OSCILLATIONS AND TRAVELLING STRIATIONS IN AN ARGON DISCHARGE TUBE

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Abstract

The effects of current and external circuit conditions on the frequency of travelling striations were observed. Some information concerning the voltage fluctuations at different parts of the tube was obtained. Electron temperatures in the positive column were determined at different pressures. A set of wave-lengths bearing simple relations with the length of the tube were calculated by means of Tonks' and Langmuir's theory of electric sound waves and the experimental values of the flash frequency.

Introduction

In the course of an experiment to determine certain quantities in the positive column of a discharge tube, the author encountered the difficulty that the voltage across the tube was not constant. After an unsuccessful attempt to eliminate this fluctuation, it was thought desirable to investigate the phenomenon in more detail.

Oscillations in a discharge tube were observed and studied quite long ago. Recent work has been done by Penning,[1] Tonks, and Langmuir,[2] Webb and Pardue,[3] Fox[4] and others. Webb, Pardue, and Fox found that the phenomenon of travelling striations studied by Aston and Kikuchi,[5] Whiddington,[6] and others was accompanied by oscillations. In this paper a few more points are reported concerning travelling striations and oscillations in an argon discharge tube with a positive column.

Apparatus and Method

The discharge tube is shown in Fig. 1. The length of the tube was 72.5 cm. The inner diameter was 7.2 cm. An oxide coated cylindrical nickel cathode C and a hollow cylindrical nickel anode A were used. The shortest distance between cathode and anode was 60 cm. The tube was baked out at about 350°C for several hours. The cathode and anode were degassed by means of an induction coil. Between the tube and the pumping system there were two liquid air traps with a stopcock between them. During a run this stopcock was closed. Liquid air was continually kept on the trap which was on the tube side of the stopcock. For the study of voltage fluctuation a cath-

[1] Penning, Phys. Zeits. **27**, 187 (1926).
[2] Tonks and Langmuir, Phys. Rev. **33**, 195 (1929).
[3] Webb and Pardue, Phys. Rev. **32**, 946 (1928).
[4] Fox, Phys. Rev. **35**, 1066 (1930).
[5] Aston and Kikuchi, Roy. Soc. Proc. London **98**, 50 (1921).
[6] Whiddington, Proc. Leeds Phil. Soc. **1**, 467 (1929).

ode-ray oscillograph was used. For the observation of instantaneous pictures of the discharge tube and the measurement of flash frequency, a stroboscope, which is essentially a rotating toothed-wheel together with a fixed slit put right behind it, was used.

Results

1. *An instantaneous picture of the discharge.* (*Fig. 1*). The negative glow and the head of positive column remain stationary. Flashes travelling from anode to cathode run into the head of the positive column but do not run across the Faraday dark space. There are cases in which the Faraday dark space is not present. In these cases, it is observed that the flashes run into the negative glow which is stationary. The distance between successive flashes is of the order of 10 cm.

2. *Fluctuation of space potential in the tube.* In a non-oscillating tube we know that there is a definite potential distribution. When oscillations are present and the potential difference between cathode and anode fluctuates it is quite natural to expect that the space potential distribution should fluc-

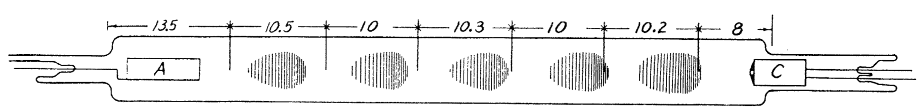

Fig. 1. Diagram of tube. The shaded regions are luminous parts. The numbers represent the distances in cm between the different probe wires.

tuate too. In order to get exact information one has to take Langmuir probe wire measurements at particular phases of the cycle of voltage fluctuation at different parts in the tube. Wishing to continue with his original problem, the author has not gone into this work. He reports here such information as he has been able to obtain otherwise. There are a number of probe wires situated at different parts of the tube. When they are left floating in the tube each of them charges up to a certain potential negative with respect to the surrounding space such that electrons and positive ions reach the wire at equal rates. If the surrounding space potential is fluctuating the potential of the floating wire must also fluctuate. The fluctuation of the probe wire potential would be just equal to that of the space potential provided the ratio of the concentration of positive ions and that of electrons and the ratio of the velocities remain unchanged. What was done, therefore, was to connect anode or cathode and each one of the probe wires successively to a pair of deflecting plates of the cathode ray oscillograph. The amplitudes of voltage fluctuation at different parts with respect to cathode and anode were observed. The results are shown in Table I. Each vertical line shows the position of a probe wire and the numbers in the column under it give the corresponding voltage fluctuations. The pressures are given in the first column. The upper row corresponding to a particular pressure gives the amplitudes of the voltage fluctuation in volts between the probe wires and the anode. The lower row gives the amplitudes with respect to the cathode.

