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The Effect of Temperature on the Energy Distribution of Photoelectrons. I. Normal Energies

LEE A. DUBRIDGE AND R. C. HERGENROTHER, *Washington University, St. Louis, Missouri*

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An experimental test has been made of DuBridge's theory of the distribution of normal energies of photoelectrons. With a modified parallel-plate method of analysis, photoelectrons were ejected from a strip of Mo foil which could be held at any desired temperature. Current-voltage curves for temperatures from 300° to 965°K show a good agreement with the theory. From the shifts required to fit the experimental and theoretical curves the values of $V_{\max}$ at 0°K can be determined. For any fixed temperature these values of V_m fit the Einstein equation, and for a fixed wave-length they are independent of T, as required by the theory.

INTRODUCTION

In a previous paper[1] one of the authors has developed a theory of the energy distribution of photoelectrons, based upon the assumption that the free electrons in a metal obey the Fermi-Dirac statistics. The theory leads to the conclusion that the energy distribution curves should approach the axis asymptotically, so that there is no maximum emission energy except at 0°K. The theory was found to be in good agreement with some preliminary experimental results. It is the purpose of this paper and the one by Dr. Roehr which follows to describe a more complete experimental test of the theory which has been carried out in this laboratory. In the present paper attention is confined to the "normal" energies, i.e., the energy associated with the velocity component normal to the emitting surface.

THEORY

If a plane metal plate is illuminated by unit energy of light of frequency ν then, as was shown in Paper I, the photoelectric current I reaching a parallel collecting plate against a retarding potential V e.s.u. should be given by

$$I=\beta AT^2\Phi_1(x), \tag{1}$$

where β is an undetermined constant, A is a universal constant[2] $=4\pi mk^2/h^3$, $x=(V_m-V)e/kT$ and $\Phi_1(x)$ is Fowler's universal function.[3] V_m is the stopping potential at 0°K and is given by the Einstein equation, $V_me=h\nu-\varphi e$, φ being the surface work function at 0°K.

For analyzing experimental results Fowler's method may be used. Eq. (1) is written in the form

$$\log (I/T^2)=B+\Phi(x), \tag{2}$$

where B is a constant independent of ν and T, and $\Phi(x)=\log \Phi_1(x)$. When the experimental results are plotted in the form $\log (I/T^2)$ against Ve/kT they should yield a curve of the same

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[1] L. A. DuBridge, Phys. Rev. **43**, 727 (1933). Hereafter referred to as Paper I.

[2] This is the correct value of this constant, rather than that given in Eq. (12) of Paper I. The latter value was that obtained by Fowler who integrated with respect to the velocity rather than the energy.

[3] R. H. Fowler, Phys. Rev. **38**, 45 (1931).

form as the theoretical curve $\Phi(x)$ *vs.* x. The vertical component of the shift required to fit the curves is unimportant, but is independent of ν and T, while the horizontal shift is equal to $V_m e/kT$.

Experimental Method

Tube and vacuum system

In order to have the photoelectrons ejected from a surface which could be maintained at a constant high temperature, the ordinary parallel-plate method was slightly modified. As shown in Fig. 1, a strip of Mo foil (38×2.6×0.01 mm) was mounted between two co-planar semicircular Ni plates which served as guard rings. Parallel to these at a distance of 4.8 mm was mounted a Ni collector plate with a narrow slit for admitting light to the Mo strip. The electric field at the surface of the Mo was thus nearly uniform and normal to the surface. The contact potential between the Mo strip and the Ni guard plates was measured photoelectrically and compensated for by an external potential divider, V_c in Fig. 2. The plates and foil were mounted rigidly on Pyrex supports in a Pyrex tube with a quartz window, connected to the usual type of high-vacuum system. The temperature of the Mo filament was determined from its resistance, and it was given a long preliminary outgassing at temperatures up to 2000°K. The Ni plates were flashed repeatedly with an induction furnace and when thoroughly outgassed their work function was sufficiently high (about 5 volts[4]) that they were practically insensitive to light of wave-length longer than 2482A. Reverse currents from the collecting plate were therefore negligible in most cases, though they were corrected for when present.

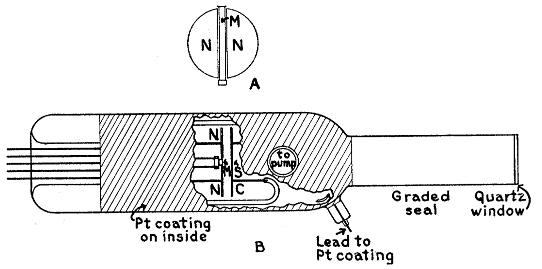

FIG. 1. *A*, front view of filament and guard plates. *B*, top view of tube. *M*, Mo foil filament. *NN*, Ni guard plates. *C*, Ni collector plate. *S*, slit.

