PHYSICAL REVIEW VOLUME 107, NUMBER 1 JULY 1, 1957

Oscillations in Direct Current Glow Discharges*

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(Received December 17, 1956)

A dc discharge can behave as an ac current generator; under certain conditions, stable oscillations appear with the same period in the current and in the light emitted by the positive column even if it seems steady to the eye.

The current oscillations have been analyzed for their harmonic content. The various wave forms of the light oscillations observed along the positive column can be attributed to the fact that the component oscillations of different frequencies travel with different speeds.

I. INTRODUCTION

SINCE it was discovered that ionized gases in an electric discharge can generate high-frequency oscillations, the various aspects of this phenomenon have been the object of many experimental studies. One of these aspects is the appearance of moving and standing striations in the light emitted by the positive column.

Investigations were carried out first by means of rotating mirrors,[1] and later by means of probes[2] and cathode-ray tubes.[3]

Several attempts to explain the origin of traveling waves of charge density in the discharge (among the latest is that of Luchina[4]) have yielded different reasons for their existence; but none of these theories is complete because the features as they describe them or the assumptions made do not fit the physical reality. Thus, in both experimental and theoretical aspects, the nature of the oscillations is not quite clear.

A few years ago in this laboratory, researches were conducted on dc discharges, mostly in argon and in mercury vapor[5]; this paper deals with the result of similar experiments on dc discharges through helium gas where the observed phenomena are less complex: for instance, at a given pressure and current the mode of oscillation is unique and quite reproducible.

II. EXPERIMENTAL TECHNIQUES

The experiments were performed with two cylindrical tubes: tube I, internal diameter 7 mm, distance be-

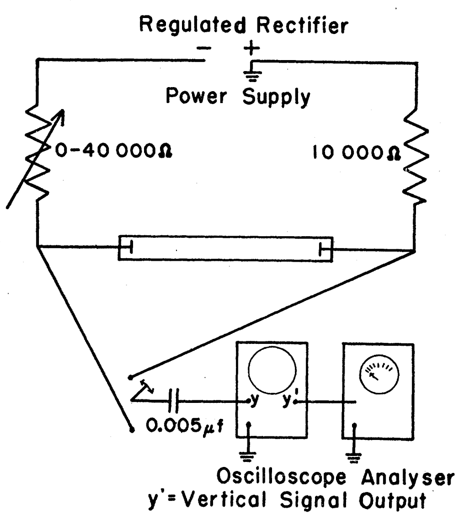

FIG. 1. Schematic diagram of the discharge tube circuit.

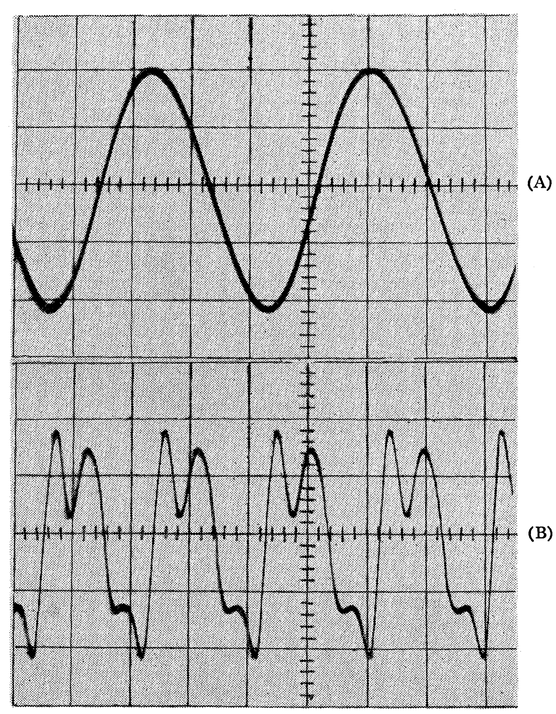

FIG. 2. Tube I. Current oscillations at 3.1 mm pressure. (A) $N=5400$ sec^{-1}, peak-to-peak amplitude $\Delta i=0.028$ ma, for $i=3.5$ ma. (B) $N=10\,500$ sec^{-1}, peak-to-peak amplitude $\Delta i=0.39$ ma for $i=21.5$ ma.

