CONTROL OF SUCCESSIVE IONIZATION BY COLLISION IN A PHOTO-ELECTRIC CELL

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A gas-filled Photo-electric Cell as used for photometry[1] or for the reproduction of sound[2] consists of a cathode covered with a layer of alkali metal and an anode at a distance of about 2-3 cm. The sensitiveness of the cell achieves its largest value for an optimum pressure of the gas. Considering the influence of potential, the sensitiveness of the cell increases exponentially with the voltage applied to the electrodes, revealing the characteristic phenomena of ionization by collision.

In practical application of the cell, a limit is set to the value of the permissible potential by the instability of the current passing the cell when the critical voltage is approached. At this stage a visible, independent discharge establishes itself, which usually destroys the sensitiveness of the cell and endangers the delicate current measuring instrument.

The present investigation is the result of an attempt to overcome these deficiencies. It was found that by the application of a thermionic valve the current through the cell can be stabilized, and that by increasing some of the dimensions of the cell, a larger photo-electrically excited current can be obtained.

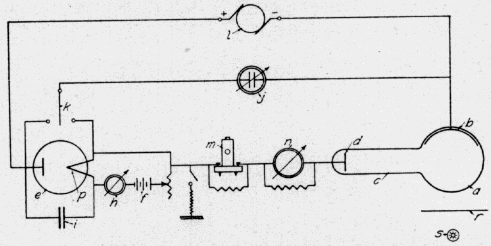

Fig. 1. Application of a Thermiamic Tube in Series with a Photo electric cell.

One of the arrangements used in this investigation is shown in Figure 1. The photo-electric cell (a) consists of a bulb, the lower part of which is silvered and covered

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1Kunz, Jacob and Stebbins, Joel, On the Construction of Sensitive Photo-electric Cells. Phys, Review, Vol. 7, 1916, p. 62.

2Tykocinski—Tykociner, J.—Photographic Recording and Photo-electric Reproduction of Sound. Trans. Soc. Motion Picture Eng. Vol. 16, 1923, p. 90.

with a layer of potassium (b). This light-sensitive layer metallically connected with a platinum wire and sealed in the glass bulb forms the cathode of the cell. An aluminum disc anode (d), 1 cm. in diameter, was sealed in a side tube (c) at a distance of 10 cm. from the cathode. The cell was filled with Helium at a pressure of about 0.01 mm. The Thermionic device (e) consisted of a Kenotron rectifying tube (Type UV-201) the filament (p) of which was heated by the battery (f). The heating current was controlled by the rheostat (g) and measured by the ammeter (h). A condenser (i) connected parallel to the Kenotron, having a capacity of about 2500 mmf., served to minimize the influence of the variable tube capacity due to space charges upon the measurements of potential at the cell. This potential was measured by means of an electrostatic voltmeter (j). A switch (k) served to connect the voltmeter either across the motor generator (l) or across the cell (a). Between the anode (d) of the cell and the heated cathode (p) of the Kenotron (e) a sensitive reflecting galvanometer (m) and a less sensitive current-measuring instrument (n) were introduced, which allowed the measurement of a large range of currents passing through the cell.

In order that a current can flow in this circuit, the cathode of the photo-electric cell has to be illuminated from a source of light (s) and the filament (p) of the high vacuum thermionic valve must be heated. Thus both cathodes have to supply the electrons which carry the current. However, the total number of thermions emitted depends only on the temperature of the filament, while the number of ions in the photo-electric cell depends in addition to the intensity of the light source also on the number of collisions taking place between the photo-electrons and molecules on their motion towards the anode. For a constant gas pressure and constant potential between the electrodes, successive collisions will take place only in case the distance between the electrodes is considerably larger than the average free path of the photo-electrons necessary for ionization. The dimensions of the cell were therefore chosen so that possibly large currents could be produced by successive ionization along the path towards the anode.

The current in the circuit, passing the cell and also the valve, is limited by the ions produced in both of them. If in one of them a smaller number of carriers will be produced than in the other, the current which can establish itself in the circuit will be limited to that corresponding to the smaller number. No amount of ions produced in excess in one of the tubes can contribute to the current in the circuit.

By varying the filament current of the valve (e) we can control the maximum current which can flow in the circuit. Instead of using a two electrode thermionic tube, a triode tube can be applied in which the potential of the grid can be regulated by means of a battery and potentiometer. With such a tube the current in the circuit can be controlled at a constant filament current. In both cases the role of the thermionic tube is (1) to limit the maximum current in the circuit, (2) to stabilize the discharge and (3) to make possible very gradual variations of current without allowing discontinuous transformations of discharges to take place in the cell (a).

Much higher potentials can be applied to a photo-electric cell of this kind. It was found possible to use the tube at a critical potential when a visible glow discharge is produced. Due to the stabilizing action of the valve (e) this glow-discharge can be maintained for a long time without appreciably changing the sensitivity of the cell. The currents obtainable by these cells with the described arrangement are of the order of a few milliamperes.

One of the advantages in using a valve in series with a photo-electric cell or other vacuum tubes is the possibility it offers for the study of current-voltage characteristics, especially in regions where sudden changes from one form of discharge into another take place.

In Figure 2 the characteristic of the photo-electric cell described above is reproduced.

