

Energy Distribution of Photoelectrons as a Function of the Thickness of a Potassium Film

JAMES J. BRADY, *St. Louis University, St. Louis, Missouri*

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Current-voltage curves were taken for photoelectrons ejected from thin potassium films of various thicknesses. The films were formed on a silvered glass surface at room temperature by means of a molecular beam. The condensing surface was a small sphere placed at the center of a large collecting sphere. The thickness of the potassium film was computed from the geometry of the photocell, the temperature and time of heating of the potassium reservoir, and data on the vapor pressure of potassium. The small inner sphere was connected to an electrometer which measured the photocurrent. The contact potential between the film and the silvered surface of the large sphere was determined from the values of the thresholds of the two

surfaces. The form of the curves near the maximum retarding potential was approximately the same for each film thickness. The curves were analyzed by DuBridge's method and were in good agreement with the theory. For films less than 3 molecular layers corrections had to be made for a constant decrease in photocurrent after the formation of the film. However, for films of greater thickness the photocurrent was quite constant. The photocurrent for films less than 3 molecular layers failed to saturate for accelerating potentials up to 20 volts. As the film thickness increased the photocurrent began to saturate at lower voltages.

INTRODUCTION

A STUDY of the spectral distribution of photoelectrons as a function of the thickness of an alkali metal film was published in a previous paper in the *Physical Review*.¹ With the propounding of DuBridge's theory² it became apparent that the study of the energy distribution of photoelectrons as a function of the thickness of an alkali metal film would be of considerable interest. Lukirsky and Prilezaev³ had previously studied the energy distribution of photoelectrons from silver films of various thicknesses and had found that the position of the maximum of the energy curves depended on the thickness of the film. Herold⁴ had found similar results in the case of platinum films. Several experimenters^{5, 6, 7, 8} have published current-voltage curves for photoelectrons emitted from alkali metal films, but they did not investigate the curves from the standpoint of varying film thickness.

The present study was undertaken with the purpose of studying the energy distribution of

the photoelectrons as a function of the thickness of a potassium film. To obtain an energy distribution curve the observed current-voltage curve must be differentiated. This is likely to introduce a considerable error. By DuBridge's method a direct comparison with experiment can be made from the current-voltage curves and thereby uncertainties involved in differentiating an experimental curve can be eliminated.

One of the apparent difficulties in this study is the fact that the photocurrent from thin alkali metal films does not saturate readily. However, this does not alter the results near the "maximum" energy part of the curve where DuBridge's theory may be applied.

APPARATUS AND EXPERIMENTAL PROCEDURE

A sketch of the experimental tube and arrangement is shown in Fig. 1. The surface from which the photoelectrons were ejected was formed on a silvered glass sphere, a little less than 2 cm in diameter. This was mounted in the center of a large silvered glass sphere 15 cm in diameter. Electrical contact was made to the inner sphere by several fine tungsten wires connected to the electrode leading to the electrometer. These wires made a brush contact with the silvered surface of the inner sphere.

The lower part of the tube was devoted to the production of a molecular beam of potassium and was like that described in a previous paper.¹

¹ J. J. Brady, *Phys. Rev.* **41**, 613 (1932).

² L. A. DuBridge, *Phys. Rev.* **43**, 727 (1933).

³ P. Lukirsky and S. Prilezaev, *Zeits. f. Physik* **49**, 236 (1928).

⁴ F. Herold, *Ann. d. Physik* **85**, 587 (1928).

⁵ H. E. Ives, *Astrophys. J.* **60**, 209 (1924).

⁶ R. A. Millikan, *Phys. Rev.* **7**, 362 (1916).

⁷ A. R. Olpin, *Phys. Rev.* **36**, 251 (1930).

⁸ Ives, Olpin and Johnsrud, *Phys. Rev.* **32**, 57 (1928).