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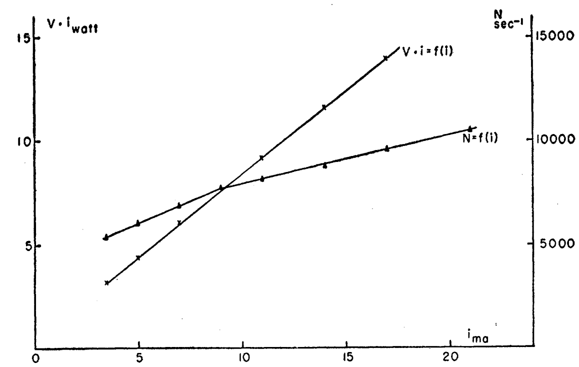

FIG. 3. Tube I. Frequency N of oscillations and static power-input $V\times i$ as functions of current for 3.1 mm pressure.

tween NI electrodes 56 cm; tube II, internal diameter 14 mm, distance between Al electrodes 42 cm.

By means of a cathode-ray oscilloscope (Tektronix 535), the periodic oscillations can be observed in the current at both electrodes, as well as in the light signal given by a photomultiplier. The photomultiplier is at the exit slit of a 1-meter Ebert spectrograph and a scanning of the discharge tube allows the different sections of the positive column to be focused on the entrance slit.

The electric circuit is shown in Fig. 1. The wave form observed on the screen of the oscilloscope is often complex. In order to determine which frequencies are contributing to it, and to what extent, the signal (either current or light) can be fed into a harmonic

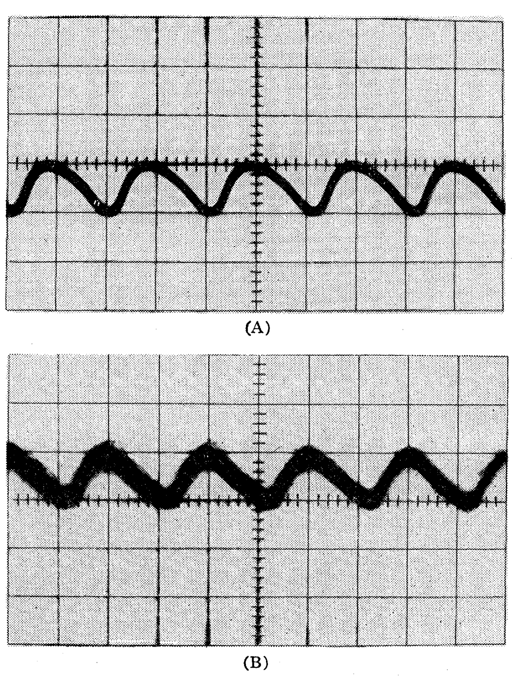

FIG. 4. Tube II. Oscillations at 3.1 mm pressure, $i=1.4$ ma. (A) Current $N=10\,000$ sec^{-1}, $\Delta i=0.018$ ma. (B) Light intensity, ac component at 8 cm from cathode.

wave analyzer of working range 0–16 kc/sec (Hewlett Packard 300 A). Higher frequencies are detected by the same analyzer after beating in a pentagrid converter 6-SA-7 with an appropriate frequency supplied by a local oscillator going up to 100 kc/sec.

III. CURRENT OSCILLATIONS (AT CONSTANT PRESSURE)

As observed in earlier experiments on rare gases,[5] stable modes of auto-oscillations exist only in a certain range of current values, for a given pressure; below the lower limit the signal has no ac component; above the higher limit the pattern on the screen of the oscilloscope shows only irregular oscillations.

