OSCILLATIONS IN THE GLOW DISCHARGE IN ARGON

By Gerald W. Fox
Department of Physics, Iowa State College

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Abstract

Report is made of radio frequency oscillations observed in argon glow discharges. The frequencies lie in the range of 10^4 cycles/sec to 10^5 cycles/sec in approximate harmonic relations. They are very sensitive to pressure changes but appear to bear no relation to the tube current. The peculiar action of a magnetic field on the oscillations is described. Some frequency calculations are made on the assumption that the potential distribution throughout the Faraday dark space can be represented by a parabola.

SOME time ago the writer[1] described experiments with oscillations observed in hot cathode glow discharges in neon. The present paper deals with a continuation of the same type of work in argon. The same discharge tube was used except that direct current was employed on the heater coil, since it was found that the a.c. introduced an extraneous sixty-cycle modulation. The argon was purified by a lengthy exposure to the action of a mischmetal arc. The experimental procedure was in all respects like that previously described.

Characteristics of the Discharge

The discharge in argon was steadier than in neon. The color appeared very nearly white to the eye but the brightness of the discharge for a given power input was not nearly so pronounced as in neon, while the heating was much greater. In neon, a current of 20 amperes could be run for a short interval and 10 amperes was possible continuously, with ordinary fan and water cooling. With argon, however, a current of two amperes caused the heavy copper anode to glow red in less than a minute and for this reason no observations were possible with currents larger than four amperes.

The pressure range over which oscillations were observed was quite narrow, the limits being approximately 0.2 mm Hg to 1.0 mm Hg. It was impossible to obtain oscillations for random current values in this pressure range. Oscillations were present only for particular values of current and pressure and when observed their frequency appeared to be independent of the tube current. As in the case of neon the discharge must be steady to exhibit oscillations. The slightest flickerings on anode or cathode produce enormous irregularities which are detected as "static" noises in the pick-up circuit. If one starts in at low pressure values a discharge may be maintained in argon at as low as 0.001 mm Hg but as listened to it is very noisy and the glow is feeble. With increasing pressure no noticeable change occurs in tube current,

[1] Fox, Phys. Rev. **35**, 1066 (1930).

tube voltage, or glow until a pressure of about 0.1 mm Hg is reached, when the light from the tube suddenly increases many times and the discharge becomes noiseless except for a slight hiss. Tuning through the frequency range then shows the presence of oscillations which seem to start simultaneously with the increase of light from the tube.

The maintaining voltage for the argon discharge averaged about 255 volts which is approximately 75 volts higher than the maintaining voltage for neon.

As in the case of neon the interesting flashes described by Whiddington[2] and Aston and Kikuchi[3] were generally present.

Results

1. Frequencies present at a given pressure.

Tables I and II show typical data on frequencies present in the discharge. As in the case of neon these frequencies seem to be harmonics of one particular frequency though this could not be observed due to the limited tuning range. In no instance was a complete series of harmonics observed nor was there exhibited any preference for particular omissions.

TABLE I. *Frequencies present in glow discharge in argon.*

(Tube current 2.6 amperes, tube voltage 255 volts, gas pressure 0.77 mm Hg).

Wave-length (meters obs.)	Frequency (cycles/sec calc.)	Order
23,200	12,930	2
15,600	19,230	3
11,400	26,320	4
5,830	51,500	8
5,200	57,700	9
4,620	65,000	10
4,215	71,200	11
2,890	103,700	16
2,390	125,600	19
1,640	182,900	28

TABLE II. *Frequencies present in glow discharge in argon.*

(Tube current 1 ampere, tube voltage 254 volts, gas pressure 0.68 mm Hg).

Wave-length (meters obs.)	Frequency (cycles/sec calc.)	Order
20,980	14,340	2
14,000	21,430	3
10,460	28,670	4
5,930	50,700	7
4,650	64,500	9
3,725	80,700	11
3,215	93,400	13
2,775	108,300	15
2,625	114,300	16
2,460	122,000	17
2,220	135,100	19
1,980	151,500	21
1,915	156,500	22

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

[3] Aston and Kikuchi, Proc. Roy. Soc. **A98,** 50 (1920).

2. Variation of oscillation frequency with pressure.

In the argon discharge, the frequency range covered was not as wide for a given pressure difference as in neon. A noticeable peculiarity was that the discharge frequency changed almost linearly with the pressure down to a certain critical value when no further change could be produced, the frequency remaining constant but becoming weaker until, on further pressure reduction, it broke completely. (Fig. 1.)

