TABLE V. *Corrections to Bethe's Table 18a*[1] *giving intensities in units of* 10^{-4} *erg/sec.*

Transition	$2p-6d$	$3p-5s$	$3p-7s$	$3p-8s$	$3d-8f$
Intensity	1.22	0.014	0.006	0.004	0.108

divided by the number of excited atoms in *each*, that is to say, radiation per $(2l^*+1)$ atoms.

Some errors remain in Slack's original[7] and revised[6] tables. These may be located by comparison with Bethe's Table 17 or Table IV, for $n \leqq 7$. Beyond this, Slack's values for $1s-8p$, $3d-9f$, $3p-9d$, $3p-9s$, and $2p-9d$, are, respectively, 26 percent, 8 percent, 15 percent, and about 10 percent high, and 5 percent low. Maxwell's table[6] for mean lives in ionized helium is also not entirely correct, and should likewise be compared with Bethe or Table IV.

I am indebted to Dr. F. G. Slack for much information and assistance received in our conversations. I also wish to acknowledge the assistance of Mr. W. J. Boyd, employed by the Federal Emergency Relief Administration, in making computations.

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The Energy Distribution of Electrons in the Photoelectric Effect

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The character of the photoelectric emission from a metal depends on the distribution of electron levels, the transition probabilities from these levels and the extent to which the levels are populated by electrons. The last of these is given by the Fermi factor. Various expressions have been suggested for the first two. These are discussed, and equations for the energy distribution derived in each case. The results are compared with experimental data for molybdenum, published by Roehr. In all cases the proportion of low energy electrons predicted appears to be too high. The theory of Mitchell comes nearest to fitting the experimental data over the low energy range. The stopping potential currents for higher energy, when plotted on a logarithmic scale as done by Roehr, fall nicely on the curve calculated on the theory of Mitchell. It is pointed out that the agreement obtained with such logarithmic plots is essentially a check on the dominating Fermi factor, and that the region of low energies in the energy distribution, for which the Fermi factor is practically unity, is the important one for studies of the electronic structure of metals.

INTRODUCTION

IN most theoretical treatments of electrons in metals[1] the state of the electrons is considered to be built up of a combination of single electron states, one for each electron, each state being characterized by a set of quantum numbers k and associated with a definite energy value ϵ. In theories of the photoelectric effect this view is always adopted, and it is furthermore assumed that each individual photoelectric process involves one single electron, originally of energy ϵ in the metal: as a result of the process this electron appears outside with an energy $u=\epsilon+h\nu$.[2] Under these conditions the energy distribution of the photoelectric emission produced by radiation of frequency ν can always be written.

$$f(u)du=F(\epsilon)\sum_{\epsilon,\,d\epsilon} P_k \tag{1}$$

with

$$F(\epsilon)=1/(e^{(\epsilon-\epsilon_0)/kT}+1). \tag{2}$$

$F(\epsilon)$ is the Fermi factor, which gives the probability of finding an electron in a state of energy ϵ, when the temperature is T; ϵ_0 is the highest occupied energy state at $T=0$. P_k is the probability of emission from the state k, if occupied by an electron, and the summation is to be extended over all states of energy between ϵ and $\epsilon+d\epsilon$, the relation of ϵ to u being that stated above. In general P_k is a function of both ν and k. With a stopping potential V applied to the

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[1] Cf. Slater, Rev. Mod. Phys. **6**, 209 (1934).

[2] Except in some theories for the selective effect, in which a process similar to an Auger effect is considered: Wolff, Zeits. f. Physik **52**, 158 (1929); Suhrmann, Ergebn. d. exakt. Naturwiss. **13**, 191 (1934); Zener, Phys. Rev. **47**, 15 (1935).

