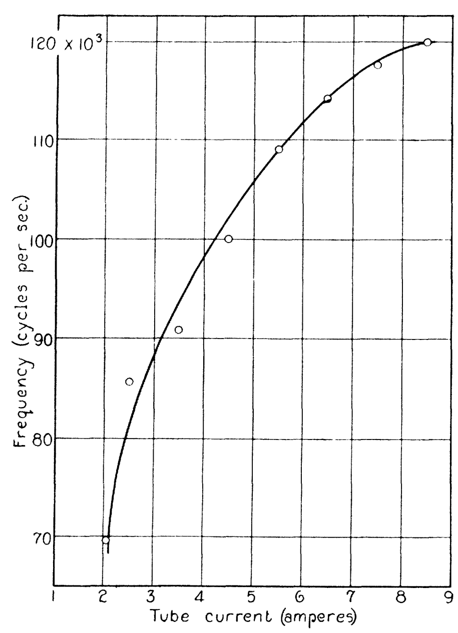

Fig. 2. Typical curve showing variation of oscillation frequency with tube current in neon.

2. *Variation of frequency with tube current.*

The curve shown in Fig. 2 is typical of the frequency variation with tube current. The frequency at first rose rapidly with the increase in current; then more slowly. However, it never reached a condition where it no longer changed with increase in current. At some current value there was always an abrupt change, the frequency stopping suddenly and some other fundamental appearing with its corresponding series of harmonics.

3. *Variation of frequency with pressure.*

The discharge frequency was extremely sensitive to pressure changes. Even the slight pressure fluctuations caused by raising or lowering the mercury in the McLeod gauge were enough to vary the beat note as heard in the

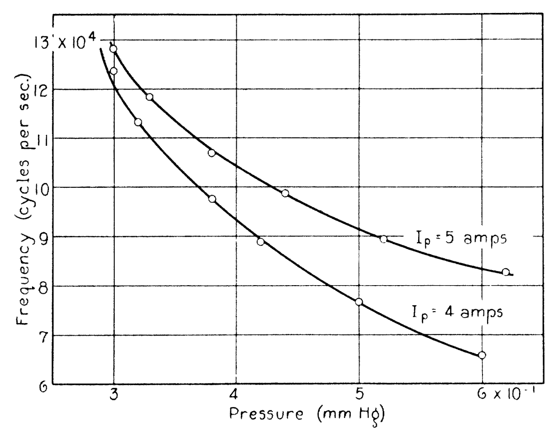

Fig. 3. Variation of oscillation frequency with gas pressure in neon.

telephone receivers as much as a thousand cycles. Fig. 3 shows typical frequency-pressure curves. The frequency rose very rapidly as the pressure was lowered to 0.2 mm of mercury. Below 0.2 mm it became increasingly difficult to maintain oscillations. Their regularity disappeared and, although even at 0.01 mm for some current values the discharge could be made to oscillate, conditions were very uncertain.

4. *Oscillations independent of series resistance.*

Table III shows that the oscillation frequency is not a function of the series resistance.

TABLE III. *Independence of oscillations of series resistance.* (Tube current = 3 amperes, pressure = 0.57 mm).

Total voltage	Tube voltage	Series resistance (ohms)	Frequency
500	175	108	88495
325	175	47	88235
230	175	18	87915
190	165	8	88626

These data were taken within a period of five minutes. The discharge was off only long enough to allow decreasing the total battery voltage.

Discussion

The oscillations here investigated exist only when the discharge is perfectly steady with a uniform positive column. They are entirely unaffected by any capacitance or inductance in parallel with the discharge. In Appleton's[3] work on ionic oscillations the inference is made that oscillations occur in sharply defined striae. In the work of Webb and Pardue[5] the oscillations do not exist so long as sharply defined striae are present but begin when diffusion between adjacent striae takes place and continue until a uniform glow fills the tube. In both the investigations mentioned the tube currents were small, of the order of a few hundred milliamperes at most, while in this investigation the tube currents varied from one ampere to as much as twenty amperes. Oscillations consisting of one or two fundamentals and numerous harmonics were present for any current in this range providing the pressure was not too low.

