THE PROPAGATION OF LUMINOSITY IN DISCHARGE TUBES

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Abstract

The velocity of propagation of luminosity in long discharge tubes, when a high potential was suddenly applied to one electrode, was studied by means of a mirror rotating between 2000 and 3000 revolutions per sec. Air and hydrogen at pressures from 0.04 to 0.5 mm of mercury were used in the tube. The luminosity always moved from the electrode to which the potential was suddenly applied toward the electrode maintained at ground potential. The velocity of the luminosity after progressing a few centimeters from the electrode to which the surge potential was applied, travelled with almost a constant speed, usually within the limits of 10^9 to 10^{10} cm/sec, depending upon the conditions of the experiment. A qualitative explanation of the results is offered based upon the formation of space charge.

IN THE case of long discharge tubes J. J. Thomson[1] was the first to observe that the luminosity did not start simultaneously throughout the length of the tube but traversed it from anode to cathode at a finite and measurable velocity. The potential across his tube was applied by attaching its electrodes directly to the terminals of an induction coil and the velocity of luminosity was measured by reflecting the light from two portions of the tube, several meters apart, by means of a rotating mirror, into the field of view of a measuring telescope. He experimented with a large variety of electrodes and came to the conclusion that the velocity was independent of the size, shape and material of the electrodes. For the velocity of the luminosity through a discharge in air at a pressure of 0.5 mm of mercury in a glass tube 5 mm in diameter, he found a velocity greater than half that of light. From this high value of the velocity he was able to conclude that the propagation of the luminosity was not due to the motion of the emitting atoms and molecules because of the absence of an observable Doppler effect in the spectrum lines. Several years later J. James[2] using the method of Abraham and Lemoine[3] was unable to observe a velocity of propagation such as might be expected from the experiments of Thomson; while the writer[4] using a somewhat similar method to study the order of appearance of spectrum lines in discharge tubes, obtained results in qualitative agreement with those of Thomson.

Whiddington[5] Zeleny and others have observed moving pulses of luminosity in a discharge tube the electrodes of which were attached to the terminals of a storage battery. The current, at least in some cases, was intermittent and the velocity of the moving pulses was much smaller than

[1] Recent Researches, 115, 1893.
[2] J. James, Ann. d. Physik **15**, 954 (1904).
[3] Abraham and Lemoine, Ann. Chem. et Phys. **20**, 264 (1900).
[4] J. W. Beams, Phys. Rev. **28**, 475 (1926).
[5] Whiddington, Nature **115**, 506 (1925).

that observed by Thomson. This however is not in disagreement with the results of Thomson and the writer for it represents a luminous velocity through a gas already ionized and where large space charges are present, whereas Thomson and the writer observed the initial pulse of luminosity through the tube when a high potential was suddenly applied across the gas in an un-ionized or weakly ionized state. Recently, further observations on this velocity of propagation in discharge tubes have been made under somewhat different electrical conditions than those previously used. It was found that when an impulse potential was applied to one end of a long discharge tube, that the luminosity in general progressed from the electrode to which the surge potential was applied toward the electrode maintained at ground potential regardless of the polarity of the impressed potential surge. The phenomenon has been studied in discharge tubes of various shapes and for different pressures of air and hydrogen but it has not yet been possible to develop a quantative theory that will explain all the observations. Never-

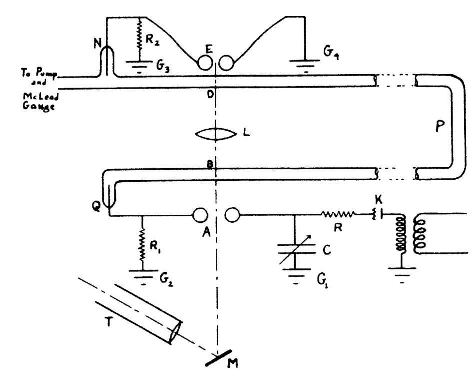

Fig. 1.

theless it may be of interest to describe some of the experiments and record the results obtained.