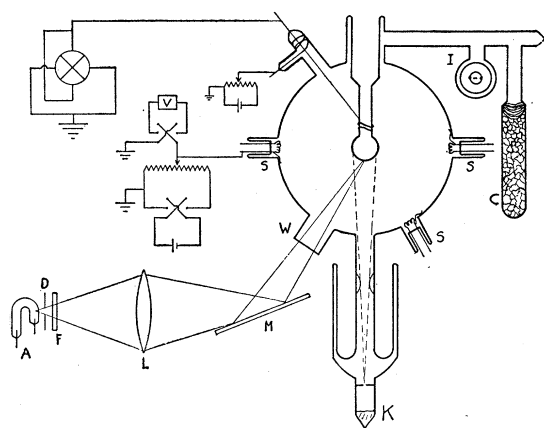


FIG. 1. Photocell and experimental arrangement. K, potassium; S, filaments for evaporating silver; C, charcoal trap; I, ionization gauge; W, window; A, mercury arc; D, diaphragm; F, light filter; L, lens; M, plane mirror.

The entire tube with ionization gauge and charcoal trap was given an extended outgassing treatment until the pressure within the tube (after it was sealed off from the pump) was in the order of 5×10^{-7} mm of Hg. By using liquid air on the charcoal trap this pressure was reduced to less than 10^{-8} mm of Hg.

While the tube was still connected to the pump the potassium was driven back and forth through a series of constrictions for about eight hours, and the ionization gauge was kept under observation to determine whether any further gas was released from the potassium. Even after this extensive treatment a slight increase in pressure was observed when the potassium was heated by a torch flame. However, this outgassing of the potassium could only be observed after a very vigorous heating. No rise in pressure could be detected when the potassium was heated later in the course of the experiment.

Silver was evaporated on the inside of the photocell by means of lumps of silver placed in the center of a heated tungsten spiral. Six of these filaments were placed in the tube in order that a number of sets of data could be taken from the same tube. Fresh silver was evaporated over the inside of the tube at the beginning of each set of data. The filaments were carefully arranged so that no silver was deposited on the window.

A mercury arc was used as a light source. Suitable filters were used to isolate the desired

frequencies. A spot of light about 1 mm in diameter was focussed on the surface under investigation.

The photocurrent was measured with a Compton electrometer having a sensitivity in the order of 6000 mm per volt at 1 meter scale distance. The retarding potential was applied by means of a simple potentiometer arrangement. The potentials were measured with a calibrated voltmeter.

The earth's magnetic field was compensated with a Helmholtz coil.

When studying films less than 3 molecular layers in thickness at room temperature it was found that the photocurrent decreased after the film was deposited. In these cases curves were plotted showing the way the current decreased as a function of the time after deposition. Then compensation could be made for this decreasing photocurrent in plotting the current-voltage curves. The rate of decrease was found to be less as the film thickness approached 3 molecular layers. For greater thicknesses the photocurrent remained very nearly constant.

The pinhole opening at the top of the potassium reservoir was 0.6 mm in diameter and was 27 cm from the condensing surface. Most of the films were formed with the potassium at 170°C which gives a computed rate of film formation of 1.6 molecular layers per hour. The vapor pressure of potassium was obtained from the work of Edmundson and Egerton.⁹ Further details in regard to the formation of the film may be found in an earlier paper by the author.¹ As before, in defining a molecular layer it is assumed that the atomic spacing in the film is the same as in a solid mass of the metal.

RESULTS

The current-voltage curves shown in Fig. 2 were observed for film thicknesses of 0.8 molecular layer and 2 molecular layers. The contact potential was determined from data on the thresholds of outgassed silver and potassium coated surfaces. The contact potential is determined by the difference in the work function of

⁹ W. Edmundson and A. Egerton, Proc. Roy. Soc. A113, 520 (1927).

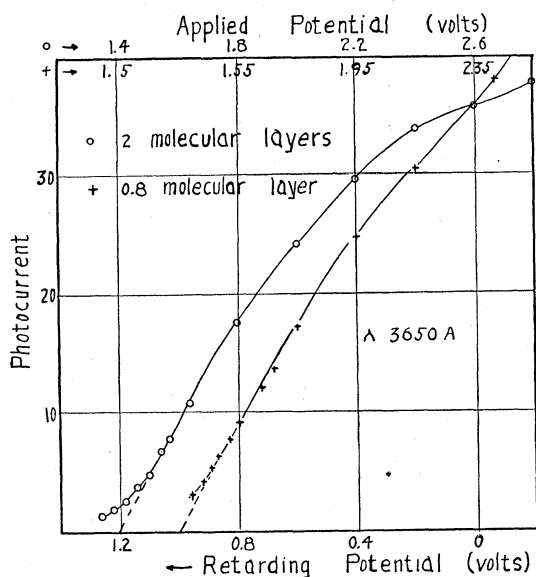


FIG. 2. Current-voltage curves for two film thicknesses using 3650Å. The applied potential was an accelerating potential and is recorded at the top of the graph. The contact potentials were 2.6 and 2.35 volts for the 2 molecular and the 0.8 molecular layer film, respectively.