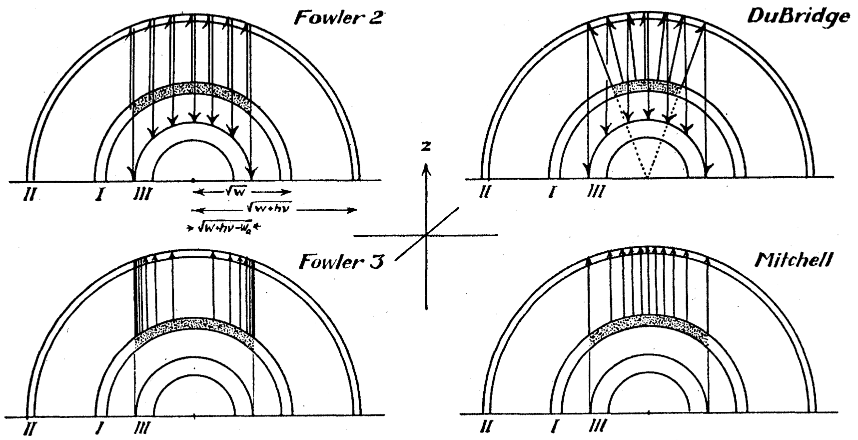

FIG. 1. Illustrating in momentum space the transitions occurring in the photoelectric effect, according to some of the hypotheses proposed. The density of transition lines indicates relative transition probability.

outer electrode in the usual spherical condenser arrangement—$(r/R)^2 \ll 1$—for determining the energy distribution, the current is of course given by

$$I(V) = e\int_{eV}^{\infty} f(u)du. \tag{3}$$

In principle both P_k and the distribution of electron states with respect to energy are uniquely determined, once the model of the metal has been chosen. Actually several different expressions for the saturation current ($V=0$) have been suggested, presumably all based on the Sommerfeld model of electrons in metals. This is due to the fact that whereas the function adopted to represent the distribution of electron states was correctly based on this model, an independent assumption was made about the form of P_k in some of the cases. This assumption was therefore not necessarily compatible with the model originally adopted.

In the following we shall consider the various hypotheses proposed for the transition probabilities in the Sommerfeld free electron model and compare the results to which they lead as regards the form of $f(u)$ and $I(V)$ with available experimental data.

THEORETICAL EXPRESSIONS FOR THE ENERGY DISTRIBUTION

According to the Sommerfeld model[3] the electron states can be represented by a distribution of points of constant density filling a three-dimensional momentum space, the Cartesian coordinates of which are proportional to the first three quantum numbers k. The fourth number stands for the spin. The number of states between ϵ and $\epsilon+d\epsilon$ is thus proportional to the volume of the spherical shell I in Fig. 1, of radii $w^{\frac{1}{2}}$ and $(w+dw)^{\frac{1}{2}}$—in units $(2m)^{\frac{1}{2}}$—where $w=\epsilon+w_a$ is the kinetic energy inside the metal, $-w_a$ being the potential energy of an electron in the interior of the metal. The direction of the normal to the metal surface will be taken to be that of the vertical z axis in this figure; only the upper half of the space with positive momentum components directed outwards is shown. For the purpose of illustration we may say, that an electron in one of the states I upon absorption of light makes a transition to some state in the shell II of kinetic energy $w+h\nu$. If this electron is emitted, it appears outside with a momentum characteristic of the shell III of kinetic energy $u=w+h\nu-w_a=\epsilon+h\nu$. The transition II→III is represented by a vertical line, since the retarding force is normal to the surface. Hence only absorption transitions to that part of II which is covered by the indicated parallel projection of III result in photoelectric emission. The discussion in the following has been limited to frequencies for which $h\nu < w_a$. We shall denote by α the kinetic energy associated with the momentum component normal to the surface inside.

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[3] Sommerfeld, Zeits. f. Physik **47**, 1 (1928).

Case (a) Fowler's 1st assumption:[4] $P_k=\text{const.}$

$$\sum_{\epsilon,\,d\epsilon} P_k=\text{const. } d(w^{\frac{3}{2}})=\text{const. } (u+w_a-h\nu)^{\frac{1}{2}}du, \quad (4)$$

$$f(u)=C_1(u+w_a-h\nu)^{\frac{1}{2}}/(e^{(u-h\nu-\epsilon_0)/kT}+1) \quad (5)$$

or
$$f(u)\sim F(u-h\nu) \quad \text{if} \quad u\ll w_a-h\nu. \quad (6)$$

This assumption is not consistent with the rule regarding the transition II→III. The results were found by Fowler not to represent experimental data on the total emission, and this assumption was therefore rejected.