At 3.1 mm Hg, tube I oscillates from 3 to 21 ma, and tube II oscillates from 0.4 to 1.5 ma. The two tubes operate very differently; this is reflected, too, in their characteristic $V=f(i)$ which has a slope negative for tube I, positive for tube II. (V is the voltage across the tube, and i is the current.)

The peak-to-peak amplitude Δi is small (for instance, in tube I: $i=7$ ma, $\Delta i=0.14$ ma) and, for a fixed dc current i, is independent of the external resistances R in the electric circuit. In tube I, when the current is increased, the wave form changes gradually from an almost sinusoidal shape to a more complex one in which harmonics up to the eighth can be detected (Fig. 2); at the same time the period T of the fundamental decreases. The corresponding frequency varies linearly with the product $V\times i$, or with i, since in the region under consideration the product $V\times i$ is a linear function of i. (See Fig. 3.)

Eventually, at the limit of stability, the trace would settle down to a completely different wave form, saw-tooth shaped, after some sudden transitions between different shapes.

In tube II, the saw-tooth shape was the rule (Fig. 4), with a period for which no variation with current could be seen in the small domain of stable oscillations.

A quantitative analysis of the current oscillations, in tube I, gives the curve of Fig. 5 for the amplitude Δi_N of the fundamental as a function of the current i. It appears to be of the form $\Delta i_N=k\log(i/i_0)$, i_0 being the lower limit for the existence of oscillations.

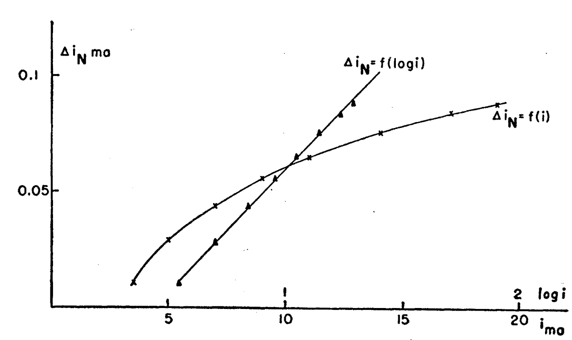

FIG. 5. Tube I at 3.1 mm pressure. Amplitude Δi_N of the fundamental as a function of current i and log$i$.

The functions Δi_{2N}, Δi_{3N}, etc., do not follow a simple law and do not even increase monotonically.

In contrast to Δi_N, the resultant Δi shows a saturation towards the upper limit of stability, due to the appearance of the other components.

The behavior of the frequency, the appearance of the saw-tooth shape, and the possible synchronization of the oscillations on an imposed frequency (see modulated dc discharge[6]), would indicate a relaxation type in which the frequency is determined by the rate at which a continuous source of energy supplies an oscillatory energy.

However, when a continuous transition occurs from a pure sinuosidal oscillation to a relaxation oscillation, the theory shows that the period T increases, which is not verified in our case of tube I. However, the transition considered by the theory involves a parameter occurring in the oscillating system only, while the actual change observed is gotten primarily through the action of the outside supply of energy.

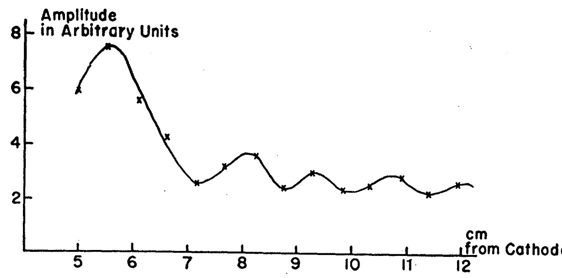

FIG. 7. Tube II. $i=1.4$ ma at 3.1 mm pressure. Amplitude of the ac component of the light signal as a function of the distance from the cathode along the positive column.