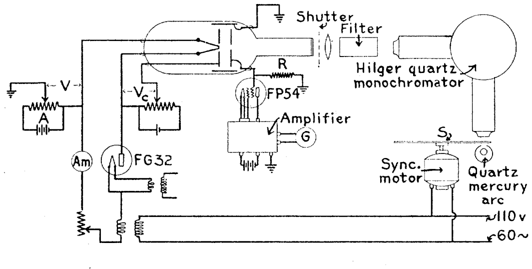

FIG. 2. Wiring diagram. *A*, potential divider. *V*, applied retarding potential. V_c, compensating potential. $R=3.9\times10^{11}$ ohms. Filter eliminates scattered light of short wave-length.

Electrical circuit

A diagram of the essential parts of the electric circuit is shown in Fig. 2. An accurately calibrated potential divider *A* furnished the retarding potential V between emitter and collector, and V was corrected for the small potential drop across the high resistance R due to the photocurrent. An FP-54 amplifier of the Soller type was used to measure the currents. For the measurements at higher temperatures it is necessary to eliminate the potential drop across the filament and the magnetic field around it, caused by the heating current. This was accomplished by heating with the intermittent current from a low voltage, 60-cycle transformer rectified by an FG-32 Phanotron (mercury vapor rectifier). A rotating sector *S* was mounted on a synchronous motor connected to the same 60-cycle mains and adjusted so that light was admitted to the tube only during the portions of the cycle when no heating current was flowing.

Results

Typical current-voltage curves for λ2400 at two different temperatures are shown in Fig. 3. At the higher temperature there is, in addition to the increased emission, a definite enhancement of the "tail" which is quite striking on a large scale diagram. On this scale the room temperature curve is almost indistinguishable from the curve to be expected at 0°K.

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[4] Cf. G. N. Glasoe, Phys. Rev. **38**, 1490 (1931).

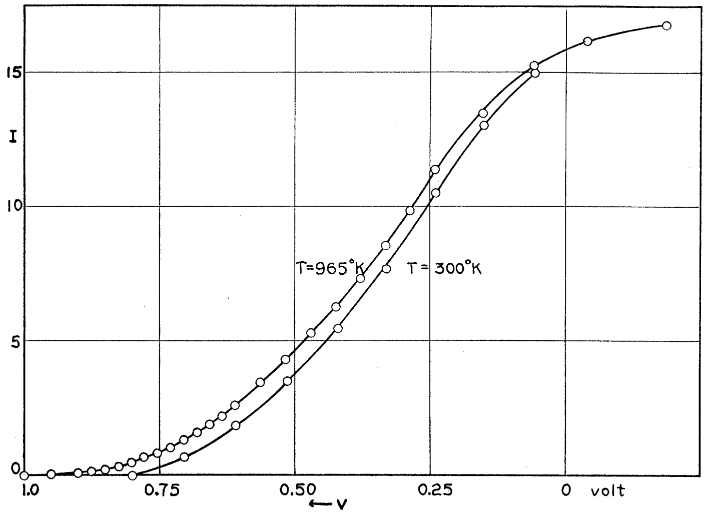

FIG. 3. Observed current-voltage curves for λ2400.

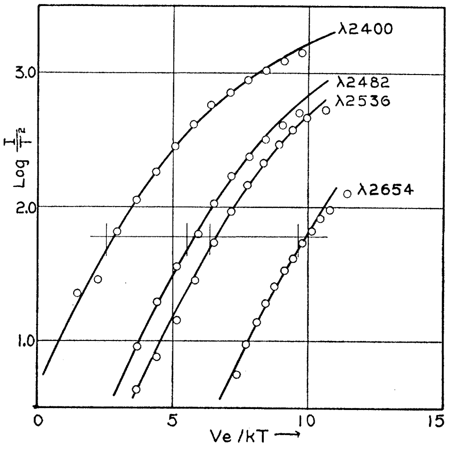

FIG. 4. Analysis of current-voltage curves at 785°K.