Case (b) Fowler's 2nd assumption[4]

$$\sum_{\epsilon,\,d\epsilon} P_k=\text{const. } (w^{\frac{1}{2}}-(w_a-h\nu)^{\frac{1}{2}})dw. \quad (7)$$

This result is obtained, if the light absorption affects the momentum component perpendicular to the surface only, and if P_k is constant for all states within that part of I which is covered by the projection of III—for all other states: $P_k=0$.

$$f(u)=C_2\frac{(u+w_a-h\nu)^{\frac{1}{2}}-(w_a-h\nu)^{\frac{1}{2}}}{e^{(u-h\nu-\epsilon_0)/kT}+1}=\frac{C_2(w_a-h\nu)^{\frac{1}{2}}}{e^{(u-h\nu-\epsilon_0)/kT}+1}\left\{\frac{1}{2}\frac{u}{w_a-h\nu}-\frac{1}{8}\left(\frac{u}{w_a-h\nu}\right)^2+-\cdots\right\} \quad (8)$$

or
$$f(u)\sim uF(u-h\nu), \quad \text{if} \quad u\ll w_a-h\nu. \quad (9)$$

This case is illustrated in momentum space by the first diagram of Fig. 1. The transition probabilities are indicated qualitatively by the density of the transition lines. That these lines must be vertical—no change of momentum components parallel to the surface!—can be shown to be required by wave mechanics not only for the square top potential barrier, which represents the surface in the Sommerfeld model, but for any kind of surface potential which is a function of the coordinate perpendicular to the surface only. Case (b) is the one mostly used in recent years for determining work functions from saturation current measurements by the so-called Fowler method.

Case (c) DuBridge's assumption[5]

$$\sum_{\epsilon,\,d\epsilon} P_k=\text{const. } ((w+h\nu)^{\frac{1}{2}}-w_a^{\frac{1}{2}})(w/(w+h\nu))^{\frac{1}{2}}dw. \quad (10)$$

In this case[6] the transitions take place radially in momentum space and with uniform density, so that $\sum_{\epsilon,\,d\epsilon} P_k$ is proportional to the volume of the emitting part of I, see Fig. 1.

$$f(u)=C_3\frac{(u+w_a)^{\frac{1}{2}}-(w_a)^{\frac{1}{2}}}{e^{(u-h\nu-\epsilon_0)/kT}+1}\left(\frac{u+w_a-h\nu}{u+w_a}\right)^{\frac{1}{2}}=\frac{C_3(w_a-h\nu)^{\frac{1}{2}}}{e^{(u-h\nu-\epsilon_0)/kT}+1}\left\{\frac{1}{2}\frac{u}{w_a}-\frac{u^2}{w_a}\left(\frac{3}{8w_a}-\frac{1}{4(w_a-h\nu)}\right)+-\cdots\right\} \quad (11)$$

or
$$f(u)\sim uF(u-h\nu), \quad \text{if} \quad u\ll w_a-h\nu. \quad (12)$$

It has occasionally been stated, somewhat inaccurately, that this theory is based on the same assumptions used by Fowler in case (b).[7] As a matter of fact the picture of the absorption process is quite different in the two cases, but the final expressions for $f(u)$ are the same to a good approximation for small energies of the emitted electrons.

Case (d) Fowler's 3rd assumption[4]

$$\sum_{\epsilon,\,d\epsilon} P_k=\text{const. } dw\int_{w_a-h\nu}^{w}\frac{d\alpha}{\alpha^{\frac{1}{2}}(\alpha-w_a+h\nu)^{\frac{1}{2}}}=\text{const. } dw\ln\frac{w^{\frac{1}{2}}+(w-w_a+h\nu)^{\frac{1}{2}}}{(w_a-h\nu)^{\frac{1}{2}}}. \quad (13)$$

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[4] Fowler, Phys. Rev. **38**, 45 (1931).

[5] DuBridge, Phys. Rev. **43**, 727 (1933).

[6] This refers to the approximate expression for ν "not too far from the threshold ν_0" given by DuBridge, which is the one exclusively used in later work by this author and by Roehr. DuBridge obtains this approximation from a general equation deduced for the velocity distribution, Eq. (25) of his paper. According to the process proposed by DuBridge, I believe that this equation should have a factor $v^2/4(v^2+\xi_c^2)^{\frac{1}{2}}$ instead of $\xi-\frac{1}{2}[1-\xi_c/(v^2+\xi_c^2)^{\frac{1}{2}}]$. Granted this, the general equation of DuBridge calls for $\sum_{\epsilon,d\epsilon} P_k=\text{const. } D(w)(w+h\nu-w_a)(w/(w+h\nu))dw$ which, except for the "transmission coefficient" D, also leads to the relation (12) above.

[7] The situation is correctly stated in the report by Darrow, Rev. Sci. Inst. **4**, 467 (1933).

