SYMMETRY OF INCIDENT AND EMERGENT PHOTO-ELECTRONIC VELOCITIES

By R. J. Piersol

Abstract

Relative maximum velocities of incident and emergent photo-electrons from a thin Pt film.—Previous observers have obtained ratios of emergent to incident energies of 1.25 or more, contrary to the quantum theory, but these ratios are shown to be due to the rounding off of the feet of the current voltage curves as a result of the presence of stray light of shorter wave-length. When monochromatic light was used and precautions were taken to avoid stray light, a photo-electric cell of the ordinary type with a thin Pt film deposited on glass as target, gave straight line curves crossing the line of zero current at the same voltage point. Additional experiments showed that the maximum energy is the same in all directions and equal to 1.76 volt for 1850 A and .20 volt for 2540 A.

RECENTLY the writer[1] has published preliminary results which show a difference of velocity between the incident and emergent photo-electrons less than experimental error. Previous to the accurate determination by photo-electronic velocity by Millikan[2] of Planck's constant, a large amount of inexact data was presented in an attempt to prove that if the quantum theory applied to the photo-electric effect at all, then there must be two values for Planck's constant, one obtained by incident and the other by the emergent photo-electronic velocity.

The asymmetry of incident and emergent photo-electric currents was first discovered by Rubens and Ladenburg[3] in gold leaf. These results were substantiated by Kleeman,[4] Stuhlmann,[5] Robinson[6] and Hughes[7] using thin cathode films of different metals deposited on quartz.

At a later date it was shown by Beatty[8] that Röntgen rays on passing through thin films produce a greater ionization current on the emergent side than the incident side, but that the velocity of the electrons on both sides is the same. On the other hand Robinson,[9] in studying the veloci-

[1] Piersol, Phys. Rev. **20**, 195, 1922
[2] Millikan, Phys. Rev. **7**, 355, 1916
[3] Rubens and Ladenburg, Ber. d. Deutsch. Phys. Ges. **24**, 749, 1907
[4] Kleeman, Proc. Roy. Soc. **84**, 92, 1910
[5] Stuhlmann, Phil. Mag. **20**, 854, 1911
[6] Robinson, Phil. Mag. **23**, 542, 1912
[7] Hughes, Phil. Trans. Roy. Soc. **212**, 205, 1912
[8] Beatty, Phil. Mag. **20**, 320, 1910
[9] Robinson, Phil. Mag. **25**, 115, 1913

ties, obtained results which seemed to show that not only is the emergent photo-electronic current greater but also the emergent photo-electronic velocity. Stuhlmann[10] repeated this work using Robinson's design of apparatus. His results show asymmetric velocities. In explanation Stuhlmann stated that the photo-electric effect depends on occluded gases since it was supposed that the photo-electric effect could be obliterated by removal of occluded gases. Later the writer[11] showed that such an explanation is not valid because a metal does have an intrinsic photo-electric effect which is independent of the effect due to occluded gases.

In using the Einstein equation, Richardson and Compton[12] from photo-electronic measurements found the value of h to be from 15 to 40 per cent less than the accepted value. Hughes attempted to explain this on the supposition that the energy of emission opposed to the direction of light, is less than the energy in the direction of incident light. This attempted explanation caused a large volume of research in the attempt to show that the emergent photo-electronic velocity would satisfy the quantum constant.

Probably the most important innovation by Millikan in his emission velocity determinations is that he did not attempt to locate experimentally that retarding potential which would just prevent the escape of an electron from the illuminated metal to the receiving gauze. It is obvious that errors due to the reflected light, reflected electrons, stray light, or insulation leakage which would not produce one half of a per cent error as compared to the value of the saturation current will produce as much as 100 percent error with a current approaching null value. Instead of direct readings Millikan plotted the values in the distribution of the velocity curve in the neighborhood of the null point and then located that point graphically by extending the curve backward to obtain the abscissa intercept.

If Millikan's extrapolation method is applied to the results of Robinson and of Stuhlmann the ratios come out approximately unity instead of 1.16 and 1.42.