The arrangement of the apparatus is shown schematically in Fig. 1. A high voltage transformer charges a variable capacity C (0.001 to 0.01 microfarads), through a kenetron K, until a spark at A occurs which impresses a potential on the electrode of the tube at Q. In a certain average time the discharge traverses the tube and finally raises the potential of the electrode N until a spark at E occurs. The appearance of the light at A, B, D and E was observed in the telescope T after reflection in a rapidly rotating mirror M. The lens L focused the light from D and E so that their images fell in the same vertical plane with A and B. A vertical slit was so arranged that, with the mirror M stationary, the images of A, B, D and E appeared one above the other in the field of view of the telescope T with their vertical edges falling on parallel lines. Hence when the mirror was rotating rapidly the time between the appearance of the light at A, B, D and E could be measured by noting the relative horizontal displacement of their respective images in T. The water resistance R_1 (10^5 ohms) and R_2 (10^8 ohms) served to keep the electrodes Q and N at ground potential until the sudden impulsive potential was applied. R_1 also prevented the spark A from stopping before the discharge in the tube could start and thus avoided troublesome oscillations. The high capacity grounds G_1, G_2 and G_3, G_4 were independent and special precautions were taken to insure that the impulsive potential surge at A did not change the potential at G_3 and G_4 until the discharge of the tube was initiated.. Impulsive surges were applied to the tube every second and the observations were obtained by waiting until the tube flashed at the proper time for its image to fall into the telescope T. The stellite mirror M was rotated between 2000 and 3000 revolutions per sec and the distance AM was one meter. The high rotational speed of the mirror was obtained by the method of Henriot and Huguenard[6] modified to insure greater stability and flexibility.[7] The tube was exausted through a P_2O_5 trap by means of a "Hyvac" oil pump and the pressure was measured on a McLeod gauge.

The first tube 490 cm in length was constructed of glass tubing 5 mm in diameter with electrodes made of 50 mil tungsten wire sealed through the glass as shown in the drawing. In the initial experiments air was used at pressures from 0.04 to 0.5 mm of mercury and later hydrogen was used over the same range. For impressed potentials of between 20,000 volts and 40,000 volts the time between the appearance of the light at A and at B was much greater than the time between the appearance of the light at B and D. In almost every case the time between the appearance of the light at D and at E was too small to measure. This short time between the appearance of the light at D and E resulted from the fact that the width of A was always more than four times that of E. Therefore E was considerably overvolted and its time lag made very small.[8]

The phenomena usually observed can be described as follows: Soon after the appearance of the light at A an intense luminosity having the shape of a solid cylinder with a conical tip, progressed relatively slowly toward B. The base of the cylinder remained at Q and the moving tip was on the axis of the tube. At a distance (usually not greater than 40 cm in these experiments) the moving tip appeared to flatten into a plane and traversed the remaining length of the tube with a much higher speed. For example in the case of hydrogen at approximately 1.5 mm mercury pressure and a gap width of 8 mm at A, the light from A appeared 1.2×10^{-6} sec. before that from B, while D appeared in only 1.2×10^{-7} sec. after B. When the light at the point P midway between B and D was brought into the field of view of T, by means of an auxiliary mirror and lens not shown in the figure, it was found to appear at a time approximately half way between B and D. This showed that the velocity from B to D was roughly constant and equal to about 4×10^9 cm/sec. in this special case. On the other hand, since the

[6] Henriot and Huguenard, Comptes rendus **180**, 1389 (1925); Jour. d. Phys. et Rad. **8**, 443 (1927).

[7] Beams, Rev. Sci. Inst. (in press)

[8] Beams, Jour. Frank. Inst. **206**, 809 (1928).

distance from Q to B was 50 cm the velocity of the luminosity between the two points could not have been greater than 3.8×10^5 cm/sec. or 1000 times less than the velocity from B to D. The time between the appearance of the luminosity at A and B was influenced by a number of factors. It was decreased with increasing potential and also with increasing conductivity of the tube. The charge on the walls the shape and material of the electrodes, together with the sputtering of the electrodes on the walls of the tube are probably very important factors.