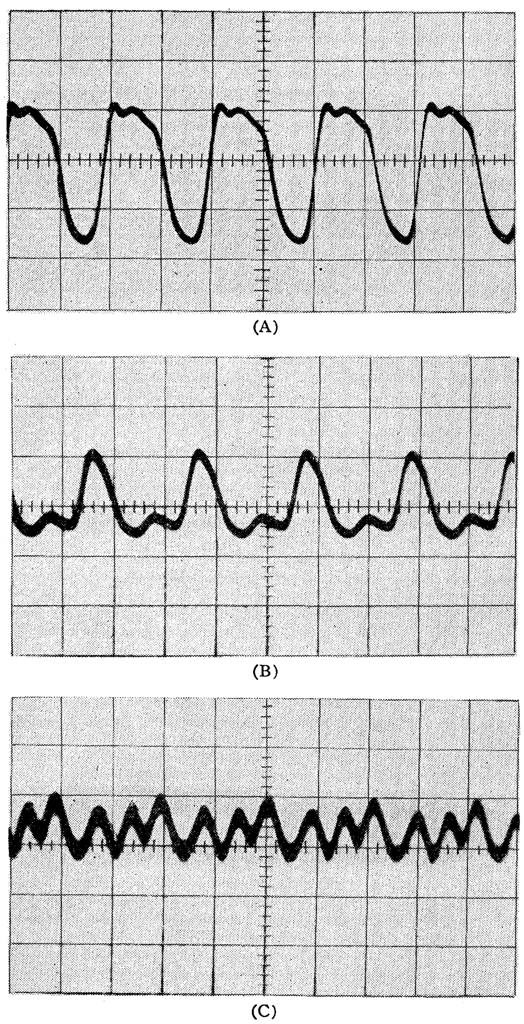

FIG. 6. Tube I. Oscillations at 3.1 mm pressure, $i=19$ ma, $N=10\,000$ sec^{-1}. (A) Current, peak-to-peak amplitude $\Delta i=0.28$ ma. (B) Light intensity at 6 cm from the cathode (ac component). (C) Light intensity at 28 cm from the cathode (ac component).

IV. LIGHT OSCILLATIONS

These have the same period as the current oscillations but not necessarily the same shape (Fig. 6) nor the same percentage of modulation, which can go as high as 100% towards the cathode end of the positive column in several instances.

When the discharge tube is scanned and the sweep of the oscilloscope triggered by a reference signal (current at one electrode), the pattern given by the light signal shows a continuous shifting, giving the evidence of the "moving striations": the peak intensity occurs at different times for different sections of the positive column.

The moving striations travel towards the cathode at speeds of the order of several hundred meters per second. For tube II, the speed is 355 meters/sec at 1.4 ma and 3.1 mm Hg, period $T=100$ μsec; the wave form stays the same. For tube I, at 18 ma, 2.7 mm Hg, $T=65$ μsec, the change in the wave form can be interpreted to give the different speeds of the two main components N and $2N$:

$$V_N=275 \text{ meters/sec}, \quad V_{2N}=600 \text{ meters/sec}.$$

Actually the speed is not uniform over the interval of a wavelength, the above numbers are an average over a path close to the wavelength. The nonuniformity is periodic. A feature common to both tubes is the damping of the amplitude, away from the cathode, in a manner illustrated in Fig. 7. The dc level of the light signal varies simultaneously: high with the high amplitude, low with the low amplitude. This causes oscillations to appear, towards the cathode, on the standard recordings of the average light emitted along the positive column, and, at times, the eye can see those "standing striations."

V. ACKNOWLEDGMENTS

The author wishes to express her gratitude to Professor G. H. Dieke for making available the full facilities of his laboratory, and for the constant interest he took in this work.