the two surfaces and the threshold is related to the work function by the relation, $V = hce/\lambda_0$ where h = Planck's constant, c = the velocity of light, e = the electronic charge, λ_0 = the threshold, and v = the work function.

The threshold for outgassed silver¹⁰ is very nearly 2600Å. This corresponds to a work function of 4.75 electron-volts. The threshold for a 0.8 molecular film of potassium on silver was determined previously¹ and found to be about 5100Å. This corresponds to a work function of 2.4 electron-volts. The contact potential between the two surfaces, then, is 2.35 volts. The 3650Å group of Hg lines was the exciting radiation in this case. The energy in a quantum having this wave-length is 3.38 electron-volts. The difference between this amount of energy and the work function of the film gives the maximum energy an electron could possess after escaping from the surface. This is $(3.38 - 2.4)$ 0.98 electron-volts. The extrapolated value of the maximum retarding potential as shown in the figure indicates a close agreement to this value.

¹⁰ R. P. Winch, Phys. Rev. 37, 1269 (1931).

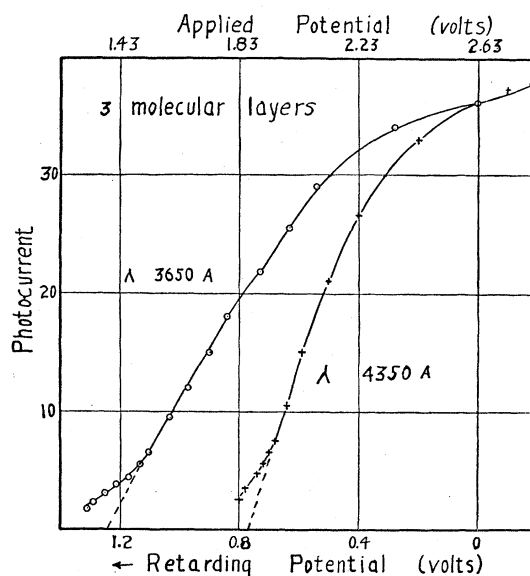


FIG. 3. Current-voltage curves for a 3 molecular layer film using 3650Å and 4350Å. The contact potential is 2.63 volts.

A current-voltage curve is also shown for a film thickness of 2 molecular layers under the action of 3650Å. The threshold for this film is approximately 5700Å. This corresponds to a work function of 2.16 electron-volts. The maximum energy an escaped electron could have under the action of 3650Å is 1.25 electron-volts. In the case of the 4350Å group of lines the maximum energy is 0.71. The extrapolated value for the "maximum" retarding potential is 0.76 volts.

Fig. 3 shows the current-voltage curves for a 3 molecular layer film. The threshold for this film is about 5800Å. The work function, then, is 2.12 electron-volts. For the 3650Å lines the maximum energy of escape is calculated to be 1.26 electron-volts. The extrapolated value of the "maximum" retarding potential is 1.24 volts. For the 4350Å lines the maximum energy is 0.72 electron-volt and the extrapolated value of the "maximum" retarding potential is 0.76 volt.