In this case (see Fig. 1) the transitions are "vertical" as in (b), but P_k is assumed to be inversely proportional to the normal component of momentum with which the electron will appear outside, i.e., proportional to $(\alpha - w_a + h\nu)^{-\frac{1}{2}}$.

$$f(u) = \frac{C_4}{e^{(u-h\nu-\epsilon_0)/kT}+1} \ln \frac{(u+w_a-h\nu)^{\frac{1}{2}}+u^{\frac{1}{2}}}{(w_a-h\nu)^{\frac{1}{2}}} = \frac{C_4}{e^{(u-h\nu-\epsilon_0)/kT}+1}\left(\frac{u}{w_a-h\nu}\right)^{\frac{1}{2}}\left(1+\frac{1}{12}\frac{u}{w_a-h\nu}-+\cdots\right) \tag{14}$$

or

$$f(u) \sim u^{\frac{1}{2}} F(u-h\nu), \quad \text{if} \quad u \ll w_a - h\nu. \tag{15}$$

Case (e) Mitchell's theory[8]

A quantum-mechanical calculation of the transition probabilities has been given by Mitchell for the Sommerfeld model with a square top potential barrier. Two cases were considered. In the first a constant amplitude was assumed for the vector potential of the radiation field. The result, illustrated in Fig. 1, is that only "vertical" transitions occur and

$$P_k = \text{const.}\, \frac{\alpha(\alpha-w_a+h\nu)^{\frac{1}{2}}}{((\alpha+h\nu)^{\frac{1}{2}}+(\alpha-w_a+h\nu)^{\frac{1}{2}})^2}, \tag{16}$$

so that

$$\sum_{\epsilon,\, d\epsilon} P_k = \text{const.}\, dw \int_{w_a-h\nu}^{w} \frac{\alpha^{\frac{1}{2}}(\alpha-w_a+h\nu)^{\frac{1}{2}}d\alpha}{((\alpha+h\nu)^{\frac{1}{2}}+(\alpha-w_a+h\nu)^{\frac{1}{2}})^2} \tag{17}$$

and, with the substitution $\beta = \alpha - w_a + h\nu$,

$$f(u) = \frac{\text{const.}}{e^{(u-h\nu-\epsilon_0)/kT}+1} \int_0^u \frac{\beta^{\frac{1}{2}}(\beta+w_a-h\nu)^{\frac{1}{2}}d\beta}{((\beta+w_a)^{\frac{1}{2}}+\beta^{\frac{1}{2}})^2}$$

$$= \frac{C_5 u^{\frac{3}{2}}}{e^{(u-h\nu-\epsilon_0)/kT}+1}\left\{1-\frac{3}{2}\left(\frac{u}{w_a}\right)^{\frac{1}{2}}+\frac{3}{5}\frac{u}{w_a}\left(2+\frac{1}{2}\frac{w_a}{w_a-h\nu}\right)-+\cdots\right\} \tag{18}$$

or

$$f(u) \sim u^{\frac{3}{2}} F(u-h\nu), \quad \text{if} \quad u \ll w_a. \tag{19}$$

Mitchell has also calculated the transition probability on the assumption that the (complex) amplitude of the vector potential is constant in the metal, but changes discontinuously at the boundary to a different, constant value outside, the relation between the two being that given by the classical theory for a metal of refractive index $n-ik$. This introduces an additional factor in the expression (16), depending on n,k, the polarization and the angle of incidence, as well as on α or β. For radiation incident near the normal this factor, expressed as a function of β, is:

$$[\beta+w_a-h\nu-(k^2-n^2)(h\nu-\beta)+2nk((\beta+w_a)(h\nu-\beta))^{\frac{1}{2}}]^2$$
$$+[2nk(h\nu-\beta)+(k^2-n^2+1)((\beta+w_a)(h\nu-\beta))^{\frac{1}{2}}]^2.$$

With such values of n and k as are mostly found, this factor does not change a great deal near $\beta=0$ for ordinary values of w_a and $h\nu$, so that the distribution would still be similar to (18) in this case.

Tamm, Schubin[9] and Blochinzew[10] have also published a wave-mechanical treatment of this problem. They obtain for the transition probability

$$P_k = \text{const.}\, \frac{\alpha(\alpha+h\nu)(\alpha-w_a+h\nu)^{\frac{1}{2}}}{((\alpha+h\nu)^{\frac{1}{2}}+(\alpha-w_a+h\nu)^{\frac{1}{2}})^4}, \tag{20}$$

which leads to the same limiting form (19) for small u.[11] The calculation of Tamm, Schubin

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[8] Mitchell, Proc. Roy. Soc. **A146**, 442 (1934).

