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HIGH FREQUENCY DISCHARGES IN MERCURY, HELIUM AND NEON*

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Abstract

Measurements were made of the potential drop at the electrodes and the electric force in the positive column of high frequency discharges in mercury, helium and neon for a large number of gas pressures and for frequencies of oscillation between 1.25 and 22.5 megacycles. The results showed that in general, the magnitude of the electric force was too small to produce electrons whose velocity would be sufficient to ionize or excite the gas. It was observed that as the frequency of oscillation increases, the potential drop at the electrodes decreases. Considering the total voltage between electrodes it was found that the high frequency discharge in mercury has its maximum conductivity when operated at a frequency of 17.5 megacycles (17.15 meters) and at a pressure of 0.002 mm; the discharge in helium has its maximum conductivity at 17.5 megacycles and 0.33 mm pressure; the discharge in neon has its maximum conductivity at 7.5 megacycles (40 meters) and 1.0 mm pressure.

Introduction

PREVIOUS work[1] on the conductivity of a high frequency discharge in hydrogen showed that a knowledge of the variation of the total voltage across the discharge with the gas pressure and the frequency of oscillation is not sufficient to determine the mechanism of the discharge, for the potential difference between electrodes consists of two parts. The first is the drop in potential in the body of gas. The second is the drop in potential at the electrodes which includes the dielectric loss in the glass under the electrodes and the drop in potential at the electrodes due to the accumulation of positive space charge, if any. In order to compare experimental results with any theory of the mechanism of the discharge, it is necessary to study the electric field in the positive column of the discharge, in particular, its variation with gas pressure and frequency of oscillation.

The apparatus used and the experimental procedure followed were essentially the same as in the work on hydrogen. Measurements were made of the voltage between electrodes necessary to produce a current of 100 milliamperes in the gas, the distance between electrodes being varied from 40 to 100 cm in 10 cm steps. If the values of the total voltage between electrodes are plotted against the corresponding distances between electrodes, a curve is obtained which, in general, approximates a straight line. Assuming that as the distance between electrodes increases, the drop in potential at the electrodes remains constant, then the slope of the line gives the electric field in

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[1] C. J. Brasefield, Phys. Rev. **35**, 1073 (1930).

the positive column which when multiplied by $2^{1/2}$ gives the amplitude of the electric force. Extrapolating the curve to zero distance between electrodes, the potential drop at the electrodes is found. Values of the electric force in the positive column of the discharge as well as the potential drop at the electrodes were in this way obtained for a large number of gas pressures and for ten frequencies of oscillation between 1.25 and 22.5 megacycles.

Results

1. Experiments on mercury. The discharge tube used was 120 cm long, 5.2 cm internal diameter while the electrodes surrounding it were of sheet copper 5 cm wide. Except for a mercury reservoir at one end, the whole tube was surrounded by an electric furnace which kept it at a temperature of about 150°C. To regulate the vapor pressure of the mercury, the reservoir

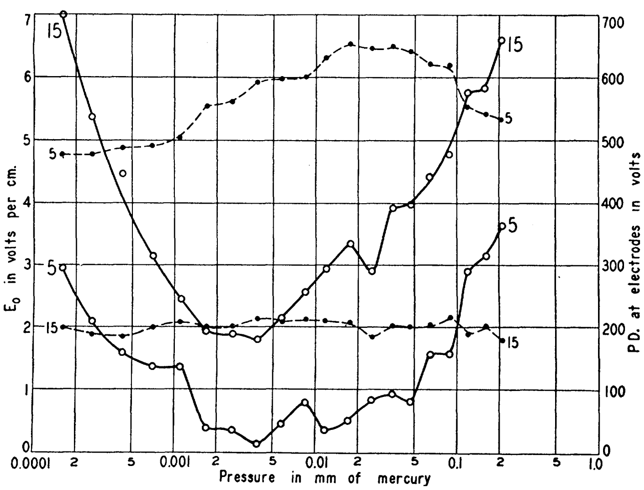

Fig. 1. The variation with pressure of the electric force (solid curves) and the potential drop at electrodes (broken curves) in a high frequency discharge in mercury operated at 5 and 15 megacycles.

was immersed in a water bath which was kept at a constant temperature within 0.2°C during a given run. Measurements were taken at 5° intervals from 0° to 95°C.