The current-voltage curves for a film of approximately 30 molecular layers are shown in Fig. 4. This is referred to as a "thick film." The threshold for this film is about 5500Å. The work function is 2.24 electron-volts. This gives a maximum energy of escape in the case of the

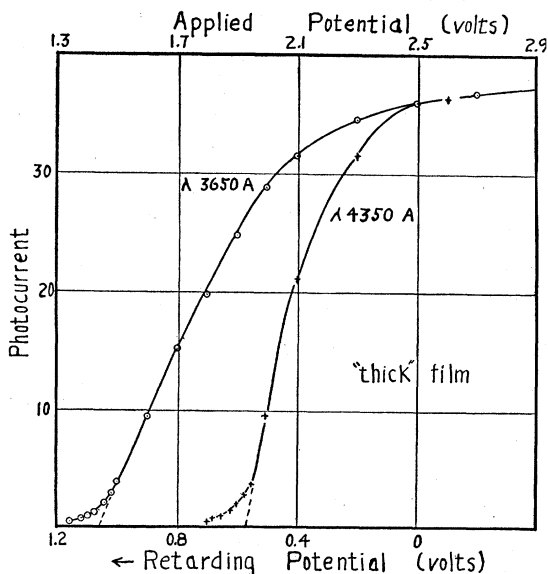


FIG. 4. Current-voltage curves for a film of 30 molecular layers using 3650Å and 4350Å. Contact potential is 2.5 volts.

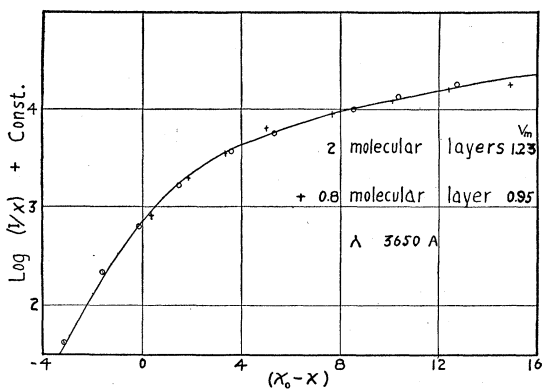


FIG. 5. Theoretical analysis of curves shown in Fig. 2.

3650Å lines of 1.14 electron-volts. The extrapolated value for the "maximum" retarding potential is 1.07 volts. In the case of the 4350Å lines the maximum energy is 0.60 and the extrapolated value 0.57.

The data for the curves shown in Figs. 5, 6 and 7 were taken from a paper by Roehr.¹¹ These represent the theoretical values for the tails of the current-voltage curves. The experimental results were then plotted in the form

¹¹ W. W. Roehr, Phys. Rev. 44, 866 (1933).

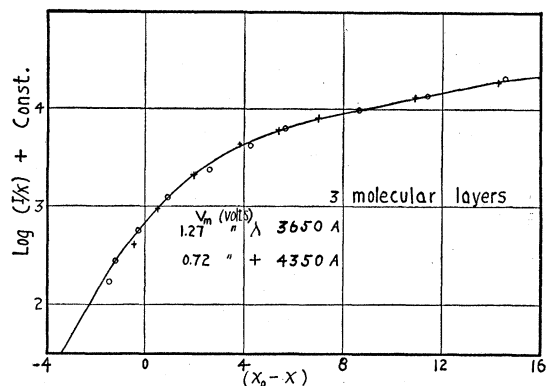


FIG. 6. Theoretical analysis of curves shown in Fig. 3.

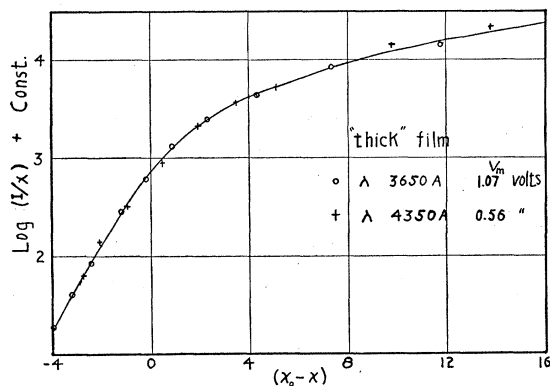


FIG. 7. Theoretical analysis of curves shown in Fig. 4.

$\log(I/x)$ against x . A horizontal and vertical shift was required in order to bring the experimental points in coincidence with the theoretical curve. The maximum energy at absolute zero could then be determined from the horizontal shift, $x_0 = V_m e / kT$. The shifts are indicated on the graphs under V_m .