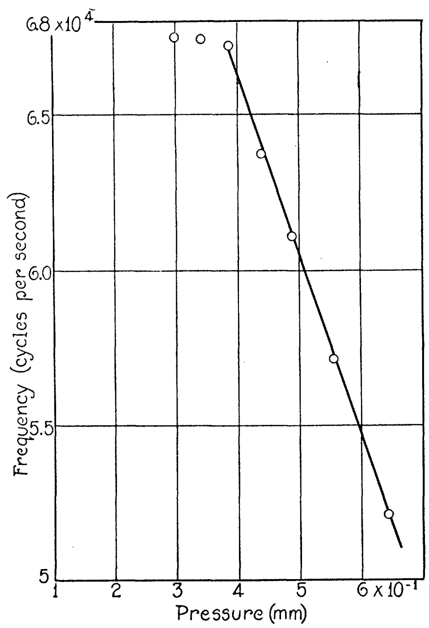

Fig. 1. Variation of oscillation frequency with pressure.

3. Relation of frequency to tube current.

It was not possible to show any frequency dependence on tube current such as appeared in neon. Having set on a particular frequency, this frequency persisted within a few cycles of the same value while the current was changed as much as an ampere when the oscillation would stop suddenly, to start again when the current was returned to its former original value.

4. Effect of a magnetic field on oscillations.

Some peculiar effects were noticed when a magnetic field was placed at right angles to the discharge. When a horseshoe magnet was moved from the anode end of the discharge toward the cathode, the frequency of the beat note in the telephone receiver fluctuated periodically from zero to a maximum, while moving the length of the positive column as shown in Fig. 2. On coming to the Faraday dark space, the regular oscillations disappeared altogether and the discharge became very noisy. Upon the removal of the magnet, however, the discharge became quiet again and the oscillations reappeared after a time of the order of thirty seconds. This observation was made repeatedly.

Discussion

From the work of Compton, Turner, and McCurdy[4] we have a fairly good picture of the potential distribution throughout the glow discharge. They have shown the existence of a potential minimum in the Faraday dark space, especially in cases of large ionization. In the discharges in both argon and neon, the tube currents were of the order of several amperes so that we may expect a large concentration of positive ions in the negative glow, for the ionization processes going on are more effective than the needs of the circuit as a whole demand. Positive ions from the cathode end of the positive column and from the negative glow, will both be accelerated into this region of minimum potential. This accelerating field is really necessary to prevent the ac-

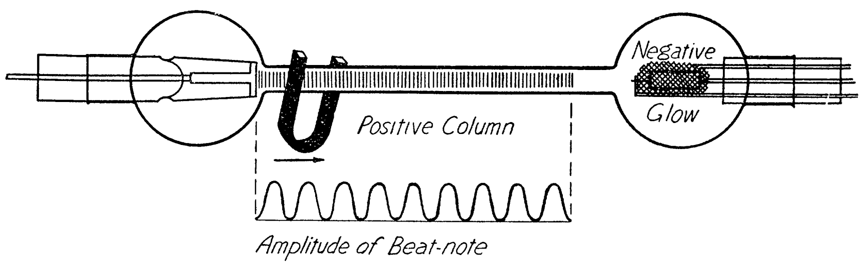

Fig. 2. As the magnet is moved along the positive column the sound in the telephone receiver fluctuates regularly in intensity.

cumulation of a negative space charge here by diffusion of electrons from the negative glow. The positive ions from the positive column and probably also those from the negative glow approach the potential minimum with terminal velocities attained in the fields through which they have travelled and, since these fields are rather weak, their velocities will be small. Thus some ions will be trapped for a time and we may imagine them oscillating about the potential minimum until they acquire sufficient energy to get over the hump on the cathode side. An ion's escape probably comes suddenly after a collision with a molecule or another ion which provides a suitable energy transfer.

The action of the magnetic field in the Faraday dark space lends some support to this idea of the origin of the oscillations. When the field is applied here, the additional magnetic force to which the ions are subjected, upsets the regularity in their motion and brings about the noise that is heard in the pick-up circuit. The high-frequency oscillatory component of the tube current is really very small. It is merely superimposed upon the main steady current through the tube. The fact that the frequency increases with decreasing pressure seems reasonable for we can imagine fewer collisions taking place to slow the ion down while it remains in motion about the potential minimum.

