NOTE ON THERMIONIC EMISSION

By Lewi Tonks

Abstract

Electron emission experiments can throw light on the surface heat of charging only if the density of electrons in equilibrium with an emitting surface is the same whether evaporation occurs with constant surface charge or with surface charge equal (and opposite in sign) to evaporated charge. This equality is proved thermodynamically in the present note.

IN A paper "On the Surface Heat of Charging"[1] it was pointed out that the difference between the cooling effect of electron emission ϕ_c and the work function determined from the temperature variation of the emission ϕ_e contains a term which is the surface heat of charging, P_s. This has been questioned[2] on the ground that the assumption in the original paper that ϕ_e is equal to ϕ_t, the thermodynamic work function, is wrong, and that the correct relation is

$$\phi_e = \phi_t - P_s$$

The argument is that under experimental conditions the electrons evaporate from a surface whose charge is constant. ϕ_t, however, is the voltage equivalent of the heat absorbed when electrons evaporate from an insulated emitter. Thus the heat absorption in the experimental case is $\phi_t - P_s$ and it is this quantity, not ϕ_t, which belongs in the exponent of the Richardson equation when that equation is applied to experimental results.

The object of the present note is to refute this argument by presenting a rigorous proof of the original assumption—namely, that the work function in the exponent of the Richardson equation is the same whether emission takes place at constant total charge (the usual theoretical case) or constant surface charge (the experimental case); that is, that $\phi_e = \phi_t$. This will substantiate the point of view put forward in the first paper.

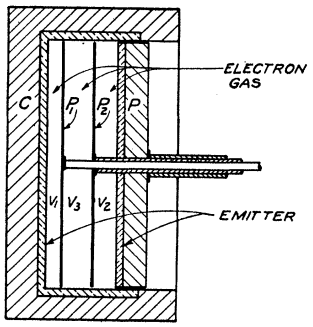

Fig. 1.

Suppose we have a cylinder and piston arrangement C, P (Fig. 1) having a large internal diameter, and throughout all operations with them let us keep the piston within a distance of the cylinder end which is very small compared with this diameter. The effect

[1] L. Tonks and I. Langmuir, Phys. Rev. **29**, 524 (1927).

[2] C. Davisson and L. H. Germer, Phys. Rev. **30**, 634 (1927). These authors also show that a term due to the energy of free electrons in the metal was neglected in the first paper. The present author wishes to acknowledge gratefully the clarification of his own ideas resulting from correspondence with Dr. Davisson.

of the sidewall of the cylinder upon the electric field and electron distribution in the enclosure can then be neglected, so that electric field, electron density, etc., are sensibly the same as for infinite plates. Let the inside of the cylinder and the end of the piston be completely covered with an electron emitter. The charge on the electrons results in a non-uniform density distribution in the enclosure, but even so, the application of thermodynamics to a volume-temperature cycle with this device leads to the Richardson equation.[3]

Now let us introduce a thin, movable, non-conducting, and perfectly reflecting partition P_1 between cylinder end and piston and parallel to them. It is obvious that the electron distribution and electric field remain unchanged. There is no force on P_1, for the electric fields and electron densities on its two faces are equal. Hence no work is done in moving it parallel to the cylinder axis, and no heat is absorbed by the system in so doing because every electron condensed on the advancing side of P_1 is balanced by one which evaporates on the receding side. The state of the electron gas after such a displacement is thus the same as before. Hence the motion of the partition can be made in an entirely arbitrary manner.

We can now use P_1 to prevent any change in the number of gaseous electrons in the volume V_1 when the piston is moved. In the case of ordinary evaporation this condition is fulfilled when P_1 is fixed. But with electrons the change in electric potential accompanying a motion of P causes a change in the average density of electrons in V_1, and to keep the total number constant, P_1 must move simultaneously with P. This can be accomplished by suitably gearing P_1 to P. A second partition P_2 may now be introduced between P_1 and P and it can be geared to P in such a way as to prevent evaporation or condensation from the piston. All evaporation is thus forced to take place at the small side-wall of the cylinder. This evaporation occurs at constant surface charge because the positive charge complementary to the evaporated electrons appears on cylinder end and piston.

It is almost obvious that the same final space distribution is reached after an expansion whether or not the partitions are present, that is, whether or not the evaporation of electrons takes place at constant surface charge. Were this not so, removal of the partitions (by sliding them out through slits in the cylinder walls, say) would leave the electron gas in a different state from that which would have been attained had the partitions never been introduced, and we should have the state of the gas dependent on its history.

How then is the unaltered distribution to be reconciled with the changed heat of vaporization? The answer is that thermodynamics deals with the total heat absorption of the system—not that at the surface of vaporization alone. Accordingly, to $\phi_t - P_s$, voltage equivalent of heat absorption on the side walls, must be added P_s, voltage equivalent of the heat absorbed in charging the cylinder end and piston positively. This gives ϕ_t as the voltage equivalent of the total heat absorption in this case just as in the usual

[3] C. Davisson, Phil. Mag. **47**, 544 (1924).

theoretical case in which the emitter hangs insulated in the middle of a piston-cylinder arrangement.

It is clear, then, that the exponential constant which is characteristic of the experimentally determined emission is ϕ_t, the result which was to be proved.[4]

It may be of interest to note that a question similar to the one answered here can arise in the case of ordinary vaporization. One recognized method of determining vapor pressure is to measure the loss of weight of the substance in a known time during which the material has been kept in a vacuum. Although the heat absorption for vaporization into a vacuum is $kT/2$ less than under equilibrium conditions, no corresponding differences in vapor pressure are either expected or found.

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[4] It is assumed, of course, that the correction for the Schottky effect has been made.