Part I. Ratio of Incident and Emergent Velocities

In order to analyze the conclusions reached by Robinson and Stuhlmann the best method of attack would seem to be an attempt to duplicate their experimental data as to velocities of emission. Thus the apparatus as shown in Fig. 1, is almost an exact duplication of the type of photo-

[10] Stuhlmann, Phys. Rev. **4,** 195, 1914
[11] Piersol, Phys. Rev. **8,** 238, 1916
[12] Richardson and Compton, Phil. Mag. **24,** 575, 1912

electric cell used previously. The outer brass cylinder A is 8×5 cm inside measurements. The inner concentric copper gauze cylinder B, 7×4 cm, is supported by a brass rod C through a ground glass joint D

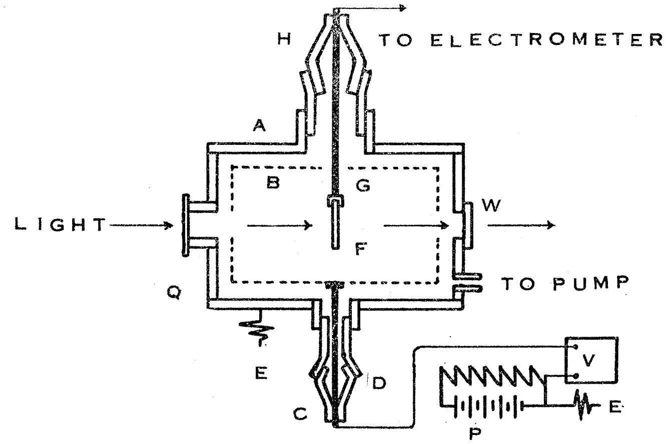

Fig. 1. Apparatus

and is connected to the potentiometer system P with a standard Weston voltmeter V reading to 0.002 volts. The ultra-violet light from a Cooper Hewitt quartz mercury arc, condensed by a quartz lens, passes through the quartz window Q and out the window W. In a position perpendicular to the light ray is placed a quartz plate F, which may be covered with a sputtered film. The plate is attached to a supporting brass rod G with a screw clamp. The rod passes through a ground glass joint H to an electrometer, which has a sensitivity of 1200 divisions per volt at a scale distance of 1 meter. The ground glass joint is used to rotate the filmed quartz plate so that it may be on the side of the quartz incident to the light or in the opposite 180° position in which the electrons will be emitted in the direction of the light. The inside of the cell is covered with camphor soot to reduce the reflected light. Since the two windows are parallel to the quartz plate, the light directly reflected from the film in either the incident or emergent position is sent back through the window Q.

The platinum films are deposited by a platinum cathode, using aluminum as an anode. A Snook-Röntgen machine is used to obtain high voltage direct current. The sputtering is done in a bell jar under a vacuum of 0.001 mm of mercury. Precautions are taken to exclude vapor from stop-cock grease, which may cause spuriously high velocities. A gold leaf mercury vapor trap is introduced between the bell jar and mercury pump. With constant cathode fall and constant current Tyndall and Hughes[13] have shown that the thickness of the film is a linear function of the time of deposition. Robinson[14] has shown that the maximum ratio of emergent to incident current takes place at a film thickness where 16 per cent of the incident light is absorbed by the film. Since the object is to investigate the maximum asymmetry of velocities, all films used are of this critical thickness, of the order of 10^{-7} cm.

Both Compton[15] and Shaw[16] have shown that an ionization method may be used to determine the contact difference of potential between the platinum film and the receiving copper gauze. A tube containing 0.98 mg of RaCl is placed near the window of the cell and the potential to which the copper gauze must be raised to give no electrometer deflection is measured.

Immediately after sputtering, the films were very erratic as to contact difference of potential, but after several hours they dropped to a very uniform value. None of the films were used until they had aged at least one week.