Fig. 4 shows the analysis by the Fowler method of curves for four different wave-lengths at a temperature of 785°K. Similar curves were obtained for other temperatures, a set for room temperature having been given in Paper I. The full lines are the theoretical curves shifted to fit each set of experimental points, the origins of the theoretical curves being shown. The vertical shifts are the same for all curves as required by the theory, the photocurrent having been reduced to unit intensity of incident light. From the horizontal shifts one obtains, after correcting for the contact potential between emitter and collector, the values of V_m at 0°K. When plotted

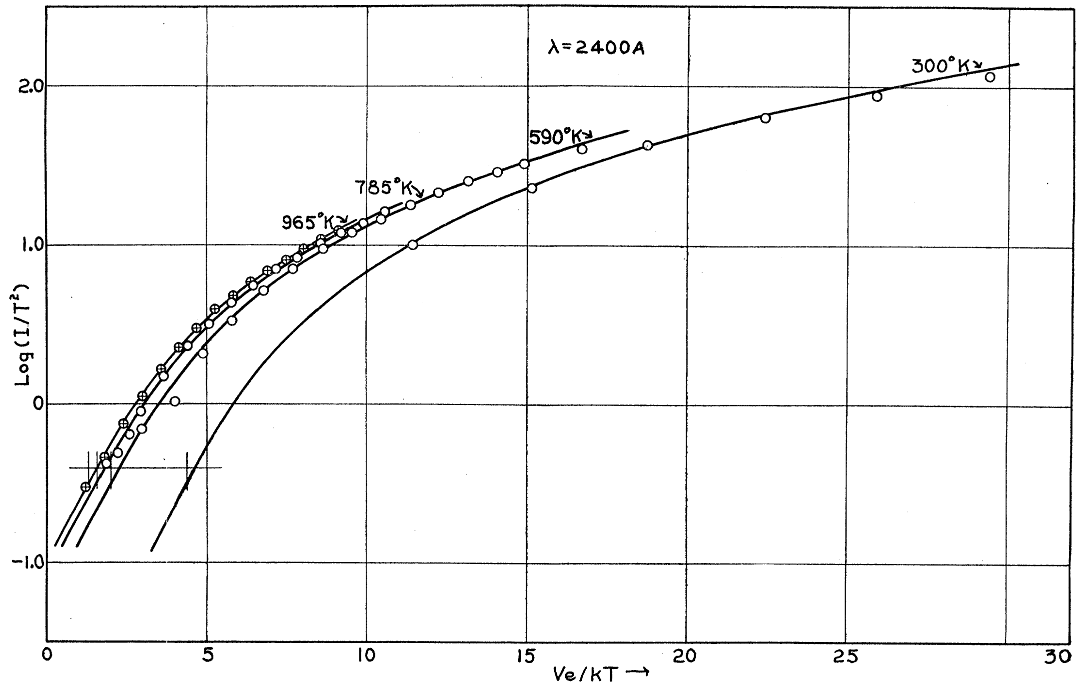

FIG. 5. Analysis of curves for λ2400. Values of V_m are: 0.107, 0.105, 0.101 and 0.113 volt.