After the luminosity finally attained the higher velocity, it apparently was not affected by the type of electrodes and did not depend critically on the pressure or voltage applied at Q. There was, however, some increase in velocity with voltage. Also when the pressure was adjusted so as to decrease the effective resistance of the tube the velocity was increased. At pressures from 0.2 mm to 0.4 mm of mercury, the light at B would usually first appear somewhat fainter than at D but become of equal intensity soon after D became luminous. Sometimes at the higher pressures (0.4 mm to 0.5 mm of mercury) a very intense luminous pulse not longer than 50 cm would traverse the tube from Q to N at a velocity of about 4.5×10^9 cm/sec., regardless of the polarity of the impressed surge (30,000 volts). As soon as the pulse of luminosity reached N the whole tube became luminous throughout. Many cases have also been observed where the luminous pulse traveled first from Q to N followed by the luminosity progressing from N to Q.

In order to study the effect of the walls on the high velocity luminous propagation, a long discharge tube, made of flexible thick rubber pressure tubing 5 mm inside diameter was substituted for the glass tube. The light was viewed through short sections of glass tubing connecting the rubber tubing at A, P and D. The electrodes were made of aluminum rods fastened into glass tubes by sealing wax. With this arrangement, although (in the case where the pressure and impressed voltage were the same) the velocity was actually measurably less than in the glass tube, the inductance and capacity of the tube as a whole were shown not to be important factors in determining the luminous velocity. By folding the tube its inductance as a whole could be almost eliminated and still the phenomenon was approximately the same as with it folded in such a way as to make its inductance a maximum. However, the inductance and capacity of the tube for electric impulses, which reach their maximum in a time much shorter than that required for the impulse to traverse the tube, may be an important factor, but the effect of this could not be thoroughly tested.

It is obvious as pointed out by Thomson that the high velocity of luminosity cannot be due to the movement of the emitting atoms and molecules because of the absence of a large Doppler effect. Nor can it result from charged atoms or molecules of any kind moving along the tube, for even the total impressed voltage is many times too small to give the ions a velocity comparable with that of the luminosity. Consider now a typical case of hydrogen at 0.2 mm pressure with a 30,000 volt positive surge impressed on the electrode Q. Light from A appeared about 7×10^{-7} sec. before it did at E and at B approximately 10^{-7} sec. before it did at D and E. The velocity of the luminosity from B to D was therefore 4.9×10^{9} cm sec. If the impressed voltage was distributed uniformly across the tube, the field would be 61.2 volts/cm. An electron would fall through roughly 24 volts between collisions and therefore could ionize the hydrogen gas throughout the length of the tube. It is not very probable, however, that many free electrons would be present in the tube at the time of the application of the potential and the fields would not be great enough to produce much ionization by positive or negative ions. The current would be small and E would remain nonluminous until space charges so arranged themselves as to allow considerable current to traverse the tube. This time required for the space charges to form throughout the tube works out to be too long and further the luminosity would be expected to appear gradually throughout the whole positive column rather than abruptly at the electrode Q and move toward N. It is possible that the luminosity did not strictly follow the current rush yet the experiments definitely showed, by the very small time between the appearance of the light at D and E, that the amount of current flowing out of the tube is very small until the luminosity completely traversed the tube. In the above discussion the assumption that the impressed voltage was uniformly distributed is of course not true for impressed surges having wave fronts which reach their peak value in a time less than the length of the tube divided by the velocity of the electromagnetic wave along the tube. This might double the field but only for a time small in comparison to the time required for the tube to start discharging. The comparatively long time between the appearance of the light at A and at B also makes it very unlikely that the velocity of luminosity observed can be identified with velocity of the potential wave along the tube.

However, when the process of formation and distribution of space charge in the tube is examined more carefully it may be possible to find a qualitative explanation of most of the results observed. The important factors in starting the ionization at Q seem to be the influence of the walls and the size and shape of the electrode to which the high potential is applied. In the neighborhood of the electrode, due to its shape and irregularities, the field is very high and intense ionization should take place. This ionization due to the large difference in the mobilities of positive ions, negative ions and of electrons respectively should result in the establishment of a space charge. This space charge, once formed near the high potential electrode Q must move down the tube regardless of the polarity of the applied potential because of the changes it produces in the field near its edges. The luminosity should then follow roughly the region of intense ionization.

The time between the appearance of the light at A and at B would then represent the period required to build up the space charges to a critical value around the high potential electrode Q, while the higher velocity of luminosity between B and D would represent the velocity with which the intense ionization moved.