TABLE I. *Amplitudes of the voltage fluctuations in different parts of the tube with respect to the anode and cathode. Pressures are all measured when the gas is at room temperature. After two hours of running the pressure does not change very much.*

Pressure (mm Hg)	Anode	Position of probe wires						Cathode
4.2			24	24	24	24	24	22
	22			5			1	
3.9			24	24	24	24	24	22
	22		7	5	3	3	1	
3.2								24
	24						1	
2.8				24				24
	24						1	
2.3					24			24
	24						1	
1.7					24			24
	24				1		0	
1.45					24			24
	24				0		1	
1.25			24	24	24	24	24	24
	24		3	2	0	11	0	
1.06			24					24
	24					11	0	
0.915								24
	24					3	0	
0.775			28	28	28	24	24	24
	24		5	5	2	13	0	
0.67			32	29	29	24	24	24
	24		7	7	5	14	1	
0.58			32	29	29	25	24	24
	24		8	8	6	3	0	
0.50			32	32	32	24	24	24
	24		10	9	8	15	1	
0.43			33	33	32	25	25	25
	25		10	10	9	25	1	
0.36			32	32	32	25	25	25
	25		11	10	10	29	1	
0.31			32	32	29	29	25	25
	25		11	11	11	29	0	
0.265			32	32	32	25	25	25
	25		11	13	11	4	0	
0.22			23	36	32	27	26	29
	29		11	15	11	3	0	
0.16			24	39	29	29	29	29
	29		15	16	10	5	0	
0.113			31	36	27	29	31	31
	31		18	18	8	2	0	
0.096			29	38	25	32	32	32
	32		18	18	9	2	1	
0.085			29	38	24	27	29	29
	29		18	14	10	2	3	
0.071			31	44	25	28	30	28
	28		16	23	14	10	2	

Travelling striations do not appear distinctly until the gas pressure is reduced to about 0.775 mm. However, fluctuations of luminosity are still present at high pressures. The frequency of luminosity fluctuation can still be measured. The probe wire nearest the cathode is on the cathode side of the negative glow, except in a few cases at high pressures when the positive column extends very close to the cathode. The position of the second probe wire with respect to the positive column goes from inside the head to just outside in the pressure range from 0.775 mm to 0.071 mm. Very little can be concluded from these values because we do not know the phase differences between the voltage fluctuations at different parts. However, we can say that the disturbance is very small in the cathode region compared with that in the anode region. This seems to agree with the fact that the travelling striations are present in the positive column. It has also been observed that when the second probe wire is situated in a rather distinct Faraday dark space, there is no voltage fluctuation between this probe wire and the cathode and also no voltage fluctuation between the first probe wire and cathode.

3. *Variation of flash frequency with current through the tube.* Whiddington observed that this phenomenon of travelling striations covers quite a large range of current. He divided the moving striations into five types according to their velocities as the current is increased. Since it is observed that the distance between successive striations does not change appreciably with current the relation between flash frequency and current is therefore similar to that between velocity and current. By flash frequency we mean the number of striations moving across a certain cross-section of the tube per second. The result is summarized in Table II. There are two modes of frequency change,

TABLE II. *Variation of flash frequency with current through the tube. Battery voltage $E=62$ volts.*

Current (amp.)	Flash frequency	Voltage across tube (volts)	Remarks
0.27	1.71×10^3	53.0	Current unsteady light fluctuation visually observed.
0.6	1.89 "	47.9	
1.0		44.0	
2.6	0.97×10^3	37.3	Steady, instantaneous picture clear.
3.0	1.14 "	34.5	
3.4	1.19 "	33.5	"
3.8	1.21 "	33.0	"
4.4	1.23 "	32.3	"
5.0	1.26 "	32.0	"
5.4	1.26 "	32.0	"
6.0	4.71 "	31.5	"
3.5	1.18 "	34.0	"

one is a continuous variation and the other is a discontinuous jump. In the continuous region the frequency increases with the current. The relation is indeed not simple. One would suspect that the current is not the only thing responsible for the change of frequency because in order to change the current other quantities in the circuit have been changed too; for instance, the external resistance in the circuit. Other observations are therefore made to test the effect of the external circuit.

