ELECTRON VELOCITIES IN A HIGH FREQUENCY DISCHARGE IN HYDROGEN

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Abstract

A high frequency discharge in hydrogen was obtained by applying undamped high frequency voltages to the movable external electrodes of a cylindrical discharge tube. The mean velocity of the electrons in the discharge was determined from the ratio of the densities of certain singlet and triplet lines of the molecular spectrum of hydrogen. It was found (1) that the electron velocity increases as the voltage between electrodes is increased, the gas pressure and the frequency of oscillation being constant; (2) for a given voltage between electrodes, the electron velocity is, in general, greater the longer the wave-length of oscillation; (3) the electron velocity decreases as the pressure is increased. The paper concludes with a discussion of the mechanism of the high frequency discharge in which an explanation of its behavior is proposed.

Introduction

In the study of any sort of gaseous discharge, one of the more important items of interest is the mean velocity of the electrons in the discharge and its variation under different conditions. The high frequency discharge with external electrodes is a very peculiar type of gaseous discharge. Studies have been made of numerous characteristics of this discharge, such as the striking and maintaining potentials[1] and the conductivity[2] but to the writer's knowledge no one has succeeded in determining the mean electronic velocity in the discharge. As a matter of fact, it would appear to be extremely difficult, if not impossible, to make such measurements by the ordinary method applied in arcs and glow discharges, namely, the Langmuir exploring electrode method. It has been suggested[3] that the mean electron velocity in a high frequency discharge in hydrogen might be determined from the ratio of the densities of certain singlet and triplet lines of the molecular spectrum of hydrogen. This method has been employed with more or less success in the present work.

Apparatus

To produce the high frequency oscillations, two U. X. 852 75-watt tubes were used in push pull in an ordinary Colpitts circuit, which is shown diagrammatically in Fig. 1. The plate voltage was supplied by a 2 KW, 3000 volt transformer, T_1, and measured by an electrostatic voltmeter, V.

[1] R. L. Hayman, Phil. Mag. **7**, 586 (1929) and others,

[2] H. Steinhauser, Zeits. f. Physik **54**, 788 (1929).

[3] C. J. Brasefield, Phys. Rev. **34**, 437 (1929).

One quarter ampere fuses, F, protected the plates from overloading. The radio frequency chokes, $R.F.C.$, were made of #30 B. & S. copper wire, $S.C.E.$, wrapped on 3-inch bakelite tubing; 65 turns for 15, 25, and 50 meters, 180 turns for 100 meters, and 300 turns for 200 meters. The mica condensers C_1 had a capacity of 0.002 μf. and could stand 2500 volts. The variable air condensers C_2 had a capacity of 0.00045 μf. and were carefully calibrated. The inductance L was a coil of 3/16 inch copper tubing 3.5 inches in diameter; 2 turns for 15 meters, 3 turns for 25 meters, 5 turns for 50 meters, 10 turns for 100 meters, and 30 turns for 200 meters. The electrodes surrounding the discharge tube were of sheet copper 2 cm wide. Copper ribbon 1/4 inch wide was used for wiring the tank circuit and the tank current was measured by a 0-15 ampere radio frequency ammeter A (thermocouple type). The grid leak, $G.L.$, was a 40,000 ohm wire wound resistor to dissipate about 100 watts. The filament current was supplied by a 175 watt, 12 volt transformer T_2, across whose secondary were the by-pass condensers C_3(0.002μf).

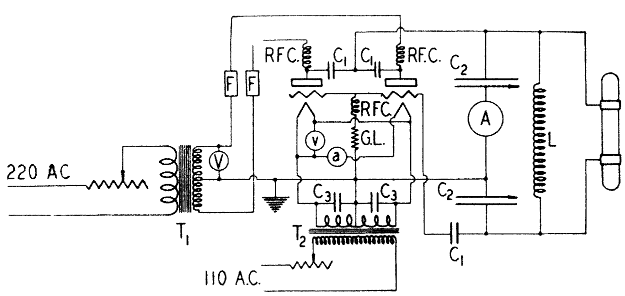

Fig. 1. Diagram of oscillatory circuit.

The discharge tube was of Pyrex glass, 30 cm long and 4.5 cm in diameter, with an optical glass window sealed into one end. Hydrogen was admitted to one end of the tube by means of a platinum tube and was pumped out at the other end, thus insuring a continuous flow of pure hydrogen. The platinum tube was 20 cm long, 1 mm in diameter with 0.1 mm walls. It was surrounded by a glass jacket through which commercial hydrogen was flowed. On heating the platinum tube to a dull red heat (about 600°K) by passing a current of about 16 amperes through it, an adequate flow of hydrogen was obtained through the discharge tube. The pressure could be varied either by changing the temperature of the platinum tube or by means of a valve which regulated the rate of pumping. Pressures were measured by a McLeod gauge.

