THE EMISSION OF ELECTRONS IN THE SELECTIVE AND NORMAL PHOTO-ELECTRIC EFFECTS.

BY A. LL. HUGHES.

THE selective and normal photo-electric effects have been investigated almost entirely through a study of the variation in the total number of electrons emitted from suitable metallic surfaces, with the wave-length of the light used. It is therefore desirable to attack the problem in another way in the hope that some evidence as to the difference between the two effects may be obtained. The author[1] attempted this in an investigation of the distribution of electrons emitted from a surface of sodium-potassium alloy. The results showed that the distribution was not identical for the selective and for the normal photo-electrons, but did not settle whether the difference was one in the *direction-distribution* or in the *velocity-distribution* of the photo-electrons in the two effects. The following experiments show that there is a definite difference in the direction-distribution of the photo-electrons.

The apparatus consisted of a glass tube about 5 cm. wide, provided with three aluminum electrodes as shown. These could be connected to an electrometer separately or together. Two small apertures, at opposite sides of the cylindrical electrode C allowed a narrow beam of light to pass in and out. The light was focused on to a small area (about 4 mm. square) at the center of the sodium-potassium alloy surface. A mercury lamp was used as source of light. To secure light of the wave-length corresponding to the maximum of the selective photo-electric effect, it was passed through a Wratten blue filter (made by the Eastman Company) to isolate the blue lines of the mercury arc. The ratios of the solid angles subtended at the center of the surface of the alloy, by the electrode A, by $A + B$, and by $A + B + C$, were roughly as 15:55:100. The tube was exhausted by the charcoal liquid air method and sealed off.

The method of experiment was to measure the number of electrons received by A, by $A + B$, and by $A + B + C$ respectively, when there was no field to make the electrons deviate from their straight line paths. It is not sufficient to connect the alloy and the electrodes to earth to secure the absence of an electric field, the contact difference of potential must be annulled. A very convenient way of doing this was suggested

---

[1] Hughes, Phil. Mag., XXXI., p. 100. Feb., 1916.

by the work of Millikan.[1] Let V be the negative potential which is necessary to apply to $A + B + C$ in order to stop the fastest electrons emitted from the alloy when illuminated by (unpolarized) light of frequency ν. Then $V + K$ is the total potential difference between the electrodes $A + B + C$ and the alloy where K is the contact difference of potential. Let ν_0 be the lowest frequency capable of causing the emission of photo-electrons from the alloy. Then we have

$$e(V + K) = h\nu - h\nu_0,$$

$$K = \frac{h}{e}(\nu - \nu_0) - V.$$

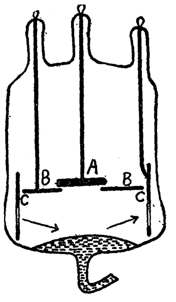

Fig. 1.

To get the lowest frequency capable of exciting the photo-electric effect, a powerful carbon arc was used to illuminate the surface in conjunction with several red and orange filters. A barely measurable effect was obtained when the light was filtered through a thin molybdenite flake which was opaque to light of wave-length shorter than λ 7,100. This was therefore taken as the long wave-length limit of the photo-electric effect of the sodium-potassium alloy. A potential of .35 volt was sufficient to stop the electrons due to the green line (λ 5,461) of the mercury arc. Applying this to the above formula, we get $K = .31$ volt. This is probably subject to an error of ± .05 volt, on account of some uncertainty in the determination of the long wave-length limit. (It should be observed that this value of the contact difference of potential between the sodium-alloy and the aluminum electrodes is smaller than might have been expected.) Thus to secure the absence of an electric field between the alloy and the electrodes A, B, and C, the alloy must be made .3 volt negative with respect to them.

On illuminating the alloy with light polarized successively in the $E\|$ and in the $E\perp$ planes (that is, with the electric force parallel and perpendicular to the plane of incidence respectively), the ratio of the selective to the normal effect for the electrons caught by A, by $A + B$, and by $A + B + C$ in turn were found to be as follows:

Collecting Electrodes	Ratio $\frac{\text{selective effect}}{\text{normal effect}}\left(\frac{E\|}{E\perp}\right)$
$A + B + C$	10.3
$A + B$	11.7
A	17.5

These observations indicate a greater concentration of the selective

---

[1] Millikan, Phys. Rev., VII., p. 18, Jan., 1916.

photo-electrons along directions near the perpendicular to the surface, as compared with the normal photo-electrons. In the normal effect the charges received by A, $A + B$, $A + B + C$, were as 16:60:100 while in the selective effect they were as 27:81:100. The normal photoelectric distribution is therefore closer to that which would be obtained on the supposition that equal numbers of electrons are emitted per unit solid angle, regardless of direction (15:55:100). No attempt was made to allow for reflection of electrons in this rough comparison. To make sure that those results might not be due in some way to the field not being zero, on account of an error in estimating the contact difference of potential, the observations were repeated twenty-four hours later with different negative potentials applied to the alloy.