[9] Tamm and Schubin, Zeits. f. Physik **68**, 97 (1931).

[10] Blochinzew, Physik. Zeits. d. Sowjetunion **1**, 781 (1931).

[11] A similar result was obtained for a somewhat different model by Fröhlich, Ann. d. Physik **7**, 103 (1930). See also Sommerfeld and Bethe in Geiger-Scheel, *Handbuch der Physik*, second edition (1933), Vol. 24/2, p. 468.

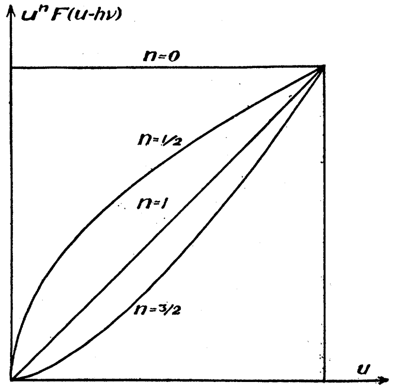

FIG. 2. Theoretical energy distributions for $T=0$.

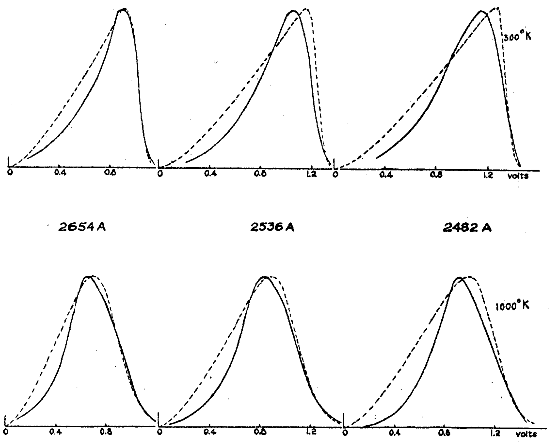

FIG. 3. Energy distributions for molybdenum.

and Blochinzew has been discussed in the paper by Mitchell. It is also interesting to note that an expression for the transition probability somewhat similar to these, namely,

$$P_k = \text{const.} \frac{(\alpha+h\nu)^{\frac{1}{2}}(\alpha-w_a+h\nu)^{\frac{1}{2}}}{((\alpha+h\nu)^{\frac{1}{2}}+(\alpha-w_a+h\nu)^{\frac{1}{2}})^2} \tag{21}$$

has been suggested by Young and Frank,[12] from a different picture of the photoelectric process. They assume that only "vertical" transitions take place entirely inside the metal, all with the same probability. The high energy electron resulting from such a transition inside eventually impinges on the surface, where it is either reflected or transmitted. The expression (21) gives the probability of transmission.[13] Because of the factor $(\alpha-w_a+h\nu)^{\frac{1}{2}}$ this expression will also lead to (19).

COMPARISON WITH THE RESULTS OF W. W. ROEHR

In recent years the variation of the photoelectric yield with frequency has been determined under high vacuum conditions for several metals, with very carefully prepared surfaces.[14] There are, however, very few results available for the velocity distribution, obtained under equally well-controlled conditions. The best energy distribution measurements are probably those for molybdenum published by Roehr,[15] working with DuBridge. Roehr determined stopping potential curves for the emission with (essentially) a spherical condenser arrangement, using monochromatic radiation of three different wavelengths, 2654A, 2536A and 2482A. The temperature of the emitter was varied from 300 to 1000°K. The results were compared with the theory of DuBridge, in which the stopping potential current is obtained from (12) by integration. From the properties of the Fermi function (2) it is easily seen that under these conditions

$$\frac{1}{(kT)^2}\int_{eV}^{\infty} f(u)du$$
$$= C\cdot\int_{u/kT=eV/kT}^{\infty} \frac{u}{kT}F(u-h\nu)d\left(\frac{u}{kT}\right)$$

will be a function of the variable eV/kT denoted by x, with the parameters C and $(h\nu+\epsilon_0)/kT=x_0$. Near the value x_0 this function can be written approximately as $C\cdot xG(x_0-x)$, with G a universal function which can be evaluated. Roehr plots his experimentally determined log (I/x) against x at constant temperature and compares this with the curve for log G. He finds that the latter can be fitted to the points obtained for any of the three wave-lengths at 300 and 1000°K by a proper parallel shift, as illustrated by Fig. 8 and Fig. 9 of Roehr's paper. The required shift

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[12] Young and Frank, Phys. Rev. **38**, 838 (1931).