[4] Compton, Turner, and McCurdy, Phys. Rev. **24**, 597 (1924).

The action of the magnetic field throughout the positive column makes one think of the presence of standing waves. It seems possible that electric sound waves of the type mentioned by Tonks and Langmuir[5] may be present, since the observed frequencies fall within the range of their calculations. The flashes, observed by Whiddington,[2] which travel from anode toward cathode, and which are of low frequency and can be observed with a rotating mirror, can be explained by assuming the presence periodically of a large anode drop which produces excess ionization in the anode sheath. This excess of positive ions would travel toward the cathode, modifying the potential distribution as they go and causing local ionization and excitation. This would appear as a travelling striation.

Simple Theory of Oscillation in the Glow Discharge

If one assumes as a first approximation that the curve representing the potential distribution throughout the Faraday dark space is a parabola, it is not difficult to arrive at an expression for the frequency of the oscillation which gives a value which is of the observed order of magnitude.

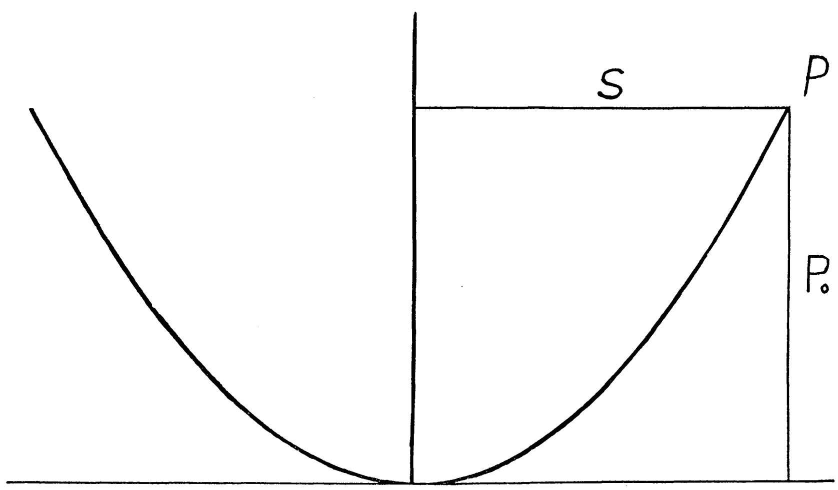

Fig. 3.

Let P represent the potential according to the equation $P=4ax^2$. Then since

$$\frac{m}{2}\left(\frac{dx}{dt}\right)^2 + 4aex^2 = W, \quad \frac{d^2x}{dt^2} + \frac{8ae}{m}x = 0.$$

The solution to this equation gives

$$x = C \cos (8ae/m)^{1/2}t + D \sin (8ae/m)^{1/2}t$$

in which it is seen that x repeats itself at intervals of 2π in the time $(8ae/\text{m})^{1/2}t$ The period of a complete vibration is $2\pi(m/8ae)^{1/2}$ and the frequency is the

[5] Tonks and Langmuir, Phys. Rev. **33**, 195 (1929).

reciprocal. The quantity a can be determined from estimates of dimensions of the Faraday dark space in the discharge. Thus assuming the dark space to be 4 cm wide and 20 volts deep, which is not unreasonable, we can write $P_0 = 4ax^2$, $a = P_0/4x^2$, or $a = 10^{-3}$ esu/cm^2 approximately. Taking e/m for hydrogen as 3×10^{14} esu/gram and 40 as the atomic weight of argon, the calculated frequency is 4×10^4 cycles per second. This is of the observed order of magnitude. The frequency appears to be quite dependent on the ratio of the width of the pit to its depth in volts. On the other hand, the frequency, is not very dependent on the type of ion in the discharge. The e/m for argon is of the same order of magnitude as e/m for neon. As mentioned before, the observed oscillations for both gases occurred in the same range.

The presence of a series of harmonic frequencies indicates that the potential distribution is not so simple a function as has been assumed. We do not know the actual potential distribution throughout the Faraday dark space, but since a slight distortion of our assumed distribution would allow the presence of harmonics, their presence can thus be accounted for.

In conclusion, the writer wishes to thank Professor H. M. Randall, director of the Physics Laboratory of the University of Michigan, for extending the privileges of the laboratory, where the experimental work was done.