The method of obtaining the characteristic curves differs from the usual one in that instead of varying the electromotive force of the direct current generator (1) a constant potential difference is applied across the combination of a thermionic valve and a photo-electric cell. The constant voltage is chosen so that it is somewhat higher than necessary to produce a visible discharge in

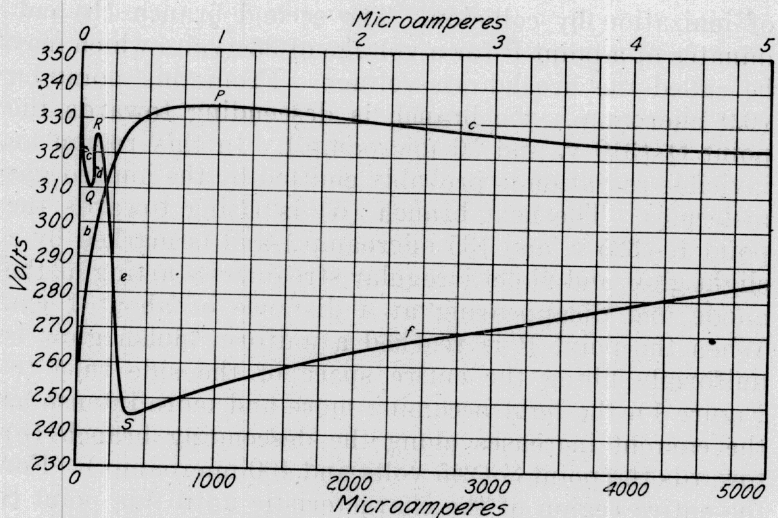

FIG. II. Current Voltage Characteristic of the Photo electric cell.

the cell. How this constant potential difference is divided between the cell and valve depends not only on the joint capacity of the condenser (i) and the valve (e) but chiefly on the temperature of the filament. The supply of electrons by the filament controls the current in the circuit. It is, therefore, sufficient to vary the current which heats the filament in order to obtain corresponding variations of the potential and current in the cell.

The characteristic curves shown in Figure 2 were obtained by the above method. The voltage at the direct current generator was maintained at 400 volts and the filament current varied by a sliding wire rheostat from 0.9 to 1.85 amperes.

The complete characteristic curve, observed over a range of 0-340 volts for currents from 0 to 4.5 milliamperes, consists of six distinct branches. To represent clearly the most interesting parts of the characteristic the graph is divided into three parts, and only the second and third parts are shown in Figure 2. The second part extending from 0.25 to 5 microamperes is drawn in a scale a thousand times larger than the third part including a range from 5 to 5000 microamperes. The first branch (a), not shown in the figure, is the part which follows an exponential low according to Townsend's theory of ionization by collision. The second branch (b) culminates at a point P for a voltage of 334 volts which may be called the breakdown voltage. From this point on (0.9 microamp.) the branch is descending towards the point Q (310 v. and 56 microamp.). In this region an invisible radiation is probably emitted by the ionized gas molecules. The next branch (d) is rising towards the point R (325 v. and 135 microamp.) and is marked by a slight glow and violet irregular streamers starting at the anode and disappearing at a distance of about 1 cm. When the point R is reached a uniform bluish glow is uniformly filling the entire space of the side tube (c. Figure 1), the light becoming more and more intense as the current increases along the descending branch (e) towards the point S (245 volts and 400 microamp.). For the entire region of the characteristic until this point S is reached, the cell retains its photo-electric properties. At every point so far recorded by the graph the value of the current becomes zero, when the source of illumination (75 watt gas-filled tungsten lamp at a distance of 25 cm.) was screened off from the cell.

Shortly before the point S is reached, the current through the cell assumes small definite values even when the cell is not illuminated. These dark currents begin then to increase and in a very narrow region, in proximity of point S, become even larger than the current measured while the cell is illuminated. Thus a reversal of the photo-electric effect could be observed for which the action of illumination consisted in causing a decrease of current passing through the cell.

When the point S is passed pulsations in the intensity of the glow in the tube (c) set in, preceding the establishment of a regular striated blue discharge extending along the entire length of the cell. The rising branch (f) of the characteristic corresponds to this form of discharge, for which the illumination has no influence whatever. Evidently when the conditions are established corresponding to the lowest point on the branch (e), the discharge is transformed from a form dependent on the supply of photoelectrons by the sensitive layer of the cathode into an independent type of discharge, in which sufficient ions are produced by successive ionization in the mass of the gas to sustain itself permanently.

The branch (e) of the characteristic curve corresponds to a luminous discharge which possesses a remarkable property of being photo-electrically controllable. If the illumination of the cell is screened off, the luminous discharge in the tube (c) disappears, reappearing immediately after the cell is again subjected to the source of light. Moreover, the intensity of the glow in the cell follows the variations of intensity produced by the illuminating source of light. Thus a phenomenon was experimentally demonstrated in which a source of light was photo-electrically excited and forced to vary following the variations of a distant source of light.

This method can be applied for stabilizing and for obtaining characteristics of other forms of discharges at atmospheric pressures and in rarified gases. The investigation is continued in this direction, and also the relation is studied between intensity of illumination and photoelectric current for every branch of the characteristic. Experiments are also conducted aiming to utilize the descending branches (c, e) of the characteristic for the production of electric oscillations.

A brief preliminary description of the arrangement was presented before the American Physical Society on December 30, 1924, and was published in the Phys. Rev., Vol. 25, February, 1925, p. 245.

This work was carried out in the laboratory of Professor Jacob Kunz, to whom acknowledgement is due for his encouragement and interest.*

* Preliminary note concerning this investigation was published in the Physical Review, Vol. 25, page 245, by J. T. Tykociner and J. Kunz.