Effect of High Frequency Oscillation on the Photo-electric Current

by Tatsumi Terada

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Abstract

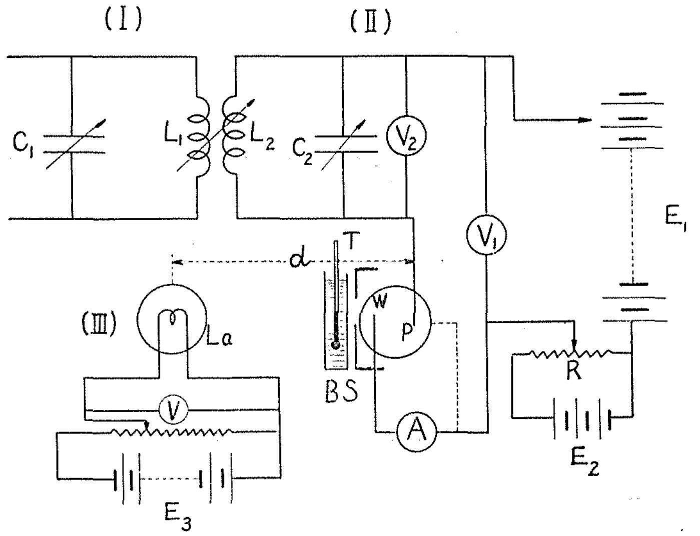
The electric current from a photo-cell increases when a very high frequency oscillation of a few volts is superposed upon a continuous voltage. This peculiar effect depends upon the intensity of illumination and the frequency of the oscillatory voltage, but is nearly independent of the temperature. The effect may be explained at least partly by the disturbances of the negative charge accumulated in front of the cathode of the cell. From this point of view, it is suggested that a critical frequency of the electrons in the cell is about 2140 kilocycles per sec.

It was found by Shenstone[1] that the photo-electric current from a plate of bismuth or of other metals was temporarily increased by the passage of an electric current, and it was attributed by him to an orientation of the elementary crystals of the metals. Horton[2] ascribed the effect to the emission of gases from those portions of the apparatus which were warmed by the current through the metals. Recently, it was concluded by Weber[3] that the "Shenstone effect" must be attributed to the removal of occluded gases from the metals.

It was found by the writer that the current from a photo-cell also increased when a continuous voltage was superposed by high frequency oscillation of a few volts. To investigate this peculiar effect, an apparatus shown in Fig. 1 was employed. (*I*) is a high frequency oscillatory circuit and (*II*) a photo-electric circuit. They are coupled by the coils L_1 and L_2. The oscillatory voltage induced in the circuit (*II*) is altered by changing the coupling and it is measured by means of Moullin's thermionic voltmeter V_2 whose scale is calibrated for every frequency before the measurements are made. A is a microammeter, V_1 a direct current voltmeter, and R is a stretched wire potentiometer of 30 ohms to be used for the fine adjustment of the continuous voltage

1. A. G. Shenstone: Phil. Mag. **41**, 916 (1921); **42**, 596 (1921), **45**, 918 (1923).
2. F. Horton: Phil. Mag. **42**, 279 (1921).
3. A. H. Weber: J. Frank. Inst. **223**, 215 (1937).

Fig. 1.



V_1. (*III*) is an electric circuit for light source, containing a gas-filled tungsten lamp L_a and a voltmeter V. The light passes through a water-vessel B having the size of 0.9 cm. in width and 12 cms. in length, and a circular slit S 4 cms. in diameter opening at a wall of a soft iron box and then it falls on the cathode P. Consequently, the heating of the cathode by the light is mostly eliminated by the water in the vessel B; and the stray magnetic field is partly screened by the soft iron box.

A voltage-current curve for a caesium vacuum photo-cell (Mazda PG-65-V) used in most of the experiments is shown in Fig. 2. It was obtained by varying the continuous voltage V_1 without applying any oscillatory voltage, when the cathode P was illuminated by the light of constant intensity emitted from a 60 watt-lamp placed at a distance of 30 cms. from the cell. In the figure, the abscissa gives the continuous voltage V_1 in volts, and the ordinate the current i_0 in microamperes.