Fig. 2 shows the first set of results, which were obtained under atmospheric conditions. Distribution of velocity curve agrees with those

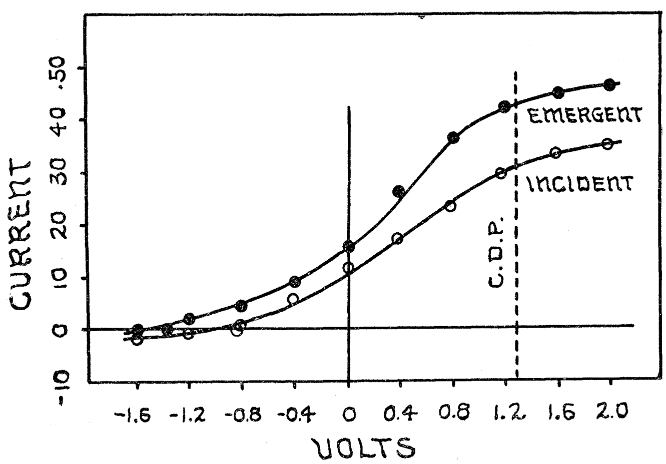

Fig. 2. Photo-electric current at atmospheric pressure.

obtained previously, showing an emergent current almost one-half greater than the incident current. Measuring the stopping potential, the emergent energy is 1.34 volts, the incident energy, 0.81 volts. The contact difference of potential is 1.27 volts. This gives a corrected

[13] Tyndall and Hughes, Phil. Mag. **27**, 415, 1914
[14] Robinson, Phil. Mag. **32**, 421, 1916
[15] Compton, Phil. Mag. **23**, 579, 1912
[16] Shaw, Phil. Mag. **25**, 241, 1913

stopping potential of 2.61 volts for the emergent energy and 2.08 volts for the incident energy or a rat'o of 1.27.

Fig. 3 shows the same film under the lowest pressure which can be obtained by a Gaede rotary mercury pump, which a McLeod Gauge shows to be of the order of 10^{-6} cm. Again the incident current is much less than the emergent current. The contact difference of potential may be obtained graphically by drawing a straight line through the ascending values of the current and another straight line through the constant saturated values of the current. The interceptof these two lines gives the position of the contact difference of the potential which is 1.50 volts.

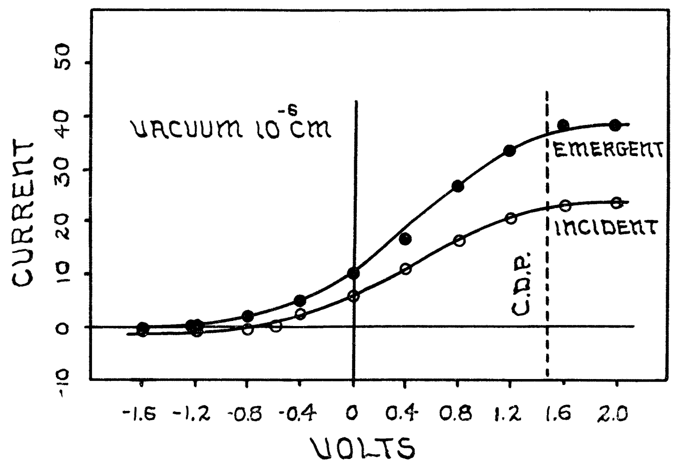

Fig. 3. Same film as Fig. 2 in high vacuum.

This shows that the contact difference of potential has shifted due to the evacuation. Since this is true, the ionization method previously described may not be reliable in the case of a vacuum. The saturation current is very constant. The energy potential for the emergent electrons is 1.23 volts as compared to the incident value of 0.60 volt. Correcting for the contact difference of potential the ratio is 1.30.

Fig. 4 shows the distribution of velocity curve under the critical pressure of 10^{-3} cm which gives about ten times the current obtained either under high vacuum or atmospheric pressure. This condition is valuable for observation as pointed out by Millikan[17] because it increases the precision of observation to within one per cent. It will be noted that the contact difference of potential is again shifted; also that the saturation current has a slight uniform increase with voltage. The emergent potential is 1.42 volts; the incident potential, 0.98 volts. The contact difference of potential is 1.15 volts thereby giving a ratio of 1.21.