Procedure

The voltage between electrodes, which is equal to the voltage across the condensers C_2 was calculated from the formula $E=I/2\pi fC$ where E is the voltage across the condensers, I is the current through them in amperes, f is the frequency of oscillation and C is the capacity in farads of the two condensers in series. The condensers C_2 were always adjusted so as to be of equal capacity. Hence, the ammeter A was at a potential node and its readings were independent of its capacity to earth.

A series of runs was taken at frequencies of oscillation corresponding to 15, 25, 50, 100, and 200 meters wave-length. The pressure was kept constant at 0.03 mm and the distance between electrodes was 5 cm. For each run, the tank current I, and consequently the voltage between electrodes E, was varied between the widest limits possible. The minimum voltage was

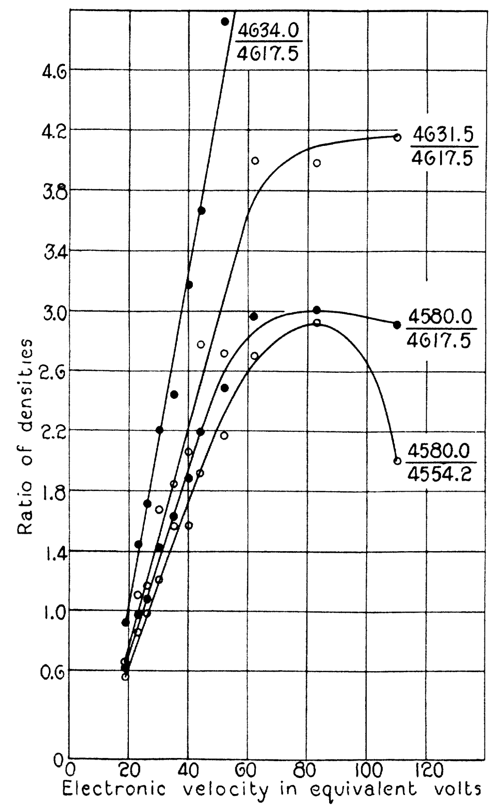

Fig. 2. Variation in the ratio of the densities of singlet and triplet lines with the electronic velocity (taken from Phys. Rev. **34**, 437 (1929).

approximately that at which the discharge first struck. The maximum voltage was determined by the output of the oscillator, that is, the voltage at which the plates of the valves became red hot.

Between these limits, photographs were taken of the discharge at regular intervals. The spectrograph used was a fairly fast two-prism glass instrument. Exposures were taken on Cramer Hi-Speed plates and were all of five minutes duration. Microphotometric traces were then made of all the spectra by means of a Moll self-registering microphotometer. From these traces, the density of the singlet line 4631.5 and the triplet line 4617.5 were obtained by use of the relation: density = log $d/d\text{-}h$, where d is the total galvanometer deflection in the absence of a line and h is the height of the peak on the trace corresponding to the line.

From the ratio of the densities of these two lines, the electron velocity could easily be determined since the variation in this ratio with electron velocity is already known[3] (see Fig. 2). It might be remarked that although the curves of Fig. 2 were obtained using electrons of uniform velocity, they also can be used to find the *mean* electronic velocity; for the contribution to the ratio of the densities of 4631.5 to 4617.5 of those electrons whose velocity is greater than the mean will be balanced by the contribution of the elec-

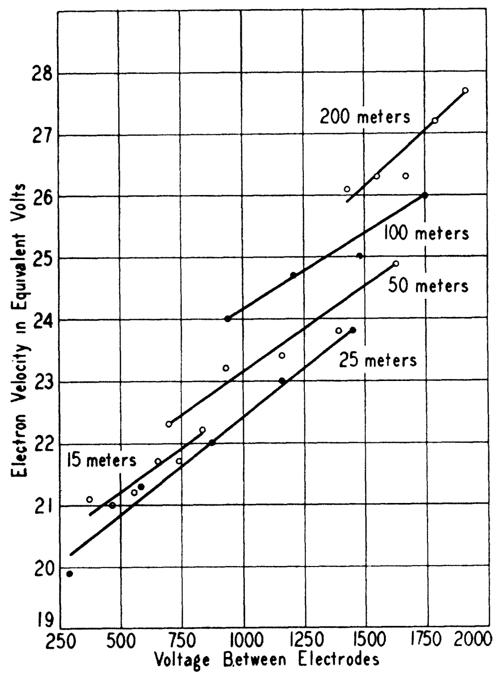

Fig. 3. Variation in electron velocity with voltage between electrodes and frequency of oscillation.

trons whose velocity is less than the mean—provided always, that the mean velocity lies on the straight part of the curves.