However, when a very high frequency oscillatory electromotive force V_2 was superposed upon the continuous voltage V_1, the photo-electric current generally differed from the value i_0 corresponding to the case employing only a continuous voltage V_1 in Fig. 2. Some observations were made with several constant continuous voltages V_1, by varying the oscillatory voltages V_2 having the constant wave-length 140 ms. In Fig. 3, values obtained of the photo-electric current i are

Fig. 2.

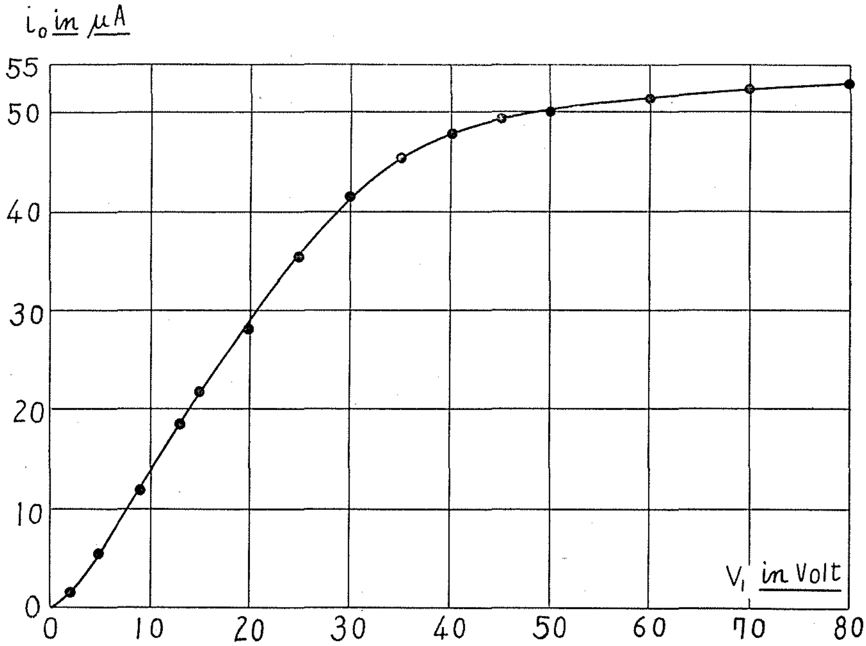
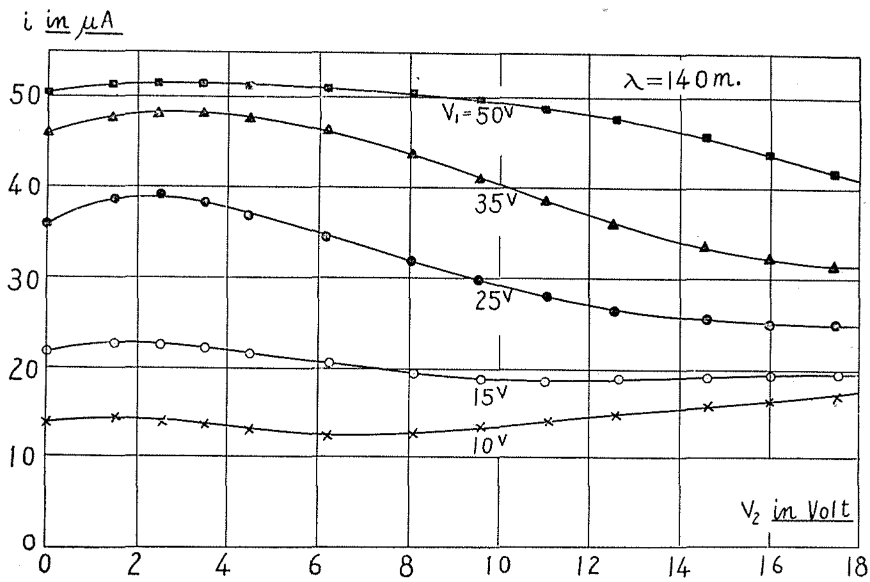

i_0 in μA
55
50
40
30
20
10
0
V_1 in Volt
0
10
20
30
40
50
60
70
80

Fig. 3.


i in μA
λ=140 m.
V_1=50^V
35^V
25^V
15^V
10^V
50
40
30
20
10
0
V_2 in Volt
0
2
4
6
8
10
12
14
16
18

plotted as ordinate against the corresponding values of oscillatory voltage V_2 as abscissa. From these curves, it will be seen that at first the current i increases up to a maximum and then begins to decrease gradually with the oscillatory voltage greater than about 3 volts, and also that the increase of the current is much more marked in the case of the continuous voltage $V_1=25$ volts, though as will be mentioned later on, it depends upon the intensity of illumination. The peculiar increase was not limited to the vacuum caesium cell. The results obtained with a gas-filled caesium cell and a gas-filled potassium cell were found to give similar curves, though the effect differed more or less in magnitude.