[17] Millikan, Phys. Rev. **7**, 374, 1916

Fig. 5 shows the results of using monochromatic light as obtained by a Hilger spectrometer of the reflecting type, using wave-length of 2537 A. The critical pressure of 10^{-3} cm is used. The curves still show "feet" to

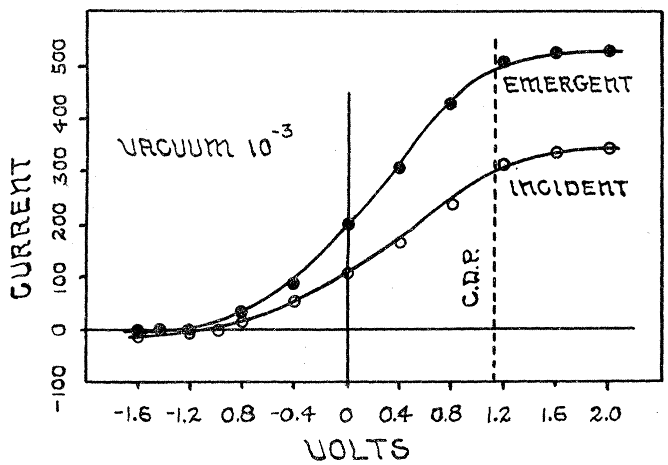

Fig. 4. Curve with critical pressure of 10^{-3} cm.

a marked degree. The characteristic of the curves is that the current increases very rapidly, showing that 2537 A is close to the threshold wave-length of platinum sensibility. The value estimated by Koppius[18]

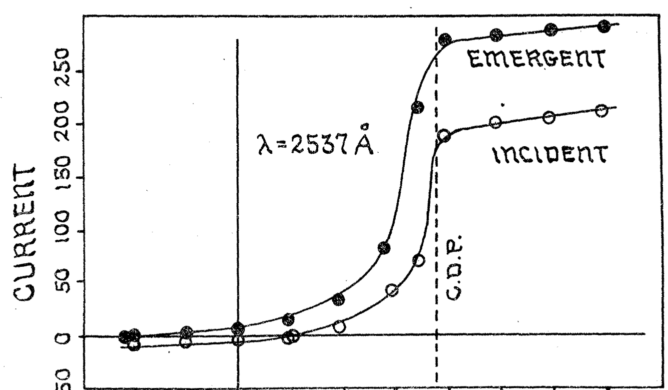

Fig. 5. Curve for monochromatic light 2537 A, pressure being 10^{-3} cm.

is 2570 A. The emergent velocity is -0.43 volts; the incident velocity, 0.21 volts. The contact difference of potential is 0.75 volts, with a resulting ratio of 2.19. Obviously this large ratio is associated with the fact

[18] Koppius, Phys. Rev. **28**, 443, 1921

that the current is asymptotic to the voltage axis. So if the influence of stray light were neglected it would appear that monochromatic light of 2537 A gives a larger divergence in emergent and incident velocities than that obtained by white light.

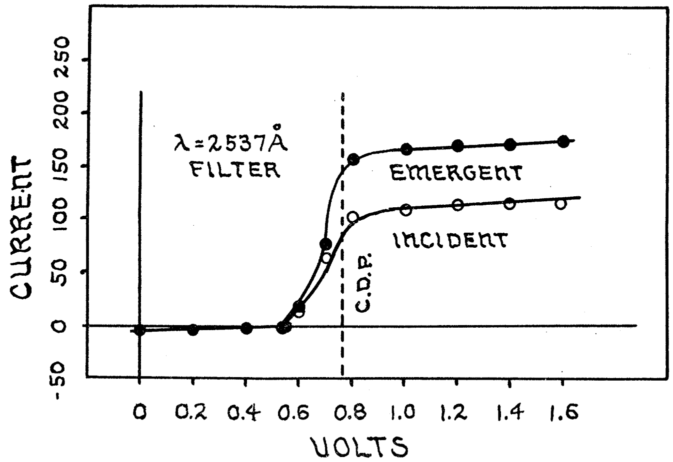

Fig. 6. Curve for monochromatic light 2537 A filtered to eliminate stray light.

In work on absorption media which has not been published, T. M. Dohn has found that a solution of thiophine transmits 2537 A and cuts

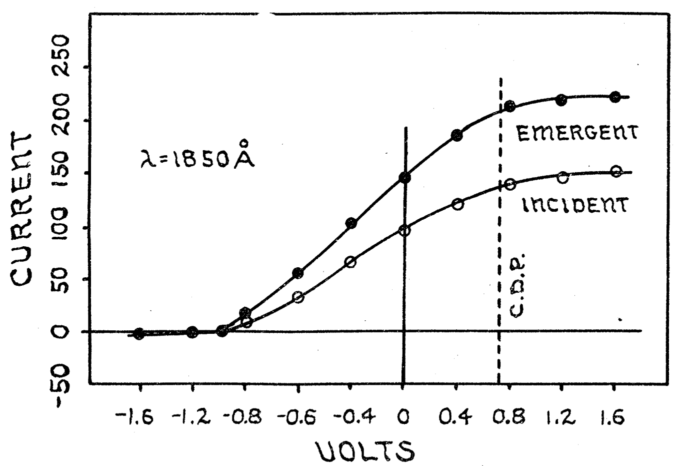

Fig. 7. Curve for monochromatic light, 1850 A.