Fig. 1 shows, for two typical frequencies of oscillation, the variation with pressure of the electric force and the potential drop at electrodes when a current of 100 milliamperes is passing through the tube. It was observed that as the frequency of oscillation increases, the potential drop at the electrodes decreases from approximately 800 volts at 1.25 megacycles to 200 volts at 15 megacycles. This, without doubt, accounts for the fact that the spark spectrum of mercury was quite pronounced in the region under the electrodes when the discharge was operated at frequencies below 5 megacycles. Considering the total voltage between electrodes, it was found that the discharge has its maximum conductivity when operated at a frequency of 17.5 megacycles (17.15 meters) and at a pressure of 0.002 mm (25°–30°C).

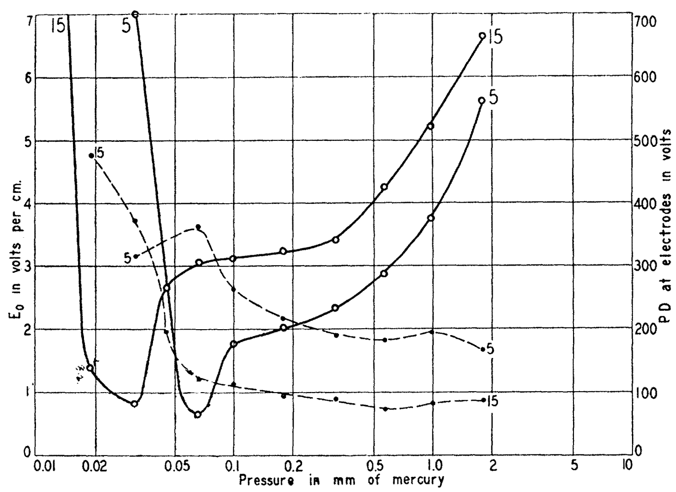

Fig. 2. The variation with pressure of the electric force (solid curves) and the potential drop at electrodes (broken curves) in a high frequency discharge in helium operated at 5 and 15 megacycles.

2. *Experiments on helium and neon.* The discharge tube used was 130 cm long, 5.1 cm internal diameter while the electrodes surrounding it were of sheet copper 5 cm wide. The helium was purified in a misch metal arc and

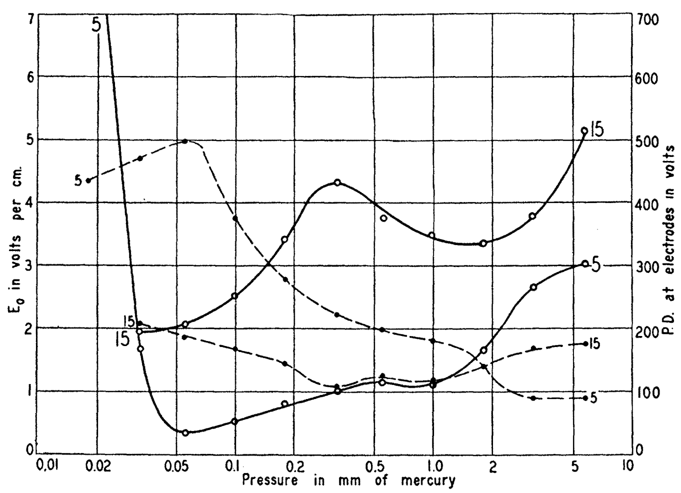

Fig. 3. The variation with pressure of the electric force (solid curves) and the potential drop at electrodes (broken curves) in a high frequency discharge in neon operated at 5 and 15 megacycles.

then circulated over charcoal in liquid air. Spectroscopically pure neon was purchased and further purified by circulation over charcoal in liquid air.