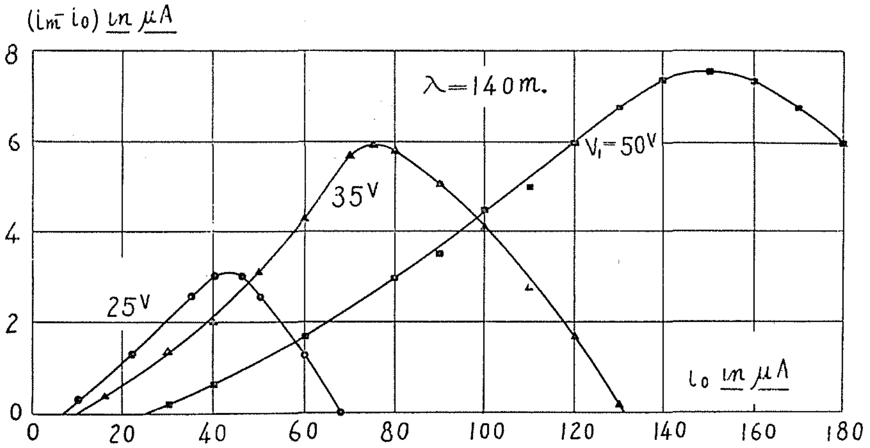
As to the causes for the effect described above, it seems almost inconceivable that the rectification of the cell is the cause of the increase of the photo-electric current. As shown in Fig. 2, the portion of the voltage-current curve which corresponds to the voltages higher than 25 volts is concave towards the V_1-axis. Thus, if the photo-electric cell used acts simply to rectify, the current due to the superposition of the oscillatory voltage V_2 should decrease rather than increase, as is revealed by the right hand part of the curves in Fig. 3.

Next, to know the effect of temperature upon the peculiar increase, another experiment was carried out. The cell was placed in a closed vessel with an automatic regulating heater; and similar observations were repeated at various constant temperatures ranging between 10°C and 60°C, and also under controlled conditions while the temperature increased or decreased at a rate of about 0.5°C per min. The results thus obtained indicated that there was no essential difference from the case shown in Fig. 3. Further, it was noticed that the rise of photo-electric current took place at the same time with the application of high frequency voltage. From these results, it seems almost certain that the rise of temperature is not the primary cause of the effect.

To learn whether the peculiar effect depends upon the wave-length of the illuminating light or not, experiments similar to those made before were made by filtering the light with Wratten filters placed in front of the slit S. The results did not indicate any distinct connection between the wave-length of the illuminating light and the peculiar effect under consideration. It was found, however, that the effect depended upon the continuous voltage V_1 and the intensity of illumination.

To investigate qualitatively the relation between the peculiar effect and the intensity of illumination, the following measurements were made. The photo-electric current i_0 obtained with a constant continuous voltage V_1 increases with the intensity of illumination. Therefore, by keeping the continuous voltage V_1 constant the photo-electric current i_0 due to V_1 was made to vary by changing the distance between the lamp and the photo-cell; and for different values of i_0 the maximum currents i_m obtained by superposing various oscillatory voltages V_2 of constant frequency to V_1 were measured. Some of the results obtained with oscillatory voltages having the wave-length 140 ms. are plotted in the curves of Fig. 4, and it is to be noticed that there is a crest on each curve. Take the curve of $V_1 = 25$ V as an example.

Fig. 4.