[13] Nordheim, Zeits. f. Physik **46**, 833 (1928); Frank and Young, Phys. Rev. **38**, 80 (1931).

[14] See Hughes and DuBridge, *Photoelectric Phenomena* (McGraw-Hill, 1932).

[15] Roehr, Phys. Rev. **44**, 866 (1933).

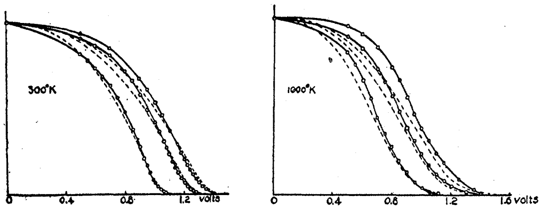

FIG. 4. Stopping potential curves for molybdenum.

along the x axis determines x_0; the procedure is very similar to that of the Fowler method in the case of saturation currents. The conclusion is, that DuBridge's theory predicts quite accurately the form of the photoelectric energy distribution curves in the vicinity of the maximum energy.

In Fig. 2 the limiting form of $f(u)$, *viz.* $f(u) = \text{const.}\, u^n F(u-h\nu)$, for small u is shown at $T=0$ for the five cases (a–e) discussed above: Eqs. (6), (9), (12), (15) and (19), with $n=0$, 1, 1/2 and 3/2. Those parts which correspond to energies less than the critical value $(h\nu+\epsilon_0)$ remain essentially the same for finite values of T, since $F=1$, practically. The experimental curves for the energy distribution are indicated by full lines in Fig. 3, reproduced from Roehr's Fig. 11 and Fig. 12. From a comparison of Fig. 2 and Fig. 3 it should be evident that (a) and (d) are definitely excluded. Of the others, which represent the facts in a rough way, Mitchell's theory, indicated by the dotted lines in Fig. 3, comes nearest to an approach to the experimental curves, although the fit is far from perfect. Roehr's data seem to require a value of n greater than 3/2, something like 2 or 5/2. It is true that the experimental curves cannot be very accurate, since they were obtained from measured stopping potential curves by differentiation. The uncertainty would be greatest in the steep parts for high energies, particularly in the curves for the lower temperature. There could be no doubt, however, that the differences for low energies are real. This should be evident from Fig. 4, in which the points and the solid lines were reproduced from Roehr's stopping potential curves in Fig. 4 and Fig. 5 of his paper. The dotted lines represent the curves calculated on Mitchell's theory.

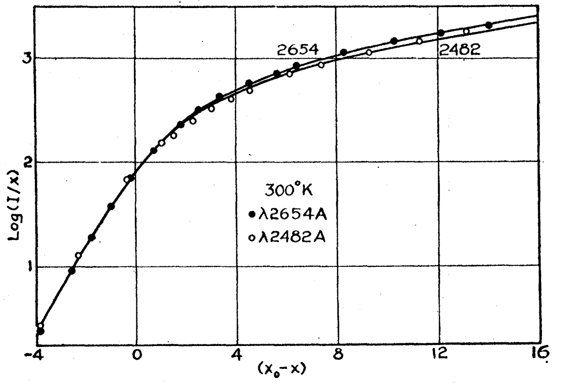

FIG. 5. Analysis of stopping potential measurements at 300°K.

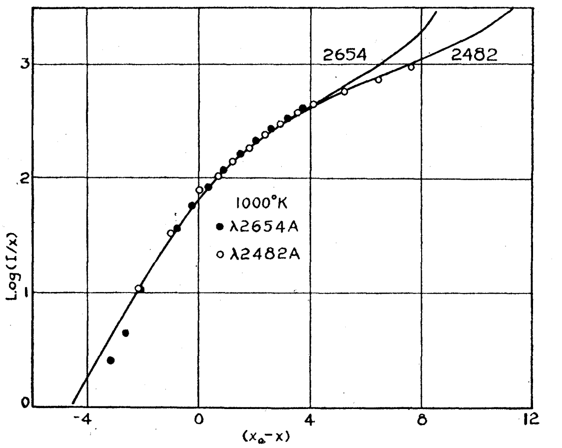

FIG. 6. Analysis of stopping potential measurements at 1000°K.