out the shorter wave-lengths given by a mercury vapor arc. Fig. 6 shows the result of such a filter on the previous curve in Fig. 5. The "feet" are entirely absent. The stopping potential for the emergent velocity is 0.56 volts and for the incident, 0.56 volts, showing direct experimental symmetry of velocity. The graphical method gives an emergent and incident intercept at 0.57 volts. This seems to prove that the experimental value of the stopping potential approaches the true graphical value only when the feet have been removed by filtering out the shorter wave-lengths.

As a check on this assumption, the shorter wave-length, 1850 A was used. This is the lowest intense line from the mercury arc which is not absorbed by the quartz. Fig. 7 shows the results. The feet are entirely absent as practically all the energy from the shorter wave-length have been cut off by the quartz. In this case the experimental stopping potential corresponds to the graphical intercept, either method giving a ratio of unity.

Although this article is concerned only with the maximum value of stopping potentials, it may be observed that the distribution of velocity is nearer linear than usual. This should be considered a characteristic of the particular photo-electric cell rather than a contradiction to the usual Maxwell distribution of velocity.

Part II. Variation of Velocity with Angle

In order to study the velocity at different angular positions a guard ring type of photo-electric cell is designed as shown in Fig. 8. The outer vertical cylindrical case A is grounded to serve as a magnetic

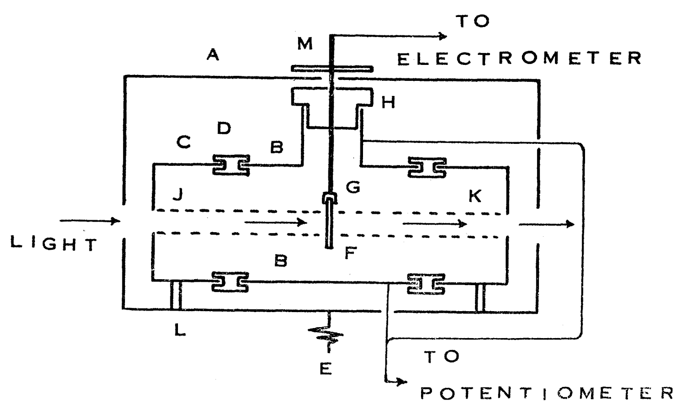

Fig. 8. Apparatus for study of variation with angle.

shield. The inner cylinder is concentric; the electrode B being separated from the grounded guard ring C by sulphur insulators D. The inner cylinder, at its guard ring, is attached to the outer cylinder by conducting supports L. The platinum film quartz plate F is supported by the rod G, passing through a sulphur support H, to the electrometer. Fixed to the rod G is a circular scale M, which reads the angular position of the film, the sulphur plug rotating in its support. The receiving electrode is connected to the potentiometer *P*. Monochromatic light, from the vapor quartz mercury lamp passing through the Hilger spectrometer, enters in the window *J* and the emergent ray passes out through the window *K*. Since the film is to be rotated through 360 degrees the reflected light will strike the circumference throughout its entire angular position. To overcome this the cylinder is made in two halves with a peripheral slit window being continuous from *K* to *J* with the exception of rods to support the upper cylinder so placed that the light reflected at 10° will not strike them. The inner surfaces are coated with camphor soot to absorb all stray light.

The velocity for each angle is obtained by plotting the current-voltage intercept. Since the tests are made in air the contact difference of potential is ascertained by the ionization method. Within experimental error the velocities are constant for all incident and emergent angular positions and equal to 0.20 volts.

Since the emission is low at 2537 A another curve was run for 1850 A. The magnitude of the voltage is about ten times that of the previous curve, being 1.76 volts.

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University of Pittsburgh,
July 3, 1923.