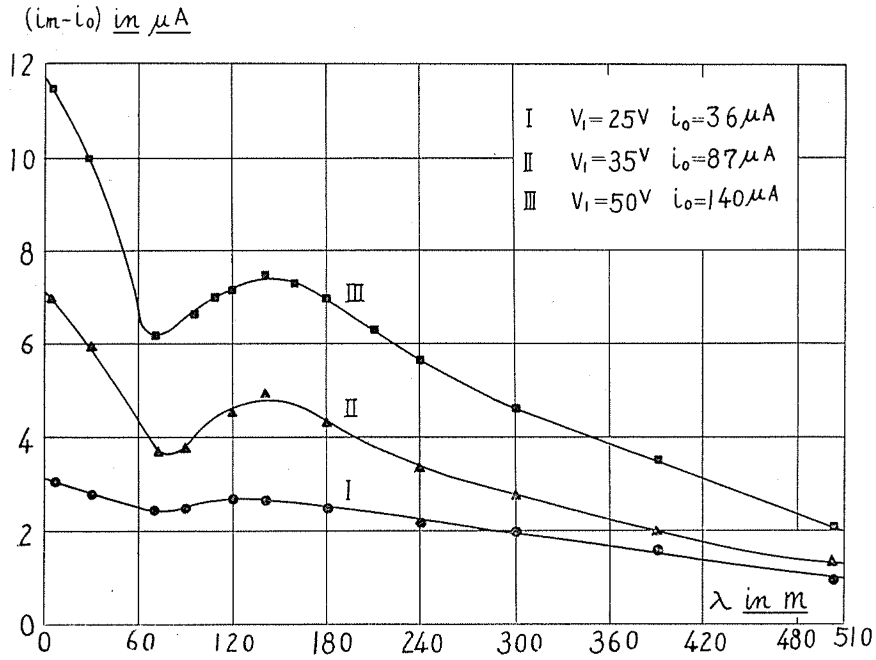


The value $(i_m - i_0)$ becomes maximum at the intensity of illumination $i_0 = 42$ microampers ($d = 29$ cms. for the 60 watt-lamp), the increase-ratio at the crest $(i_m - i_0)/i_0$ being 7.5%. However, when the intensity of illumination becomes greater the increase-ratio reduces, and at an illumination stronger than $i_0 = 60$ microampers ($d = 15$ cms. for the same lamp), it changes into negative.

Since the number of electrons emitted from the cathode is directly proportional to the intensity of the illuminating light, as was verified over a wide range, we can say that the effect under consideration has an important connection with the number of the emitted electrons.

Lastly, the effect of the frequency of the oscillating voltage was investigated. In such experiment the intensity of illumination i_0 and the continuous voltage V_1 were kept constant; and the maximum currents i'_m obtained by applying various oscillatory voltage V_2 having different frequencies were measured. The results obtained are shown in the curves of Fig. 5. It is to be noticed that the peculiar effect $(i'_m - i'_0)$ generally decreases with the increase of the wave-length; for example, it disappeared at $\lambda = 1000$ ms. for the curve *I*, and that a maximum appeared in each curve at the wave-length of about 140 ms. The

Fig. 5.



results obtained with the other photo-cell also were found to give similar curves.

From the facts stated above, it seems probable that the peculiar increase of the photo-current is at least partly due to the disturbances caused by the oscillatory voltages upon the negative charge accumulated in front of the cathode when the photo-electric current is smaller than that of saturation: the electrons arriving at the anode will become more in number when such accumulated negative charge is disturbed by the oscillatory voltage. If so, the peculiar effect should be more remarkable at the oscillatory voltage whose frequency is in resonance with that of the electrons and the critical frequency of the electrons in the cell is found to be about 2140 kilocycles (wave-length 140 ms.) in the present case. About ten years ago, Nichols and Schelleng[1] published a paper as to the propagation of radio waves and concluded that the critical frequency of the electrons in the air was 1400 kilocycles (214 ms.). After that, Deutsch[2] observed that the electrons in an atmospheric pressure were in resonance with the wave-length of about 50 ms. The critical wave-length obtained by the writer is shorter than that of Nichols and Schelleng, but longer than that of Deutsch.

The fact that the peculiar effect is not marked when the initial photo-electric current i_0 comes near to the saturation current may be explained simply by the scanty accumulation of the negative charge in front of the cathode. The decrease of the value $(i_m - i_0)$ for the stronger illumination may be due to the fact that greater oscillatory voltage is necessary to disturb the accumulated negative charge, and that the effect of the rectification becomes predominant.

In conclusion the writer's sincere thanks are due to Prof. U. Yoshida for the interest he has taken in the research.

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1. H. W. Nichols and J. G. Schelleng: Nature, **115**, 334 (1925).
2. W. Deutsch: Ann. d. Physik, **26**, 195 (1936).