Results

Variation of electron velocity with voltage and frequency. The variation in electron velocity with voltage between electrodes and frequency of oscillation is shown in Fig. 3. At all wave-lengths, the electron velocity increases as the voltage between electrodes is increased. Moreover, for a given voltage between electrodes, the electron velocity, in general, increases with the wave-length of the oscillation. (The electron velocities at 15 meters seem to be an exception to this). The error in this method of finding electron velocities is estimated at 2 volts while the experimental error is something under 0.5 volts. In other words, if two electron velocities were found to be 20 and 24 volts, they both might be in error by 2 volts, but their difference would not be in error by more than 0.5 volts.

Variation of electron velocity with gas pressure. To find the variation of electron velocity with gas pressure, a series of exposures were taken at various pressures between 0.01 mm and 0.06 mm. The wave-length of the oscillations was 25 meters, distance between electrodes 7 cm and voltage between electrodes 1020 volts. Since the ratio of the densities of the singlet and triplet lines varies with pressure as well as with electron velocity, it was necessary to correct the values of the ratio of 4631.5 to 4617.5 for the change in pressure. To the writer's knowledge, there has been only one attempt to find the effect of pressure on the excitation of the secondary spectrum. The results presented in that paper[4] were of such a nature that the correcting factor could only be calculated roughly. Very approximately, then, it was found that the mean electron velocity decreased from 25 volts at 0.01 mm to 23 volts at 0.06 mm. pressure.

Variation of electron velocity with distance between electrodes. In general, a change in the distance between electrodes produced only a slight change in the electron velocity. At 15, 50, and 100 meters, increasing the distance between electrodes seemed to produce a slight increase in electron velocity, while at 25 and 200 meters, a slight decrease in electron velocity was found.

Discussion

It is not difficult to understand why the mean electron velocity should increase when the voltage between electrodes is increased, and decrease when the pressure is increased; but at first one does not see why the electron velocity should increase when the wave-length of the oscillations is increased. To understand this, it will be necessary to consider more in detail the functioning of a high frequency discharge with external electrodes.

In a direct current Geissler tube discharge, with cold cathode, we know that the discharge is started by a few stray electrons in the gas which, under the action of the electric force between electrodes, produce more electrons by ionizing gas molecules. In this way, the number of electrons is increased to the point where the discharge strikes. Because of the unidirectional current, it is essential that there be a source of electrons, namely, the cathode. This source of electrons would not have been necessary, however, if the direction of the applied electric force were reversed before the electron cloud had time to disperse (by leakage along the walls of the tube, recombination with positive ions, etc.). This condition of affairs is obtained by applying high frequency electric forces to the discharge and since a source of electrons is no longer necessary we are able to use external electrodes.

Before a high frequency discharge will strike, however, a second condition must be fulfilled, namely, that the electrons shall attain ionizing velocity before they reach the end of the discharge tube. As a matter of fact, they

[4] P. Lowe, Trans. Roy. Soc. Can. **20**, 217 (1926).

probably must attain ionizing velocity before they have travelled the distance between the electrodes, since it is in this interval that they are under the influence of the electric forces. If, now we keep the voltage applied to the electrodes constant and increase the wave-length of the oscillations, it is evident that the time required for the electric force to reach its maximum value becomes longer and longer. Consequently, it will take the electron more time to reach ionizing velocity at the longer wave-lengths than it does at shorter wave-lengths. In other words, if an electron is to reach ionizing velocity in the same time at two different wave-lengths, the applied voltage must be increased for the longer wave-length, which means that the minimum striking potential will increase with the wave-length of the oscillation. This fact has been verified in the present experiments (see Fig. 3) as well as in those of others.[1]

It has also been shown by others[2] that a discharge has its maximum conductivity under the same conditions that give the minimum striking potentials. Hence, by referring to Fig. 3, we must conclude that the conductivity of the discharge decreased with increasing wave-length. So if the discharge were operated at two different wave-lengths of oscillation, but with the same voltage applied to the electrodes, we would expect to find a smaller drop in potential along the positive column of the discharge which had the greatest conductivity. That is, for equal voltages applied to the electrodes, there will be a smaller drop in potential along the positive column of the discharge when it is operated at shorter wave-lengths. Consequently, at shorter wave-lengths, we would expect to find smaller electron velocities. This explains why, for a given voltage applied to the electrodes, the electron velocity increases with the wave-length of the oscillations.

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