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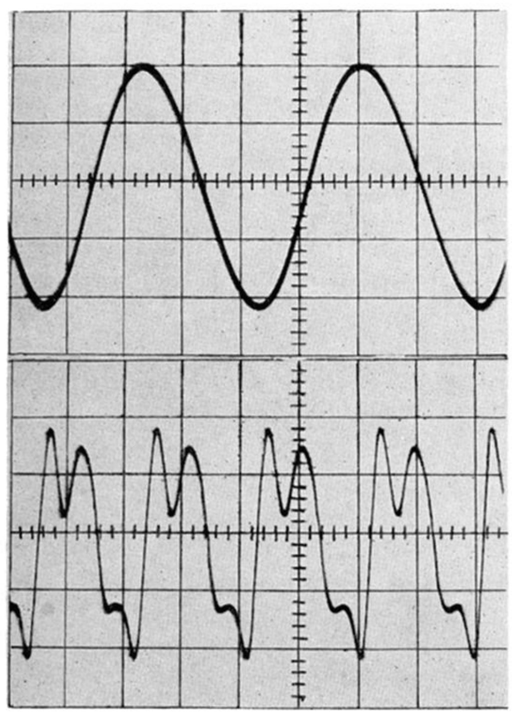

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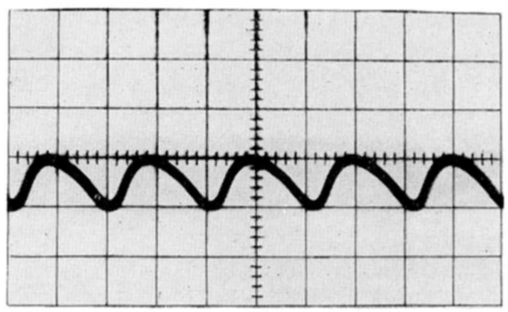

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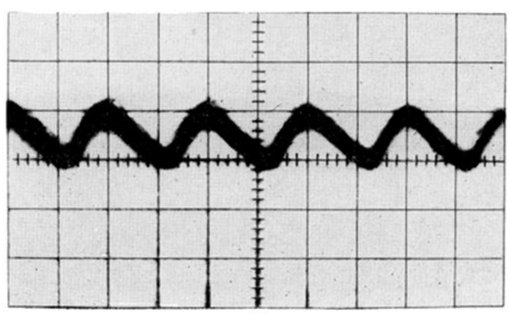

(B)

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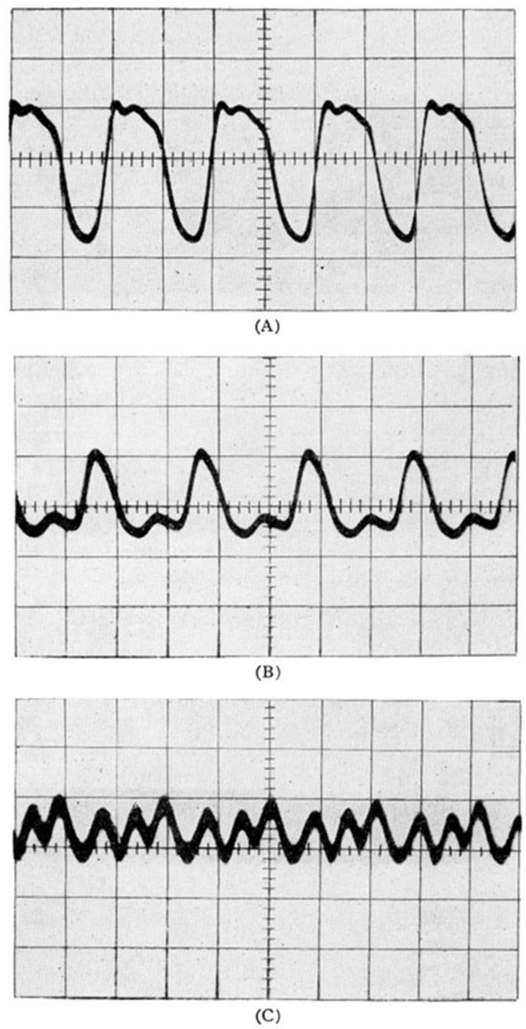

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