The data for Fig. 8 were obtained from a 3 molecular layer film after removal of the liquid air from the charcoal trap. This marked change in the current-voltage curve was undoubtedly due to some gas which had been condensed by the liquid air cooled charcoal. The effect of the removal of the liquid air became less after the repetition of a few sets of data. This indicates that the gas or vapor which caused the change was adsorbed and disappeared in the potassium film. The change in the current-voltage curve stresses again the importance in obtaining gas free surfaces in a study of this kind.

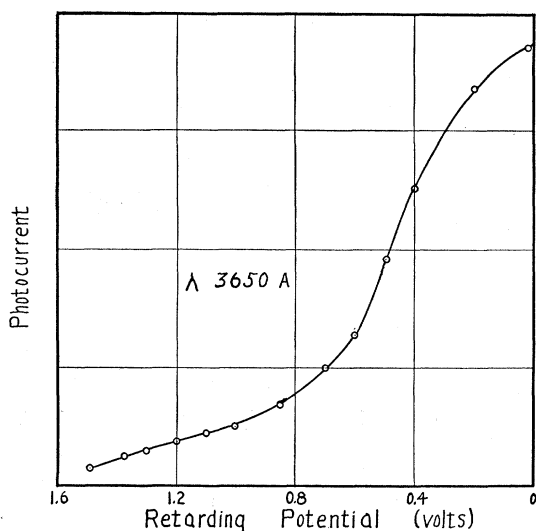


FIG. 8. Current-voltage curve for a 3 molecular layer film after the liquid air had been removed from the charcoal trap.

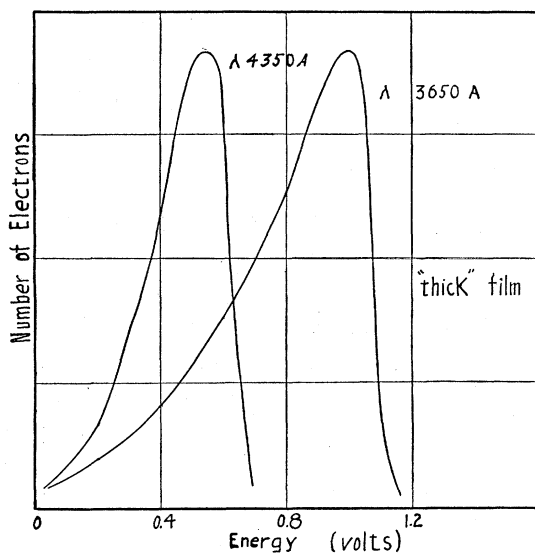


FIG. 9. Energy distribution of photoelectrons from a 30 molecular layer film.

FIG. 9 was obtained by differentiation of the current-voltage curves of Fig. 4. The curves have been reduced to a common level at the most probable value of the energy. Because of

the great similarity of the current-voltage curves for all film thicknesses, the energy curves for the other films are not shown. The results are in agreement with the theory.

CONCLUSION

Three separate methods were used to determine the maximum retarding potential at 0°K (V_m), and in general the agreement is very good. The three methods were; extrapolation of the current-voltage curves, computation from data on the values of the thresholds of the surfaces, and from the shift ($x_0 = V_m e / kT$) of the theoretical-analysis curves.

In contrast to the results of Lukirsky and Prilezaev on silver films there was no appreciable difference in the position of the most probable energy for different film thicknesses.

Because of the failure of the very thin films to give saturation of the photocurrent and also lack of knowledge at present concerning the transmission coefficient, it is difficult to compare the complete current-voltage curves for different film thicknesses. The procedure has been to reduce all curves to the same value of photocurrent at the corrected zero retarding potential. The two factors just mentioned affect the curves near the zero values of retarding potential, and both of these factors vary with the thickness of the film. The slight differences which are seen in the curves may be due to these factors.

The fact that the photocurrent decreased after the formation of the very thin films (less than 3 molecular layers) and remained nearly constant for the thicker films indicates that the potassium "dissolves"* in the silver much more readily before a continuous film is formed than after. It was also noted that the rate of decrease for the very thin films was less when the condensing surface was cooled with liquid air or solid carbon dioxide. The work on the temperature effect is being continued and will be published later.

* Note: The lack of saturation of the photocurrent indicates that this effect is most likely due to the formation of patches.