Collecting Electrode.	Ratio $\frac{\text{selective effect}}{\text{normal effect}} \left(\frac{E\parallel}{E\perp}\right)$. Potential on the Alloy.		
	—.5 Volt.	—.3 Volt.	—.1 Volt.
$A+B+C$	9.6	10.2	10.1
$A+B$	11.1	11.5	10.7
A	13.3	13.8	14.8

These results show that slight departures from exact compensation of the contact difference of potential do not affect the ratios to any great extent. We may therefore conclude that the ratios really indicate a difference in the direction distribution of the photo-electrons in the selective and normal photo-electric effects. That the selective photo-electrons tend to crowd more along the perpendicular to the surface than the normal photo-electrons might, at first sight, be expected, since the electric force in the light has a component along the perpendicular to the surface. Calculation shows however that it is impossible for an electron vibrating about a position of equilibrium, to acquire energy of the order of that possessed by a photo-electron, from the electric force in the light beam, unless we suppose that the vibration is undamped and that the electron can go on accumulating energy undisturbed, for over a million vibrations. One then turns to the view that there are vibrating systems, which, over a certain range of frequency, are more easily broken up by alternating electric forces (of the right frequency) perpendicular to the surface, than by electric forces parallel to the surface.

The presence of a maximum on the curve connecting the number of electrons emitted per unit energy of the incident light, with the wavelength, has been taken to mean that the selective photo-electric effect is a resonance phenomenon. As Pohl and Pringsheim[1] have shown in the

---

[1] Pohl and Pringsheim, Verh. d. Deutsch. Phys. Ges., XV., p. 111, 1913.

case of one metal at least, the mere presence of a maximum may be completely accounted for by a consideration of the depth to which the light penetrates into the surface and the chances which the photo-electrons produced at different depths have of emerging. When the conditions are arranged so that the light is absorbed in a very thin layer (that is, by using a very oblique beam), so that all the photo-electrons released in the surface have a greater chance of emerging, then the maximum disappears. The real selective photo-electric effect as defined by Pohl and Pringsheim, however, needs more than a maximum on the curve to indicate its presence; the photo-electric effect associated with light polarized in the $E||$ plane must be several times larger than that associated with light polarized in the $E \perp$ plane, and also must possess a pronounced maximum at some wave-length in the region where the maximum appears. Indeed, the maximum appears only in the photo-electric effect produced by light polarized in the $E||$ plane. Moreover this maximum must become more and more pronounced as the obliquity is increased, that is, as the electric force in the light beam becomes more and more perpendicular to the surface. Either the light polarized in the $E||$ plane is absorbed in a very much smaller depth than the light polarized in the $E \perp$ plane, with the result that the photo-electrons produced by light polarized in the $E||$ plane escape from the surface in greater numbers; or else there must be resonance systems in the surface which have the property of responding only when the electric force in the light beam has a component perpendicular to the surface. There is no evidence from optics to support the first hypothesis. So far as the maximum emission velocity is concerned, the work of Richardson and Compton[1] and of Millikan[2] shows that there is nothing unusual in the behavior of the photo-electrons from sodium, even in the region where the maximum selective effect is observed, when compared with other metals which give only the normal effect. Hence on the second hypothesis, it would be necessary to suppose that the special systems which give rise to the selective effect are fundamentally of the same nature as those which give rise to the normal effect. The selective effect would then be due to the fact that there is an exceptionally large number of systems of a certain period so oriented as to respond to light polarized so that there is an electric force perpendicular to the surface.

The results obtained in this paper suggest a systematic examination of the velocity distribution and the direction distribution of photo-electrons

---

[1] Richardson & Compton, Phil. Mag., XXIV., p. 575, 1912.

[2] Millikan, Phys. Rev., VII., p. 355, March, 1916. Millikan and Souder, Proc. Nat. Acad. of Sci., II., p. 19, Jan., 1916.

emitted from surfaces illuminated by polarized light. It is proposed to carry out the experiments on metals which show the selective effect such as sodium-potassium alloy and on metals such as mercury which show only the normal effect. By using liquid surfaces, we can be much more certain that the plane of polarization of the light has a definite meaning with respect to the plane of the surface.

These experiments were carried out in the Palmer Physical Laboratory at Princeton during the summer of 1916. I wish to express my best thanks to Professor Magie for placing the facilities of the laboratory at my disposal.

THE RICE INSTITUTE,
HOUSTON, TEX.