It should be stated that the accurate expression (18) has been used throughout for $f(u)$ in the curves based on Mitchell's theory, Figs. 3, 4, 5 and 6. Thus $\sum P_k$ is not simply proportional to u^n, as in the approximate expression (19) or the one used by DuBridge, (12). I have computed $\sum P_k$ as a function of u by graphical integration, using the values $w_a=14$ and $w_a-h\nu=9$, both in electron volts, for all three frequencies. As a matter of fact, for the range in question $0<u<1.5$, $\sum P_k$ is rather insensitive to changes in these parameters. The values used for $h\nu+\epsilon_0$, which enters in $F(u-h\nu)$, were those found by Roehr in each case.

It is interesting to see how the theory of Mitchell compares with the experimental data when plotted as log (I/x) against x, as in Roehr's Fig. 8 and Fig. 9. This has been done in Fig. 5 and Fig. 6 for the longest and the shortest wave-lengths used by Roehr and temperatures 300°K and 1000°K. The points are Roehr's measured values, the solid lines represent the curves to be expected by using the form (16) for P_k given by Mitchell. The curves have been displaced parallel to themselves to produce the best fit, as in the method used by Roehr. The fact that there is a different curve for each wave-length is of course not a feature characteristic of Mitchell's theory alone. On the assumption used by DuBridge the curves calculated from (11) or (12) are really different for different wave-lengths in a way similar to this.

The agreement in Fig. 5 and Fig. 6 appears to be about as good as that found by Roehr on comparison with the curve of DuBridge. This, I believe, illustrates a point which has not always been clearly recognized, although there is good evidence for it already in the paper by Fowler.[4] The fact that a good agreement is obtained with logarithmic plots like these or like the ones used in the Fowler method shows that the state of all the electrons must be described by an antisymmetric wave function (exclusion principle), so that the distribution of electrons over the available single electron levels will be given by the Fermi function. But it proves very little about the correctness of the model used. Thus Fowler found it very difficult to decide whether his 2nd or 3rd assumption was the better one, from comparison with the experimental data, using logarithmic plots. The great value of these methods then lies in the fact that they permit an accurate determination of the work function (Fowler method) or of u_m, the maximum energy of escape if the electron temperature were 0, in the stopping potential method. In the latter case the essence of the method is, that it provides a means of recognizing, in curves for different frequencies, the contributions of electrons that originated in the same energy level in the metal —which is necessary for a photoelectric determination of h. It must be borne in mind, however, that the horizontal shift of the theoretical curve required to fit the experimental data is not entirely independent of the expression chosen for the quantity $\sum P_k$, and this sets a limit to the accuracy of the work function or u_m determined by these methods, until we know the correct form of $\sum P_k$.

Evidently the part of the energy distribution which will prove or disprove something about the model is not the high energy end, where practically all other features are masked by the very rapid variation of the Fermi factor, but the low energy part, where this factor is constant. It seems desirable to obtain more data on the energy distribution in this region by some direct differential method, so that the inaccurate procedure of differentiating stopping potential curves could be avoided. An attempt in this direction is now being made in this laboratory.

The fact that the experimental energy distribution falls below the one predicted by DuBridge in the region of low energy is attributed by Roehr to a transmission coefficient less than unity in this region, a possibility already discussed by DuBridge.[5] This explanation is, of course, not in conflict with the original assumptions on which DuBridge's calculations are based. It is characteristic of the Sommerfeld model, however, that the electrons are entirely free inside the metal and therefore not capable of absorbing radiation. Only at the surface is there a binding and hence a possibility of light absorption, as emphasized by Tamm and Schubin and others. In directions parallel to the surface the electrons are still effectively free and hence unable to absorb, which is the reason why the transitions must be "vertical." Since therefore the photoelectric process for this model actually takes place in the surface of the metal, the entire effect of the potential barrier must be included in the transition probability P_k and there is evidently no place for an additional transmission factor in this case.

Further discussion of the remaining discrepancy between theory and experiment as regards the energy distribution for the photoelectric emission had perhaps better be postponed until more experimental material is available. It is possible that the fit could be improved, by taking into account the variation of the vector potential with depth near the surface, recently considered by Schiff and Thomas,[16] or if reasonably good approximate solutions could be found for other types of surface barriers than the square top one.

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[16] Schiff and Thomas, Phys. Rev. **47**, 860 (1935).