4. *For a given current the frequency changes with the external resistance (non-inductive).* An interesting fact was observed. When a large battery voltage (E) is used, thus with large external resistance, the Faraday dark space exists. When E is small the Faraday dark space disappears. On one occasion I was able to observe a Faraday dark space, although not so distinct, by using E equal to about 60 volts. The frequency measured was 1.61×10^3. Suddenly the Faraday dark space disappeared and the frequency became 9.8×10^2. This change seems to correspond to a change-over from a "fast-type" to a "slow-type" in the previous current-frequency relation.

TABLE III. *Variation of flash frequency with external resistance.*

Current	Battery voltage	Voltage across tube	Flash frequency	External series resistance
0.4 amp.	60 volts	53.1	9.88×10^2	18 ohms approx.
0.4 "	118 "	51.7	1.92×10^3	166 " "
0.4 "	345 "	51.7	2.09×10^3	733 " "

5. *Inductance increases the frequency, capacity decreases it.* The frequency decreases rapidly with increase in the capacity put in parallel with the tube.

TABLE IV. *Variation of flash frequency with inductance and capacity.*

Flash frequency	Condition in external circuit
2.22×10^3	Only noninductive resistance about 300 ohms
1.92×10^3	With a condenser of 2 mf connected parallel to tube
2.40×10^3	An inductance in series with series resistance
E equal about 120 volts $V=58.8$ volts $i=0.2$ amp. kept same in three cases	

When the capacity in parallel with the tube was large, the Faraday dark space disappeared. Under this condition, although no distinct striation can be seen, there are bright and less bright regions. These regions fluctuate violently in position.

6. *The filament current has an effect on the frequency. An increase in the filament current decreases the frequency.*

TABLE V. *Variation of flash frequency with filament current.*

Filament current	Current in tube	Voltage across tube	Flash frequency	External resistance
6.2 amp.	0.3 amp.	87.5 volts	2.21×10^2	842 ohms
8.7 "	0.3 "	51.7 "	2.08×10^2	961 "
$E=340$ volts				

7. *A search for electric sound waves: variation of flash frequency with pressure.* That the flash frequency is the same as the sound frequency heard in a telephone receiver connected to the circuit suggests that there might be present a kind of electric sound wave such as Tonks and Langmuir derived in

their theory of plasma ion oscillation. Their expression for the velocity of electric sound waves is this

$$v = 3.9 \times 10^5 \left(\frac{T_e m_e}{m} \right)^{1/2}$$

where T_e is the electron temperature in degrees m_e and m are the masses of the electron and the argon atom, respectively. The frequency of the electric sound wave is indeterminate from their theory. The only condition is that λ is very much greater than $(\pi k T_e/ne^2)^{1/2}$. Experimental values of T_e and calculated values of v at different pressures are given in Table VI. They are not in agreement with the flash velocities. If the flash frequency were the

TABLE VI. *Experimental values of electron temperature and calculated values of velocity of electric sound waves. Current is kept at 2 amperes for all readings.*

Pressure (mm Hg)	Flash frequency ν	Flash velocity (cm/sec.)	Electron temperature (volts)	Calculated velocity of electric sound wave v_s	$\lambda_s = v_s/\nu$	$\lambda_s/72$
0.071	1772	2.52×10^4 (i)	2.22	2.30×10^5	130	1.81
.085	1500	2.18 " (i)	1.78	2.07 "	138	1.92
.096	1286	1.86 " (i)	1.67	2.01 "	156	2.17
.113	1106	1.60 " (i)	1.59	1.96 "	177	2.46
.16	940	1.50 " (ii)	1.71	2.03 "	216	3.00
.22	701	1.12 " (ii)	1.73	2.04 "	291	4.04
.265	667	1.07 " (ii)	1.68	2.01 "	302	4.19
.31	561	8.98×10^3 (ii)	1.71	2.03 "	362	5.02
.36	494	7.89 " (ii)	1.59	1.95 "	395	5.48
.43	453	7.25 " (ii)	1.55	1.93 "	427	5.93
.5	359	3.95 " (iii)	1.36	1.81 "	502	6.97
.58	332	3.48 " (iii)	1.18	1.68 "	504	7.00
.67	311	4.36 " (i)	1.35	1.80 "	579	8.04

Another set of electron temperature measurements taken at a different time and using another probe wire in the positive column are given below.