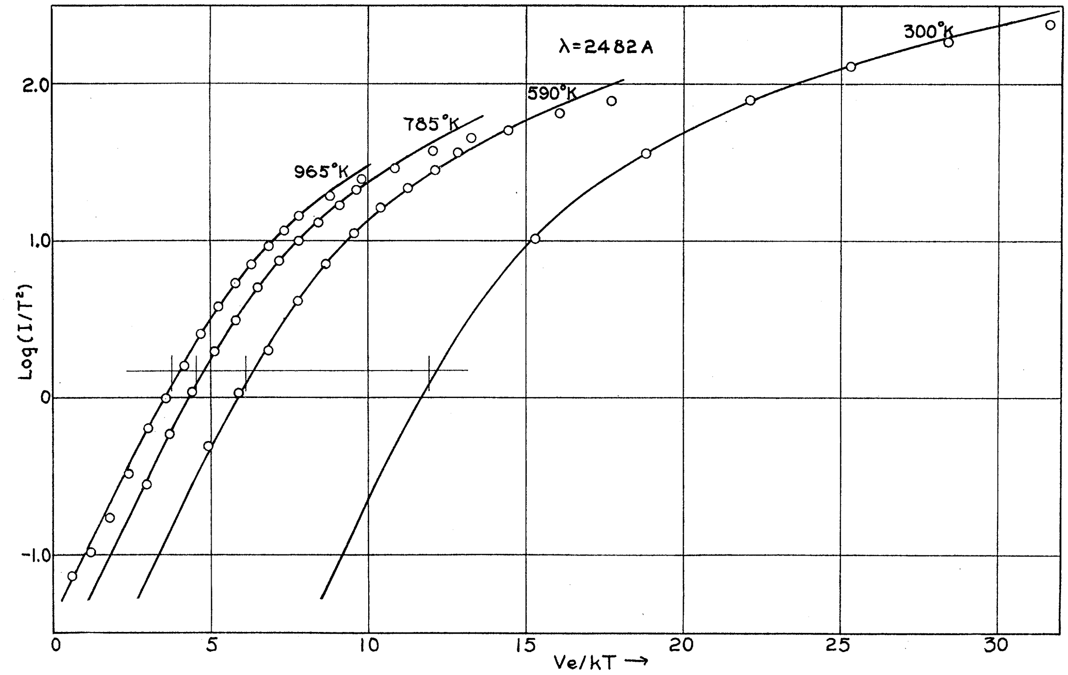

FIG. 6. Analysis of curves for λ2482. Values of V_m are 0.312, 0.307, 0.314 and 0.309 volt.

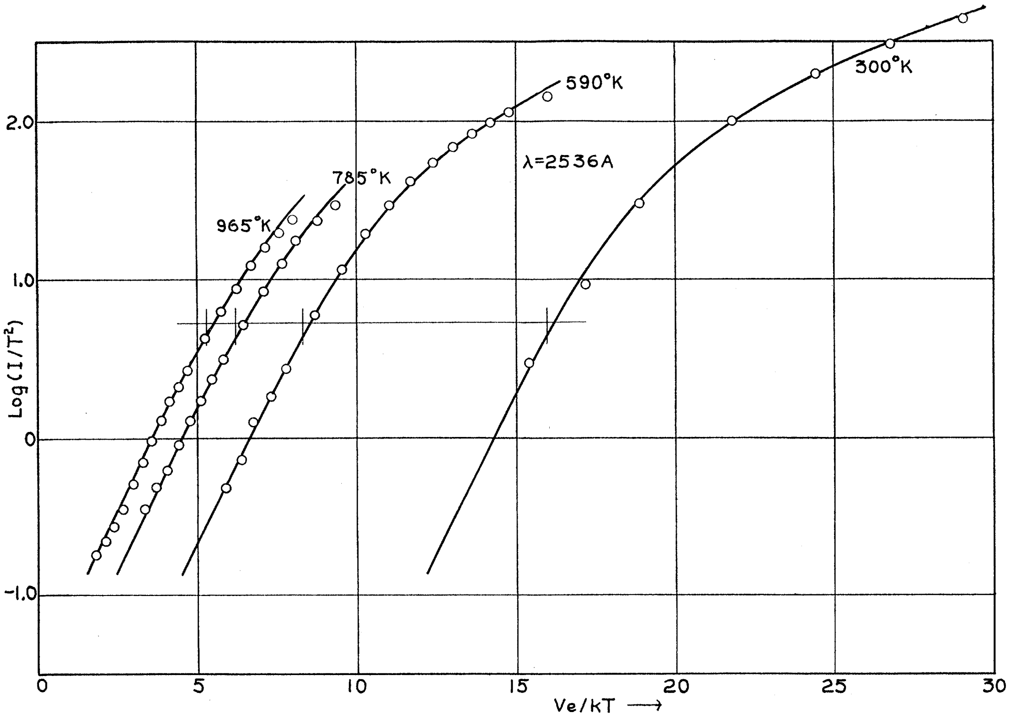

FIG. 7. Analysis of curves for λ2536. Values of V_m are: 0.44, 0.42, 0.42 and 0.41 volt.

against ν these values fit, within experimental error, a straight line whose slope is h/e. Because of the uncertainties in the graphical fitting process there is an uncertainty in V_m of about 0.01 or 0.02 volt.

For the purpose of testing more precisely whether the current-voltage curves vary with the temperature in the manner predicted by the theory, curves for a fixed wave-length were taken in rapid succession for a series of temperatures. The results of analyzing these data are shown in Figs. 5, 6 and 7. The vertical shifts are again the same, and it is seen that the values of V_m obtained from the horizontal shifts are, within experimental error, independent of T. This is an important confirmation of the theory.

CONCLUSION

It is quite evident that the theory predicts quite accurately the general form of the lower portions of the current-voltage curves obtained in these experiments. This alone might not be conclusive, for it is possible that if the experimental curves had been of a slightly different shape it would still have been possible to fit a portion of them to the theoretical curve. However, since the lower portion of the theoretical curve is nearly linear comparatively small deviations in the shape of the tail of the experimental curve would have shown up quite clearly. Furthermore the fact that when the fit is made the vertical shifts are all the same, and the horizontal shifts give consistent values of V_m, must be interpreted as giving strong support to the theory. Still more accurate and convincing evidence is given in the paper by Dr. Roehr.

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