Figs. 2 and 3 show, for two typical frequencies of oscillation, the variation with pressure of the electric force and the potential drop at the electrodes for high frequency discharges in helium and neon carrying 100 milliamperes. As in mercury, the potential drop at the electrodes decreases as the frequency of oscillation increases. Considering the total voltage between electrodes, it was found that the discharge in helium has its maximum conductivity when operated at a frequency of 17.5 megacycles (17.15 meters) and at a pressure of 0.33 mm. The discharge in neon has its maximum conductivity at 7.5 megacycles (40 meters) and 1.0 mm pressure; under these conditions it was possible to obtain a current of 520 milliamperes through the discharge, which was limited, of course, only by the output of the high frequency generator.

In neon, striations were observed at frequencies below 10 megacycles. At frequencies below 5 megacycles, if the pressure was in the neighborhood of 1.0 mm, these striations moved along the tube from one electrode to the other. Moreover, both the direction and velocity of motion could be changed either by varying the current through the tube or, if the current was properly adjusted, by moving one's hand toward or away from the tube. It is suggested that this phenomenon might be produced by beats between plasma ion oscillations and the applied high frequency oscillations.

Discussion

The motion of an electron in a high frequency electric field can be represented by the equation

$$m\ddot{x} = eE_0 \sin(2\pi ft + \delta) \tag{1}$$

where E_0 is the amplitude of the electric force, f the frequency of oscillation and δ a phase constant which depends on the value of E_0 at the instant the velocity of the electron is zero. Integrating Eq. (1), we get the velocity of the electron at any time t,

$$\dot{x} = -\frac{e}{m}\frac{E_0}{2\pi f}\cos(2\pi ft + \delta) + \frac{e}{m}\frac{E_0}{2\pi f}\cos\delta \qquad (v_0 = 0). \tag{2}$$

It is evident that for a given E_0, f and δ, an electron will have its maximum velocity after a time $t = 1/2f$, that is, after it has been under the influence of the electric force for one half cycle. The value of this velocity is

$$v = \frac{e}{m}\frac{E_0}{\pi f}\cos\delta. \tag{3}$$

Moreover, those electrons for which $\delta = 0$ will have the greatest velocity for a given E_0, namely

$$v_{\max} = \frac{e}{m}\frac{E_0}{\pi f}. \tag{4}$$

Hence if we substitute for $v_{\max}$ the ionizing velocity of electrons for the gas in question, we should get the minimum value of E_0 necessary to sustain a high frequency discharge in that gas. For 10 volt electrons (mercury) we find $E_{0\min}=0.34\times10^{-6}\times f$ volts per cm. For 25 volt electrons (helium and neon) we find $E_{0\min}=0.53\times10^{-6}\times f$ volts per cm. A glance at Figs. 1, 2, and 3 shows that the majority of the experimental values of E_0 are still less than these minimum values. It appears, therefore, that in the high frequency discharge, electrons whose velocity is sufficient to ionize (or even excite) a gas molecule cannot be produced in the positive column of the discharge.

Of course, it is not necessary that ionization processes in the high frequency discharge be very efficient since the only way ions can disappear is by recombination or diffusion to the walls. The same cannot be said of the excitation processes, however, for the intensity of the light produced in the positive column is quite comparable with the intensity of the light emitted by the positive column of an ordinary Geissler tube carrying the same current. The only source of high velocity electrons imaginable is the region under the electrodes; but it is hard to believe that these electrons should be responsible for all the ionization and excitation in the positive column of the discharge. The writer confesses that he is unable to suggest any reasonable solution of the problem from a consideration of the mechanics of individual electrons; whether or not an explanation of the phenomena can be worked out by considering the volume of ionized gas as a plasma has not as yet been determined.

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