Pressure (mm Hg)	Flash frequency ν	Flash velocity (cm/sec.)	Electron temperature (volts)	Calculated velocity of electric sound wave v_s	$\lambda_s = v_s/\nu$	$\lambda_s/72$
0.068	2404		1.27	1.75×10^5	72.7	1.01
	1220 (ii)	1.41×10^4	1.96	2.18 "	178	1.47
	980 (ii)	1.14 "	1.44	1.86 "	190	2.64
	758 (ii)	8.8×10^3	1.47	1.88 "	247	3.43

(i) Distance between successive striations = 14.5 cm. approx.
(ii) Distance between successive striations = 16 cm. approx.
(iii) Distance between successive striations = 10.5 cm. approx.

same as that of electric sound waves, the wave-length would be very long compared with the distance between flashes. However, there is a very peculiar relation between all these calculated λ's. Most of them are integral or half-integral multiples of a certain length which is rather closely the length of the whole tube. (A few deviate from integers or half-integers but most of them are within experimental errors. Flash frequency is subject to 1 percent error. Electron temperature may have a maximum deviation of 5 percent.) This would mean that if we take the frequency of electric sound waves (suppose there is such a kind of wave in the tube) equal to some higher harmonics of the flash frequency the wave-length of the electric sound waves turns out to be a fraction of the tube length like a standing wave in that distance. The author does not attempt to interpret this phenomenon but believes that the fact is a real one, and may be very significant. The relation between flash frequency and pressure is plotted in Fig. 2.

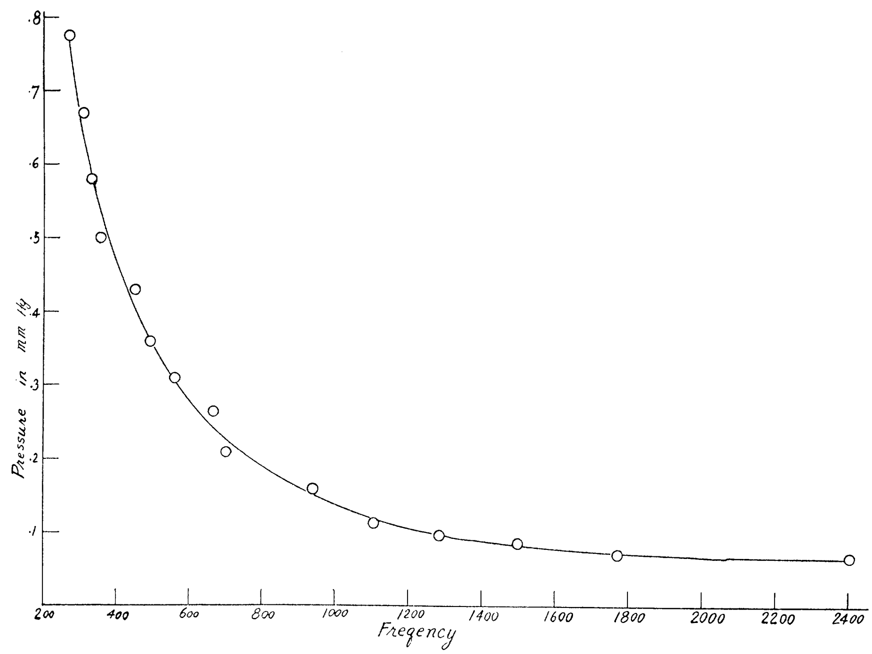

Fig. 2. The relation between flash frequency and pressure.

8. *Miscellaneous note.* There is often found a ring of glow light surrounding the anode. As the pressure is reduced this ring of velvet glow moves down towards the end of the anode. Sometimes the discharge is so unsteady that the needles of the voltmeter and the ammeter vibrate. In the range of pressure in which travelling striations are observed it is often possible to restore the discharge to steady condition by putting a magnet somewhere near the tube. Then distinct travelling striation patterns can be seen. There are a certain number of definite regions in which the magnet must be put in order to be effective. Right above the head of the positive column, and above the negative glow are favorable places but by no means the only places. Once the magnet had to be put a little behind the cathode. In some previous observations, some places near the anode are also effective.

In this laboratory, Dr. Cravath found oscillations too in his mercury discharge tube. His tube had about the same length as mine; the diameter was even larger. It was suggested that the large diameter of the tube is responsible for oscillations because the larger the diameter the smaller will be the area of the wall surface per unit volume of the tube. Loss of ions and electrons due to recombination at the wall will be less, so that the concentrations of ions and electrons in the tube are large. Therefore the process of cumulative ionization is favorable for the production of ions and electrons. The rate of production of ions and electrons by cumulative ionization processes is proportional to the square of the electron concentration. A small change of electron concentration will cause a large change in the rate of production of ions and electrons. This is a state of instability. A tube of about one inch diameter was built. However, oscillations existed as badly as in the tube with large diameter. This would mean that the above theory is certainly incomplete, if not wrong.

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