In their theory of plasma-ion oscillations Tonks and Langmuir[6] have developed an expression for the frequency of ionic oscillations. The limiting value is given by:

$$\nu = e^2\left(\frac{n}{\pi m}\right)^{1/2}. \tag{1}$$

Under the conditions of their experiments the limiting value for mercury vapor comes out to be about 1.5×10^6 cycles per second. According to their theory the plasma-ion type of oscillation is likely to go over into electric-sound waves, whose frequency may extend up to 6.5×10^5 per second. The frequencies observed in this investigation fall in this range. The variation of frequency with gas pressure is in general agreement with the curves of Webb and Pardue.[5]

It seems very certain that the type of oscillation herein described does not depend on series resistance. As shown in Table III there is a negligible frequency change for different values of series resistances. In fact the discharge has an entirely positive characteristic since it will run steadily with no series resistance at all, except the very small value due to lead wires from the storage batteries, provided the total voltage across the tube does not exceed by more than a few volts the usual drop across the tube (about 170 volts for this tube). The cathode temperature is not affected appreciably by positive ion bombardment but is wholly controlled by radiation from the heater coil.

Compton and Eckert[7] have shown that oscillations may exist in discharges of the low voltage arc type when there is a high resistance in series with the arc. As the voltage across the tube increases to the ionization potential of the gas, the arc strikes. The negative space charge surrounding the filament is at once neutralized by the positive gas ions. Bombardment of the filament in-

[7] Compton and Eckert, Phys. Rev. **24**, 97 (1924).

creases its temperature, thereby further increasing the emission and hence the arc current. But the resulting large IR drop in the series resistance lowers the voltage across the tube. This constitutes one type of oscillation. The glow discharge is not greatly different from a low voltage arc except for the long positive column. One might expect, therefore, a similar explanation of the origin of the oscillations, but the evidence is against this.

At all times during the experiments, the interesting flashes described by Aston and Kikuchi[8] and Whiddington[2] were present. The suggestion is made that the ionic high frequency oscillations are modulated by these rather low frequency pulsations, since on zero beat a note of about 150 cycles was always

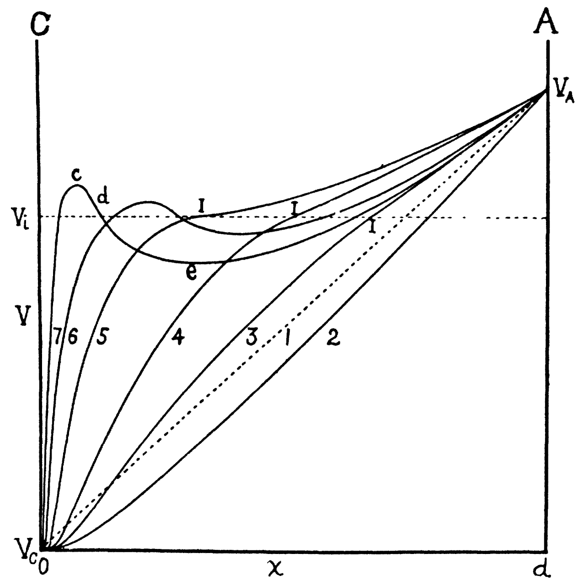

Fig. 4. The effect of increasing amounts of ionization on the distribution of potential between two parallel electrodes one of which is a source of electrons. Curve 1 shows the electrostatic distribution, curve 2 the distribution in the presence of space charge from electrons, and the remaining curves the distribution in cases of successively increasing amount of ionization at the ionizing potential V_i. (From Compton, Turner and McCurdy.)

heard. This is roughly the frequency of the flashes. It is to be noted also that these flashes only occurred in the positive column. Examined by the aid of a rotating mirror they appeared very bright from anode to Faraday dark space, where they disappear. The light of the negative glow is entirely uniform.

The question of the origin of the oscillations is a puzzling one. It seems possible that they orignate in the Faraday dark space. A small bar magnet moved about in the vicinity of the discharge had very slight effect except in the region of the Faraday dark space where its motion changed the oscillation frequency very markedly.

[8] Aston and Kikuchi, Proc. Roy. Soc. A**98**, 50 (1920).

In their theory of the glow discharge, Compton, Turner, and McCurdy[9] have shown the possibility of a reversed field in the region of the negative glow, especially in cases where there is large ionization. As shown in Fig. 4, increasing ionization leads finally to the potential distribution shown in curve 7. There is no reason to suppose conditons should not become even more exaggerated until the potential of the gas in the negative glow should actually be higher than the potential of the gas in the negative end of the positive column. Compton and Eckert[10] have shown this possibility for the case of the low voltage arc. The suggestion seems reasonable that this reversed field is the cause of the ionic oscillations. The positive ions fall through the potential gradient at the cathode end of the positive column with gradually increasing speed, in spite of numerous collisions, until they run into the reversed field which sends them back toward the anode. A back and forth motion of the positive ions results which constitutes the ionic oscillation.

[9] Compton, Turner and McCurdy, Phys. Rev. **24**, 597 (1924).
[10] Compton and Eckert, Phys. Rev. **25**, 139 (1925).